Joint Defra/EA Flood and Coastal Erosion
Risk Management R&D Programme

The advantages and disadvantages of adopting consistent standards for communities

R&D Technical Report FD2009/TR



Environment Agency

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Authors:
David Ramsbottom, HR Wallingford Ltd,
Colin Green, Flood Hazard Research Centre

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Statement of use
This report investigates different criteria for providing 'Consistent Standards' of flood alleviation for communities. The report is intended to provide information for Defra and the Environment Agency on the implications of adopting 'Consistent Standards'.

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Research contractor contact details:
David Ramsbottom, Technical Director, HR Wallingford Ltd, Howbery Park, Wallingford, Oxon, OX10 8BA. Email: dmr@hrwallingford.co.uk

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Defra project manager: David Richardson, Defra, 3D Ergon House, Horseferry Rd, London, SW1P 2AL. Email: david.richardson@defra.gsi.gov.uk

Publishing organisation:
Defra
Flood Management Division
Ergon House
Horseferry Road
London SW1P 2AL
Tel: 020 7238 3000
Fax: 020 7238 6187
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Executive Summary

Current methods of design and appraisal for flood defence can lead to varying levels of protection. This can occur nationally or regionally (for example, between different schemes) or within communities. There is a concern that the adoption of different defence standards within a community is undesirable, and an alternative approach should be sought in order to provide consistent standards of defence for communities.

The purpose of the project is to examine the advantages and disadvantages of adopting a policy of consistent standards of flood alleviation for communities, make recommendations for any changes in future appraisal guidance and identify any further research required to reduce areas of uncertainty.

A total of nine different definitions of 'consistent standards' have been identified. Four of these were rejected as not being practical options. The other five have been applied to seven case studies to identify the advantages and disadvantages of such approaches. The five criteria are as follows:

- Economic efficiency
- Population efficiency, intended to protect as many people as possible
- Equal cost per property
- Equal threshold of flooding, using a range of threshold standards
- Equal vulnerability, in which vulnerable people are protected

The evaluation of these criteria included an assessment of the following:

- Impacts on people
- Impacts on the community
- Effects of larger floods
- Economic impacts, including cost per property and total cost of different options

The results have been used to clarify some key issues and suggest some different approaches that might be considered by stakeholders. One primary conclusion follows from Sen's observation that the achievement of one form of equality tends to preclude the achievement of another form of equality. Consequently, there is no criterion which can be mechanically applied and which will result in universal happiness.

A second conclusion is that, rather than seek an alternative criterion such as a consistent standard of flood alleviation, it may be more helpful to look at and to seek to address the wider policy issues of how we may best achieve a sustainable flood risk management policy within the context of integrated catchment management over the longer term.

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1. Introduction

1.1 Background

Current methods of design and appraisal for flood defence can lead to varying levels of protection. This can occur nationally or regionally (for example, between different schemes) or within communities. A typical example of the latter case is where a river flows through a community and the flood defence standard on one side of the river is higher than the standard on the other side.

Concern has been expressed, by members of affected communities and others, that the adoption of different defence standards within a community is undesirable, and an alternative approach should be sought. The Environment Agency has become particularly concerned about this issue because a number of schemes have met with strong community opposition where defence standards vary within a community (and, in many cases, some parts are not protected at all).

This project is intended to investigate alternative approaches that might be adopted in order to achieve Consistent Standards within communities, and identify the advantages and disadvantages.

1.2 Purpose of the project

The overall purpose of the project is:

"To examine the advantages and disadvantages of adoption of a policy of consistent standards of flood alleviation for communities, make recommendations for any changes in future appraisal guidance and identify any further research required to reduce areas of uncertainty."

In order to achieve this objective, the first step is to investigate criteria for defining 'Consistent Standards'. Thus the purpose of this report is to:

- Identify potential criteria for defining 'Consistent Standards';
- Apply the criteria to a range of case studies and identify the implications of 'Consistent Standards';
- Identify the main advantages and disadvantages;
- Provide suggestions for changes to flood defence policy (if any).

It is clear that terms and their definition are important to this project, because different actors may have different definitions of key terms or different interpretations of those definitions. The definitions in Table 1.1 have been used to state the purpose of the project. The definitions are developed in Section 2, which sets out the definitions adopted for the project.

Table 1.1 Definitions of key terms

Terms	Concise OED definitions
Consistent	"Constant to (the) same principles"
Principle	"Fundamental truth as basis for reasoning; general law as guide to action; law of nature"
Standard	"Degree of excellence (etc) for particular purpose"
Community	"Body of people living in the same locality"

So, to adapt the above, what is required in this project is an analysis of:

> The advantages and disadvantages …from national, regional and local perspectives … of constant adherence … to a general law guiding action … as to the degree of excellence of flood defence provided for … people living in the same locality.

The objective of the project is therefore to identify options for the "general law" that should guide actions, and identify the advantages and disadvantages of the options.

2. Definitions

The definition of a ‘community’ has always been found to be particularly problematic: Etzioni (1997) reports that there have been more than 90 definitions of community and that some sociologists have concluded that it is impossible to define ‘community’ in any consistently meaningful way. A large number of sociological texts deal with the difficulties of defining a community by avoiding any definition at all.

One route to definition is simply administrative; those people living in a common government area. A significant problem with this definition are that there are several layers of local and central government and so it would be necessary to decide which is the appropriate level of government (the current assumption is that it is the country as a whole). A second route is by geography: a community is simply the people living within some defined area. This definition is essentially meaningless in that it does not define what is the relevant area; any criterion must define boundaries and do so in a way that is not arbitrary. The third definition is social: a community is a group of people who share at least one common interest and who interact; one such form of interaction is an elected government. In principle, this feels closest to what we mean by ‘community’ (e.g. a community hall is a place where people meet to interact and share interests). One consequence is that an individual can be a member of several different communities simultaneously.

Polanyi (1969) argued that we can communicate using words to denote general concepts without an explicit or shared definition of the concept in question. In short, we may be able to recognise a community when we see one without necessarily being able to provide a definition which is broad enough to include all forms of community and narrow enough to exclude groups or places that share some of the characteristics of a community without being a community.

The question of justice and equity have been the concern of philosophers and lawyers for several thousand years, and more recently of social psychologists. They are central to this project and will developed in detail, although Green (2003) does outline the issues.

The definitions adopted in the project are listed in Table 2.1.

Table 2.1 Definitions adopted

Term	Definition
Community	"The quality of appertaining to all in common"; "Common character; agreement, identity"; "A body of people organised into a political, municipal or social unity"(Shorter OED 3rd edition) "Community is defined by two characteristics: first, a web of affect-laden relationships between a group of individuals, relationships that often criss-cross and reinforce one another ……and second, a measure of commitment to a set of shared values, norms, and meanings, and a shared history and identity – in short, to a particular culture." (Etzioni 1997) "Sociologists generally use the term 'community' in a combined social and spatial sense, referring to an aggregate of people who occupy a common and bounded territory within which they establish and participate in common institutions. I shall employ the term in a purely social sense, however, to describe the set of institutions and organisations used by the West Enders to perform functions that cannot be taken care of within the peer group society." (Gans 1962) "A group of properties located in a contiguous area (though not necessarily within a single administrative area) that are exposed to risk of flooding from a given fluvial or coastal flood event." (Environment Agency discussion note 'Meeting expectations – providing a consistent standard', November 2001)
Consistent	"Constant to the same principles"
Design standard of protection	The most extreme event with which the intervention is intended to cope without any significant losses or impacts being experienced. Usually expressed in terms of the probability of that flood.
Equity	"That which is fair or right; impartiality; the recourse to the principles of justice; the quality of being equal or fair" (Shorter OED 3rd edition).
Justice	"The quality of being (morally) just or righteous; the principle of just dealing; just conduct; integrity; rectitude" (Shorter Oxford English Dictionary). "Treat like cases alike" Hart (1961). "… Formal justice requires the equality of treatment in accordance with the classification laid down by the rules...." Lloyd (1991).

Principle	"Basic truth, law or assumption; a rule or standard"
Standard	"Measure of fitness of purpose for a particular purpose." "An acknowledged measure of comparison for quantitative or qualitative value."
Sustainable development	"Development which meets the needs of the present without compromising the ability of future generations to meet their own needs."

3. Criteria for consistent standards: issues

3.1 Introduction

Currently, flood alleviation schemes are designed to achieve some specified design standard of protection, defined as the probability of the most extreme flood against which the scheme will provide protection against flooding. For example, a '1% standard' provides protection against a flood event with a 1 in 100 chance of being equalled or exceeded in any year. In practice, flood alleviation schemes have some residual capacity to take account of uncertainties in event predictions, and the event which causes flooding is likely to be greater than the design standard. For example, flood walls and embankments have a 'freeboard' allowance above the design flood level.

In addition, the frequency with which properties flood will vary across the floodplain. Those located close to defences are likely to flood during any event that overtops the defences, whereas properties further away from the defences may have a higher threshold of flooding.

This design standard is chosen through a benefit-cost analysis to be that design standard of protection, within an indicative range of exceedence probabilities, for which the ratio of benefits to costs is the maximum. Appraisal guidance including a decision rule is provided by Defra (Defra 1999). In developing and comparing the options, the logical approach of providing defences for entire hydraulic cells is also adopted.

There are three consequences of this approach:

- Different areas of a single community may be provided with defences to different design standards; for example, properties on one side of the river may be protected to a different design standard to those on the other bank of the river;
- Communities in different parts of the country and on different parts of the same river may be provided with defences to different design standards;
- Over the country as a whole, the greatest reduction in flood losses is achieved for the expenditure of the available resources.
- It has been argued that the provision of different design standards to different parts of the same community is unfair, that within a single community, all properties should be protected to the same design standard.

An additional complication is the fact that flooding can also occur from other sources including urban drainage systems, groundwater and overland flow. The frequency of flooding from these sources is often greater than from rivers and the sea. This is often justified by the fact that the affected areas are relatively small, but from the public point of view, a flood is a flood whatever the source.

The economic ‘optimum’ design standard and a community consistent design standard are two possible criteria that can be adopted and there are others. The question is: which criterion ought to be adopted? The approach adopted in this report to addressing this question is to make the ‘right’ choices, choices that are consistent with what are effectively moral or ethical arguments. So, in developing some criterion we must consider both what we mean by ‘right’ and test this definition against the practical consequences of adopting a criterion based upon such a conceptualisation of what is right.

It is clear that the choice of criterion is not a technical question, it is a moral or ethical issue that goes to both how we should as a society make choices and what choices we ought to make. In turn, although economists like to believe that economic efficiency is itself purely a technical matter and devoid of any ethical or moral content, it is in fact founded on a series of moral or ethical claims. As a result, if we define ‘politics’ as the formal system of social interactions through which choices are made about collective action, then the choice of a decision criterion and, indeed, the decision in individual cases, has to be a decision reached through a political process. It should be informed by technical knowledge as to the implications of adopting each of the options available. ‘Bad politics’ are then practices which are based purely upon ideological or sectional interests and which exclude technical knowledge as having any relevance to the decision.

That the choice of the criterion to adopt is not a technical question is demonstrated by the existence of the debate as to whether a consistent standard approach ought to be preferred to an economic efficiency approach. It is not possible to claim that one criterion is objectively preferable to all other possible criteria since the answer to why it is better always turns upon claims as to what we should understand as being ‘better’. In particular, to claim that one criterion is fairer than another is an explicit reference to a moral claim.

In particular, the purpose of any criterion is to differentiate between that which ought to be done from that which should not be done. Any criterion which results in flood alleviation works always being undertaken is not a criterion. It is consequently important to be clear in what conditions undertaking a flood alleviation scheme, or providing a particular design standard of protection, would be in some sense ‘wrong’. In considering changing the criterion, we do not want to do so only then to discover that we are implementing schemes that are seen to be ‘wrong’ in some other sense.

Finally, a decision criterion may have the effect of determining the flood risk management policy to be adopted. Or alternatively, the decision criterion may follow from the flood risk management policy that is adopted. The adoption in the Netherlands of fixed design standards of protection for both river and coastal flooding, although with different design standards for each, has had the consequence of canalising rivers within dike lines. It has had the effect of making the policy debate on the ‘room for rivers’ policy more difficult. Working from the flood risk management policy to the resulting decision criterion appears to be the most logical approach.

In addressing this question, the approach adopted here is:

- To set the discussion in the evolving context of flood management, notably the implementation of the Water Framework Directive and the UK Government's requirements for engagement with the stakeholders (Section 3.2);
- To outline the nature of choice (Section 3.3);
- To discuss what are reasonable criteria for the selection of a design standard criterion: what is it that we require both of the way in which we make choices about design standards for flood alleviation and of the outcome of those choices. We want to make the right choices by an equitable process (Section 3.4);
- To summarise the nature of flood management as this influences what design standard of protection is achieved (Section 3.5);
- To consider the physical environment and the way it affects approaches to flood management (Section 3.6);
- To consider flood management options and the impacts these can have on flood defence standard and flood risk (Section 3.7);
- To consider in what ways we may make the 'wrong' choice in individual cases either an inadequate flood alleviation scheme or providing a flood alleviation scheme when one ought not to be provided (Section 3.8);
- To compare a number of alternative decision criteria that can be adopted to select the design standard of protection adopted for individual flood alleviation schemes (Chapter 4).

3.2 The context of flood risk management

This is a time of transition; any criterion must be appropriate not only in the short term, but in the context of the quite dramatic changes that will take place over the next few years. Mostly immediately, the Water Framework Directive starts to take effect from the end of this year. Thereafter, flood management will progressively be viewed in the context of the river basin management plans. In principle, therefore, there will be no more flood alleviation works but only actions to improve the performance of a catchment, including its performance in regard to flood risks. In addition, there are moves towards the establishment of a European flood management policy, led by the Dutch and German governments with the usual strong influence on that policy development by the WWF.

Compensation of flood victims

The UK is also almost unique in that UK governments have never compensated the victims for their losses in a natural disasters. It is questionable whether this policy can survive much longer particularly now that, after the Elbe floods, the European Commission has established a fund to aid governments in the payment of such compensation. It can be anticipated that in the event of a flood that affects both the UK and continental European countries the media will question why victims in Britain are not receiving compensation but those in other countries are receiving compensation. One can visualise the headlines in the Daily Mail in particular.

At the same time, the ABI is limiting the conditions under which its members will be prepared to offer domestic policy holders insurance against flooding. The underlying problem here is that not all retail insurers are members of the ABI and hence they can undercut the price of insurance offered by ABI members as a result of excluding those at risk of flooding from coverage. From the government perspective, the problem with insurance is that it is a luxury good, with the take-up of contents insurance being income dependent. At some point, some new public-private partnership with regard to compensation for flood losses is likely to develop. A 1.3% annual probability of flooding (flood return period 75 years) is currently being used by the ABI in the commercial pricing of flood risk. A similar type of threshold could be considered as a trigger to justify other options of public funding, for example compensation and buying properties.

Public involvement

In addition, government policy requires a higher level of public involvement in decision making than the minimum standard of consultation that is required by the Directive. Article 14 of the Directive simply requires that Member States "*encourage the active involvement of all interested parties in the implementation of the this directive, in particular in the production, review and updating of river basin management plans*." Whereas, for example, the Cabinet Office (Cabinet Office nd) guidance states: "*Involving the public and civil society groups in the work of government has become an integral part of the policy making process. It is not simply about more open-government, although that too is important, it is also about making policies more effective by listening to and taking on-board the views of the public and key stakeholder groups.*" Similarly, the command paper on sustainable development (H M Government 1999) gave one criterion as: "*Transparency, information, participation in decision-making, and access to justice should be available to all.*" The most forcible requirement for involving the public in decision-making was given by the DETR (2000): "*It is also a moral duty. Public authorities work for the public*."

Water Framework Directive and public engagement

The implications of the implementation of the Water Framework Directive are that there will be a shift of focus towards the River Basin Districts and catchments and away from individual schemes. Concurrently, the government's emphasis on public involvement in decisions implies that decisions as to whether, in what form, and on the basis of what criterion, a flood alleviation scheme should be constructed will be the outcome of a process of engagement with the public and other stakeholders. Unfortunately, the strategy for public engagement by the Environment Agency under the Water Framework Directive has not yet been determined although in the case of non-main watercourses, the Audit Commission (1999) has provided guidance for local authorities as to the procedures to be adopted at present. However, it is foreseeable that when the process of public engagement is adopted under the Water Framework

Directive, the stakeholders will expect to be engaged in decisions as to the appropriate decision criteria to be adopted across catchments. Preparatory work on these issues is already being undertaken by the Environment Agency. In the short term, this report can only contribute to wider discussions with the stakeholders and is intended to provide a basis for such a discussion.

Catchment management

A main element of the Water Framework Directive is the adoption of a catchment approach to water management. This involves integration in three ways:

- Across a catchment as a whole;
- Between land and water use; and
- Between the different uses of water and the activities associated with water.

As far as flood risk management is concerned, this implies:

- Starting from a concern with the functioning of the catchment as a whole rather than from local problems;
- Management of the entire process of runoff, groundwater stocks and flows, surface water stocks and flows rather than a focus solely upon single aspects such as extreme flows. This process concern implies an integrated approach to the issues of surface water drainage, the operation of surface and combined sewers, and to flooding from both ‘main’ and ‘non-main’ rivers;
- A recognition that a catchment involves stocks and flows of ‘pollutants’ as well as of water, and also of erosion and deposition of sediment.

Taken together, there is an implication that multi-functional options are likely to be preferred to approaches designed to address a single problem; and that options that seek to enhance the performance of the catchment as a whole are likely to be preferred to options that seek to fix a local problem.

The question of achieving consistent standards becomes far more complex when considered over an entire catchment where a range of flood mitigation measures might be employed.

Local Government decision-making and funding

A further change is affecting one of those stakeholders: the ODPM is examining new options of funding local government, as well as promoting a shift in emphasis away from central government to regional assemblies. Compared to local government in many other countries, local government in England and Wales is very much dependent on central government for funding. In turn, this means at present, flood and coastal defence is effectively funded out of central tax revenue and hence a major stakeholder in the decision is the general taxpayer. As a result, Defra and the Treasury have an important proxy role for the general taxpayer in decisions as to the decision criterion to be adopted. The introduction of direct funding to the Environment Agency means that the Agency's Board also has a proxy role in decision making.

Should the local government become responsible for raising a significant proportion of their income in other ways, or be given the equivalent of the constitutionally guaranteed shares of national revenue found in Germany, then this could imply that local governments should have much greater freedom in the decisions as to the decision criterion to adopt. Clearly, under the developing pattern of local government, and particularly planning, the key local government stakeholder will be the regional assemblies, whether or not these are directly elected.

Flood risk is changing

Another element of change is climate change. Both rainfall intensities and the distribution of rainfall over the year are expected to change. Extreme sea levels are expected to rise and wave heights to increase. This will result in a reduction in standards for existing defences and an increase in the frequency of flooding. Flooding from other sources including urban drainage and groundwater is also likely to increase for the same reason unless mitigation measures are provided.

One current constraint on adaptation to the resulting changes in flood risk is that it is not currently possible to use Defra funds to purchase and demolish properties simply because they are at risk of flooding. Since there is no duty to provide protection against flooding, those at risk bear those risks. H M Treasury could be expected to be, as it has in the past, extremely resistant to any change to allow central government funds to be used for this purpose, not least on the grounds of creating a precedent. There are obviously no such legal constraints upon the sewerage companies using their revenue to buy out and demolish properties at high risk of flooding from sewers. From the customers' viewpoint, consistency is an issue for all types of flood irrespective of source of flooding and institutional and funding arrangements.

In other countries, notably the USA, Canada and France, the purchase and demolition of properties in high risk flood zones is being increasingly adopted. If and when a UK government introduces some system of compensation for victims of natural disasters, it is reasonable to expect a system whereby owners of high risk properties can choose to be bought out as the alternative to foregoing compensation in future floods.

New approaches to appraisal

Finally, research is currently underway to examine the potential role of Multi-Criteria Analysis in appraising schemes, scheme options and prioritising schemes within programmes.

3.3 Why do we have to choose?

Choices

A decision criterion is a rule by which to determine which option to adopt in a choice. If we are to select an appropriate decision criterion then it must be grounded in the reasons that make choices necessary in the first place. We only have a choice when there exist at least two mutually exclusive options and it is not self-evident to everyone which option should be adopted. Thus, for a choice to exist, there must be at least one reason why one option should adopted over all others, and at least one reason why an alternative option should be chosen.

There are three bases for arguing that one option should be preferred over all others. The simplest is that different groups or individuals simply like one option rather than another, or one option leaves them personally better off than all others. The second basis for arguing for one option rather another is that there are moral, ethical or religious reasons why we ought to prefer one option rather than another. The third rationale is the pragmatic one that in any group, the different members of the group must see their interests as, on average, gaining more from membership than they lose.

More fundamentally, there are a number of reasons why the alternative options may be inherently mutually exclusive. These include mutual exclusivity in time and/or space: a wetland and an oak forest, for example, cannot occupy the same space. There may also be no option which is superior to all others when considered against all of the objectives that we bring to the choice. For example, when applying the Brundtland report’s definition of sustainable development, it is not inevitable that there will always be an option which simultaneously satisfies the needs of the present and the interests of future generations. If there does not happen to be such an option, then we are forced to choose between satisfying our short term needs or interests, and those of future generations. The Habitat Directive’s definition of the conditions when it is permissible to allow harm to occur to a Natura 2000 site specifically refer to just such a potential conflict: harm is only permissible if the socio-economic requirements are overwhelming and there is no means of satisfying those requirements which will not result in harm being done to the site.

When there is no option that is superior to all others in terms of the objectives that we bring to the choice, then the critical issue is the relative weight or importance to be given to each of those objectives. We often disagree what weights ought to be given to these different objectives and these arguments are themselves often moral or ethical in nature.

Finally, resources are limited. The effect of this is to act as an external constraint on specific choices. So, we might all agree that health care policy A should be preferred to health care policy B even though health care policy B requires less resource. Similarly, we might also all agree that everyone should be protected against all except the most extreme floods against an alternative policy which either only protects some people or provides a lower standard of protection. The problem arises when there are insufficient resources to adopt both health care policy A and the preferred flood management policy. We then have to choose between a combination of the best health care policy and the second best flood management policy or the second best health care policy and the best flood management policy. The significance of the scarcity of resources is that it forces us to decide what are our immediate priorities.

Who chooses?

The importance of these different issues, particular those concerning the objectives and resources, depend upon who has an interest in the particular choice. When considering a choice as to the provision of a flood alleviation scheme, we can distinguish between three different groups of people: those who will be at a lower risk of flooding as a result, those who will pay the costs of the proposed scheme, and those who will be positively or adversely affected by the proposed scheme in other ways (Figure 3.1). Those who benefit from flood alleviation include households, industrial & commercial enterprises, people who travel through flood risk areas, etc. Flood alleviation can also have regional and national benefits, for example the protection of central London.

Those who are incidentally affected by a choice typically differ in terms of the nature and direction of the affect, as well as the magnitude of that affect. In the simplest case, each set would be composed of a single individual or household: that household would be at a reduced risk of flooding, bear all of the costs, and nobody else would be affected by their decision to undertake flood alleviation works. More usually in collective choices, the three sets only partially overlap so that some people gain the benefits but do not contribute to the costs and others are adversely affected whilst not gaining any benefits, and so on.

The interests of all three groups need to be properly taken into account in a decision. The extent of the affect of any option usually differs markedly between the different groups and in the case of a flood alleviation scheme funded out of general taxation, there are a very small number of people benefiting significantly from the scheme. Conversely, a very large number of people each pay a very small amount towards the cost of an individual scheme, commonly around 30p per household.

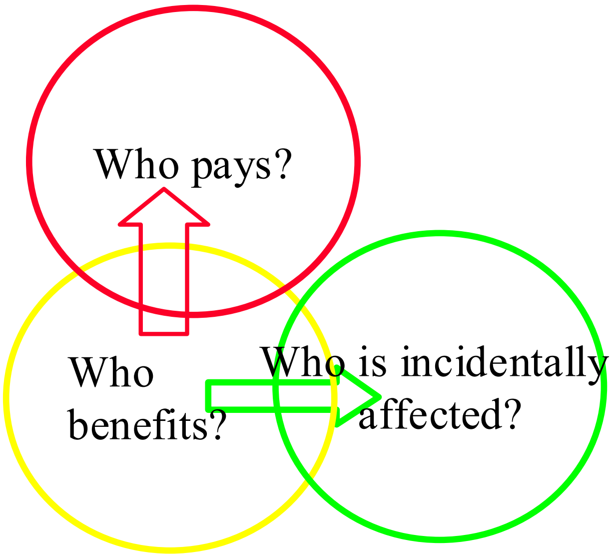


Figure 3.1 Interests in flood risk management

The difficulty in deciding what flood alleviation schemes to undertake and what standard of protection to adopt, lies precisely in the degree of separation between the three groups of people. If those at risk of flooding bear all of the costs of providing the flood alleviation scheme and what they did had no negative effects on anyone else, then this debate about criteria would not be taking place. Instead, we would be having a debate as to whether it was fair that the rich could afford to provide themselves with a higher standard of protection against flooding than the poor.

In that the costs of providing flood alleviation schemes are carried by the general taxpayer, they have a legitimate interest in how their money is spent. However, given the small cost to each of them of a single scheme, they are unlikely to be highly motivated to engage in the decision process. That decision process is consequently likely to involve primarily, those who will benefit from the proposed flood alleviation scheme and those who will be adversely affected by it. However, if the average cost of flood alleviation schemes is £12,000 and 10% of the country is at risk this means that the average household which is not at risk of flooding is transferring £1200 to those households who are at risk.

It is clearly reasonable that decisions taken as to whether to undertake individual flood alleviation schemes and the design standard of protection that is provided should be made in a transparent and consistent way in order to achieve accountability. At the same time, it is easy to see circumstances when the rest of the population would conclude that it was unfair to expect them to contribute towards the costs of protecting others against flooding. For example, suppose that someone, knowing the risks of flooding, chooses to live overlooking a river because of the attractions of living next door to the river. But they would only make that choice because they expected that flood alleviation will be provided for them at other people's expense. In this case, the fairness of expecting the rest of the country to pay the costs of providing flood alleviation for them appears questionable.

Whilst it was hoped to avoid a discussion of why those not at risk of flooding either choose or deem that they ought to contribute to the costs of reducing the risk of flooding to others, this has proved impossible. For those who will pay the costs of a scheme, the decision criterion logically follows from the reasons why they are prepared to pay in the first place. Possible reasons why they may either wish to contribute to the costs, or believe that they ought to contribute to those costs, are:

- The actions of others have imposed the risks on those at risk; those flooded are flooded by other people's water;
- The risk of flooding has increased in an unforeseen way since those at risk settled in the area at risk;
- Those at risk were encouraged by society to settle in the area by, for example, the zoning of the area for development;
- For reasons of communal solidarity, the Preamble to the constitution of France, for instance, asserting that there will be national solidarity in the face of natural catastrophes;
- Flooding can have a much wider impact than on just those who live and/or work in flood risk areas, for example flooding of central London or central Birmingham;
- Those who settled in the area were ignorant of the risk and it is unreasonable to expect that they should have known the risks;
- Those at risk are the poor or otherwise especially vulnerable and so especially deserving of help;
- There are gains to the country and community as a whole from settlement on flood prone land, and corresponding national responsibilities to those who settle on that land;
- There is no where else for settlement, all available land is already in some use (in England, 22% of all land is in some urban usage, the different environmental designations cover 42% of all land).
- When the community does not specifically prohibit some action, then there is a duty to assist those who come to harm (e.g. to rescue rock-climbers who have accidents);
- Sympathy: floods destroy people's lives.

The third interested group are those affected by the decision in either a positive or negative way. These externalities can vary in their direction, nature and extent. One obvious group are those living upstream or downstream of any proposed scheme, if that scheme changes the risk to them as well. Other groups who may have an interest in any proposed scheme are anglers, boaters, and those with an interest in the environment. Arguably, the most extreme case is when one group has to bear the disruption and other costs of works which provide flood alleviation to others.

Summary

Consequently, a decision criterion may have to serve two different purposes:

- To enable the stakeholders to make better choices; and
- To demonstrate accountability in the spending of public monies.

Those choices involve selecting:

Between different options to provide flood or sea defence in a specific location; To establish the priority of undertaking specific schemes across a catchment, region or the country as a whole.

3.4 What is a better choice?

Ideally, we want to make the 'right' choices where 'right' carries both connotations of 'just' and 'correct'. We want both to achieve the just balance of objectives and to achieve that, we must correctly identify that option which will be most successful in achieving them. If the balance of objectives that should be achieved in any choice were to be immutably determined prior to that choice being made, then we could simply look for the correct choice. But since our objectives may themselves be mutually exclusive in the particular circumstances of the choice, we may be forced to choose the ends as well as the means in a particular choice.

To seek to make the 'right' choices is an optimistic goal so we may settle for being more successful than we are at any given time in either in determining what is just or identifying the right option to achieve that end: simply to seek to make 'better' decisions than we have in the past.

Definitions of justice involve two components: an outcome that is based upon some concept of justice where that outcome is arrived at through the consistent application of a system of rules which are themselves just. Thus, definitions of justice include: "*the quality of being (morally) just or righteous; the principle of just dealing; just conduct; integrity; rectitude" (Shorter Oxford English Dictionary);* "*Treat like cases alike*" *Hart (1961); and "… Formal justice requires the equality of treatment in accordance with the classification laid down by the rules....*" *Lloyd (1991).*

Similarly, equity has been defined as: "that which is fair or right; impartiality; the recourse to the principles of justice; the quality of being equal or fair" (Shorter OED 3rd edition). The International Court of Justice defines it as a "general principle directly applicable in law."

What these definitions of justice and equity therefore share is that both have two components: the objective of doing that which is just or righteous and a requirement as to the characteristics of the process to be adopted in seeking to achieve that objective. So, equity can be defined as: "*A moral principle consistently applied*." Consistency does not imply uniformity.

If, for example, we decide that it is appropriate in judging those who have killed someone else to take account of the circumstances that lead up to the death, then justice requires that we do so when judging all killings, and take account of these circumstances in the same way in each case. As this example illustrates, a distinction must be made between the consistent application of the rules and uniformity of outcomes. For justice, outcomes must be uniform only when there is uniformity of conditions that give rise to those outcomes. If conditions differ then it may be a necessary consequence of the rules that the outcomes also differ.

If equity can be defined in terms of a moral principle consistently applied, then it follows that economic efficiency is simply another claim as to what should be the moral principle adopted in making choices. It is the assertion that the basis for collective choices ought to be the maximisation of the total value of all consumption relative to the resources required to provide that consumption. Economic efficiency, the basis for cost-benefit analysis, is not a technical question but a moral claim.

In the specific case of a criterion to determine the design standard of protection to be offered in flood alleviation schemes, the two key questions are therefore:

- Which is more important? – uniformity of outcome or consistency in the application of the rules?
- Which is the moral principle that should be applied?

It also follows that the criterion must be capable of being consistently applied. If it is technically impossible to apply it across all cases, then neither uniformity of outcome nor consistency in approach will be achieved. If it is not technically possible to provide a specified design standard of protection in every case, then it will not be possible to achieve either uniformity of outcome or consistency in approach.

3.5 What is risk?

If we adopt a consistent standard of risk criterion then it is important to be clear what we mean by risk. Risk is such a useful word because it is so ambiguous, the main two meanings, although others are also used, being associated with it are ‘probability’ and ‘expected value’: the product of probability and outcome. There is always an implied ‘of’ attached to risk since a probability is always the likelihood of some event or outcome and hence even when used as a synonym for probability, an outcome or event is implied.

Choices are always about the future; we can try to reduce the affects of floods in the future but unfortunately we can do little about past floods other than try to mitigate any continuing after effects of those floods. Since choices are about the future, any choice is necessarily based upon some prediction of the future where those predictions can only be based upon our knowledge and understanding of the past where that knowledge and understanding is generally only partial. Our dilemma is that we have to try to predict the future whilst being bound to doing so upon our understanding of the past. Hence, we should not be surprised if those predictions are only partially accurate.

The conventional approach to predicting the risk of flooding affecting a particular town is to take the past record of flood flows and to fit a statistical distribution to that record. It is then usually necessary to infer from that distribution what is the probability of the flood that is of interest.

Two points of importance:

- An apparently random pattern of occurrences does not necessarily mean that these are generated by a random process, only that we neither understand the process that generated them nor can we predict the outcomes. There is an important distinction between a random process and a series of outcomes that appear random;
- Of the two main conceptual bases for probability theory, a reliance is being based upon the frequentist school.

The limitation of using history to predict the future is that it assumes that the future is the same as the past and that the past itself was unvarying. In practice, the past is not constant and the future need not be a simple extension of the past. Nor is the pattern of floods necessarily the result of random processes. In practice, we can look for three patterns over time in past floods:

- Trends
- Cycles
- Unpredictable changes

The past behaviour of a catchment provides the best guide to future behaviour. A common approach is therefore needed that takes account of past behaviour and recognises present and future uncertainty. Climate change is one obvious source of trend change but others include changes in land use and hence runoff, and changes in the form of the river itself. Franks (Kiem et 2002) has shown that there are strong associations between the cyclical variations in the Southern Pacific Oscillation (ENSO) and flooding in Australia; Wirrety (2003) has found a similar relationship between the North Atlantic Oscillation and flooding in Scotland.

The residual variation in flooding over time might be the outcome of random processes or chaotic processes; most generally, it is simply the variation in flooding that is currently impossible to predict. Within this third category is included the problem of antecedent conditions; the consequences of a particular meteorological event depend upon what has occurred previously and hence whether the catchment is already saturated with water, or frozen, or baked dry so that a high proportion of rainfall will become runoff.

There are two implications:

- Whilst flood risk management is necessarily concerned with the management of risks in the future, those risks will almost certainly be different from risks now;

- The risks now are not known with either accuracy or precision so that the uncertainties concerning risks in the future can be substantial.

Consequently, to shift to an approach based upon equalising probabilities would be somewhat problematic. Within a small community, it would be possible to apply consistency in terms of a flood level but if consistency is required across catchments as a whole or across the country as a whole, then a probability based approach is the only option. Given likely systemic errors in the estimation of probabilities, relying upon probabilities will disadvantage those communities where it is most difficult to assess probabilities.

3.6 The physical reality

For most forms of flood alleviation works, the costs are proportional of the length of river along which protection must be provided. This is the case for flood embankments or walls, or channel improvements in the form of widening or deepening the channel. Conversely, the benefits of a scheme are a function of the area protected and the value per unit area protected. Consequently, the benefit-cost ratio of a scheme is determined by the ratio of the area protected per unit length of works and potential loss per unit area. It follows that it will usually be easier to justify works on lowland rivers than on upland rivers (Figure 3.2) simply because the width of the flooding across the floodplain is greater for lowland rivers. This dependency of the benefits upon the area protected holds for other forms of flood alleviation even when the cost of those works is not related to the length of the river - an obvious example being the provision of storage. Whether the costs of storage are then sufficiently low to redress the balance of advantage between lowland and upland rivers is not known.

Geometry also tends to shift flood alleviation works in favour of the lower income groups rather than the better off. If the cost of a flood dike is £7000 per metre, then a row of C19th terraces with an average frontage of 4 metres, benefits of £28,000 per dwelling are required. If instead the properties protected are detached houses with an average frontage of 15 metres, then benefits of £105,000 per dwelling are required. If the losses from flooding to a depth of 0.6 metres to a pre-1914 detached house occupied by social class AB are compared to those to a pre-1919 terrace house occupied by social class DE, the loss to the former comes to £63,420 and to the latter, £20,260. A study done about fifteen years ago took account of overall density, there being many more terraced houses per hectare than there are detached houses, concluded that the benefits of flood alleviation were highest for high density housing which tends to be occupied by the economically deprived. The adoption of the income weights in the latest version of the Treasury's 'Green Book' (H M Treasury 2003) will, in any case, shift the balance towards those with lower incomes.

There is an argument that when housing is lost through either erosion or very frequent flooding, then, since house prices are used to evaluate the loss, there is a bias towards higher income areas. But the bias here will be between regions, a terraced house in the south-east having a market value of around twice that of one in the East Midlands. Within a region, the loss per unit length argument works against a bias towards higher income areas and, again, the adoption of income weights will shift the balance towards those with lower incomes. But that leaves open the question as to whether adjustments should be made between regions.

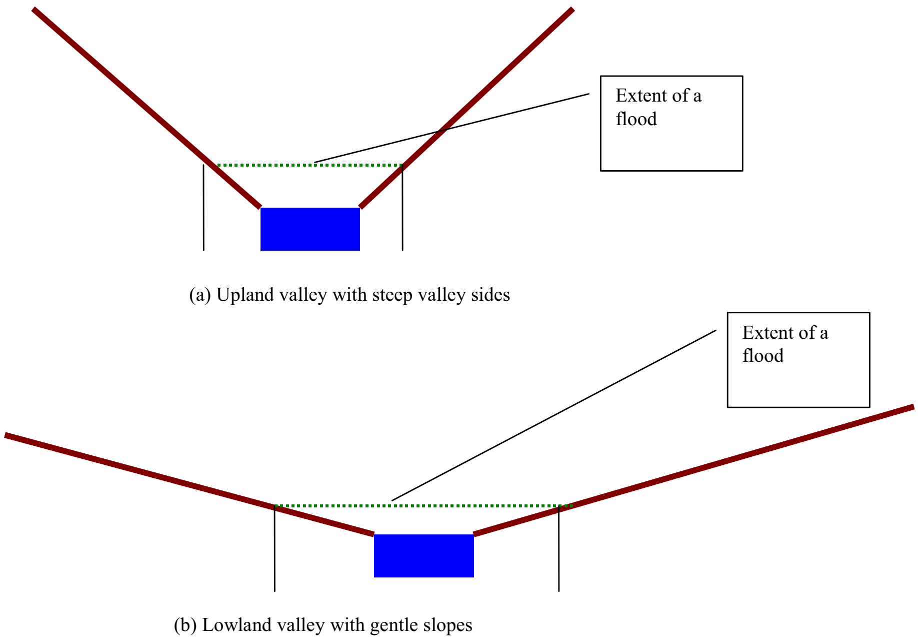


Figure 3.2 Valley form and flood extent

Secondly, a design standard of protection defines only the same threshold risk for all properties protected. It does not give every property the same risk of flooding, the same loss when a flood does occur, or the same expected value of the loss. For example, Figure 3.3 is a cross section of the not uncommon case where a natural or artificial (e.g. a road) ridge of land protects a lower lying area of land behind it from flooding. Property B lies on the ridge line itself and enjoys a view of the river; properties A and C are located in the area behind the ridge.

Suppose a flood wall is now built to improve the protection offered. Figure 3.4 then illustrates the loss-probability curves for each of the properties. Properties A and B both flood from a flood with the same return period; one that just overtops the defences (for simplicity, the volume of water that overtops the wall is assumed to be very large). Property C lying somewhat up a rise behind the hollow is not flooded by this event but would be by a more extreme event. In any event that does overtop the flood wall, A will experience a greater loss than property B because flooding will be deeper. So, the expected value of the loss, that would be the statistically fair insurance premium, would be highest for property A and lowest for property C.

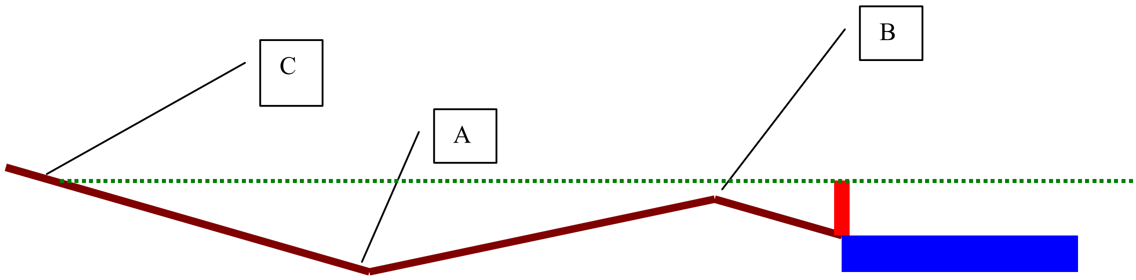


Figure 3.3 Cross section for one bank of a hypothetical valley

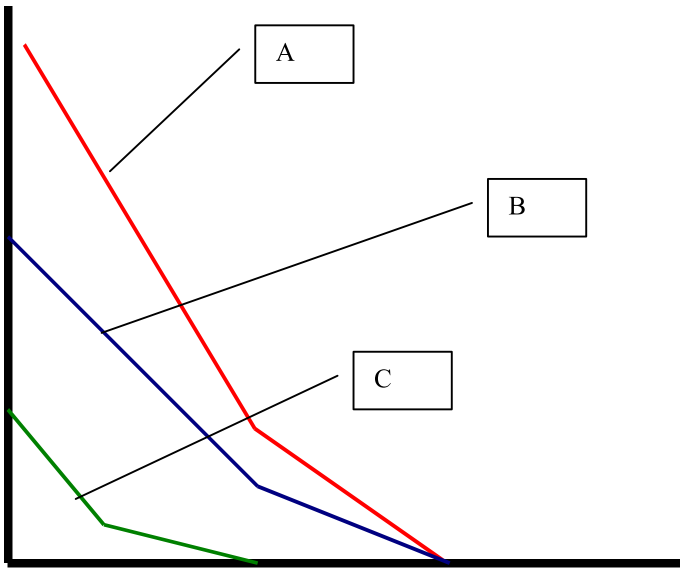


Figure 3.4 Loss-probability curves for the three properties

3.7 Flood management options

Typology

It has previously been argued that geometry is a very important aspect of flood management so one dimension of a typology is consequently a range of geometries. The second dimension is the generic range of options although in any particular scheme, the number of feasible options will be less. For riparian schemes, these options include:

- Storage
- Bypass channels
- Channel "improvements"
- Separation e.g. embankments, flood proofing

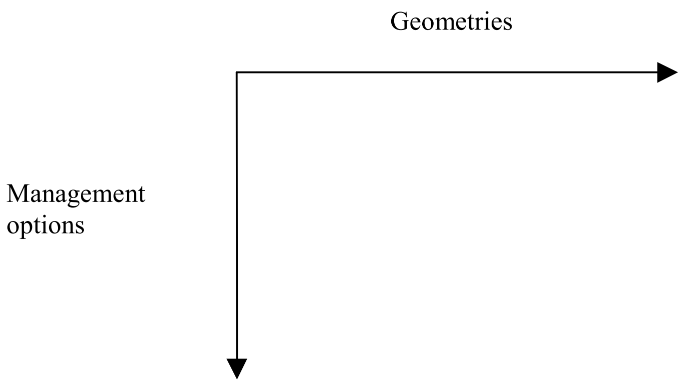
In practice, the majority of schemes are variants of the fourth strategy and this is reflected in the selection of case studies. Six of the seven case studies were fluvial flood defence schemes involving walls/embankments. The seventh involved a combination of channel “improvements” and flood storage.

However, it is possible that the catchment approach to flood management could lead to an increase in storage schemes and the growing desire for environmental enhancement could lead to the restoration of river corridors including demolition of properties adjacent to rivers to make room for the ‘floodway’.

On the coasts, the problem is one of energy management so the three options are:

- Energy attenuation (e.g. wetlands)
- Energy absorption (e.g. big beaches)
- Energy resistance (e.g. sea walls)

This gives a typology defined in the form of the matrix shown below.



The limitation of actual case studies is that the information may not be available to develop the concept of different management options for different geometries, but this is discussed in general terms in the following sections.

Design standards of protection

As noted earlier, the usual approach to the design of a flood alleviation scheme is to seek to achieve some design standard of protection. However, the use of the concept of design standards of protection in flood risk management has been criticised on the grounds that, faced with changing and uncertain risk, the rational approach is to design for all floods and not just for some. It is therefore necessary to plan how we will manage all floods rather than consider only those floods up to some design standard of protection.

Consequently it is necessary to consider the ways in which systems and elements may fail, the consequences of such failures, and how we will cope with such failures. In turn, faced with either a failure that occurs below the notional design standard event or in a more extreme event, it is necessary to consider the flood fighting strategy to adopt. This will frequently involve deciding what areas to sacrifice to provide emergency flood storage in order to protect other more critical areas; for example, we would probably sacrifice a number of houses in order to protect a district hospital from being flooded. Such an approach has been traditionally adopted in flood risk management in different parts of the world (for example, Figure 3.5).

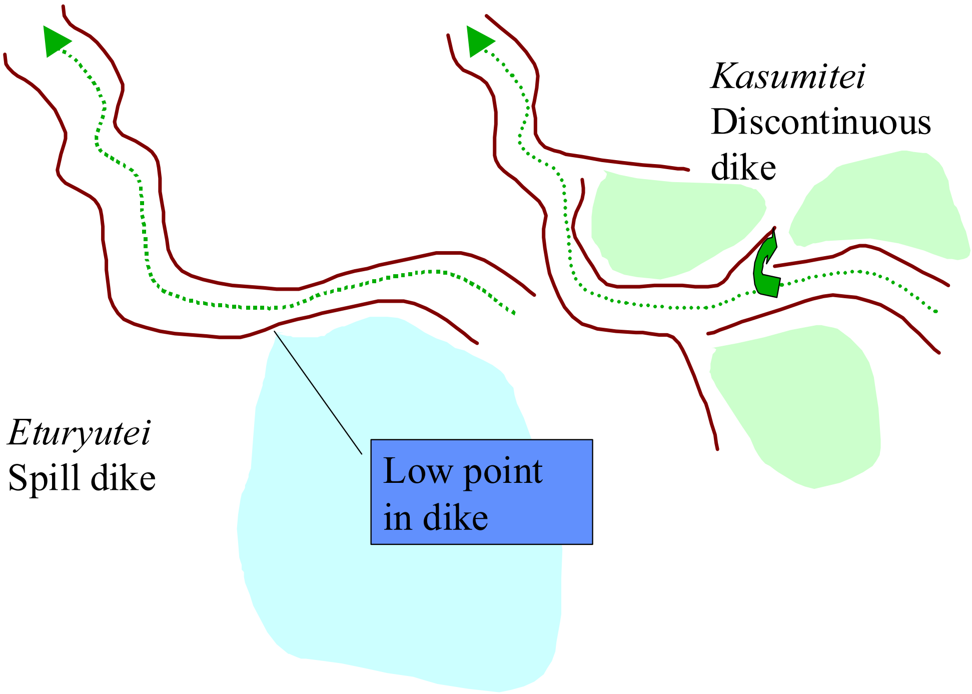


Figure 3.5 Traditional approaches in Japan to managing all floods rather than just some

There are also constraints on the standard of protection that can actually be achieved, depending on physical limitations and the resources needed to provide flood defence. Examples are as follows:

- Flood walls or embankments that exceed a certain height may be considered unacceptable because of the consequences of overtopping or failure;
- The cost of providing walls/channel enlargement in a dense urban area may be unacceptably high;
- Where old river walls exist, there is a very high risk involved in works that could affect the stability of the walls and associated buildings;
- Old arch bridges often cause constrictions in the centre of towns, and this may limit the standard of protection that can be provided. Increasing the standard of protection would involve works to the bridge which may be unacceptably expensive or environmentally undesirable;
- Flood walls or embankments may not be a practical option because of local drainage problems in the flood risk area. The standard provided by other options, for example, flood storage, may be limited by the availability of suitable sites and the amount of water that can actually be stored.

Thus there are cases where desired standards of protection cannot be achieved.

In addition, the impacts of climate change are likely to affect the standard of defence. Current predictions indicate that flood flows will increase, thus leading to a reduction in defence standards. A key element of flood defence design must therefore be consideration of how standards can be increased in the future, and this should be incorporated into any new flood defence scheme.

Another factor to consider is the difference between different defence standards. If, for example, the difference in flood level and cost of defence works for the 2% and 1% flood defence options was small, it would be advisable to adopt the higher defence standard even though it may not strictly comply with a decision rule.

Generally there is a steady increase in river level / sea level / wave height as the frequency of flooding reduces, and therefore defence costs also increase. However there are cases where the difference can be very small, for example:

- Schemes on the edge of very wide river floodplains where the range of flood water levels is small;
- Tidal schemes in areas where the range of tidal water levels is small.

In such cases, it is suggested that a high standard of defence is provided where it is easy to do so.

Features of flood management options

The following sections outline features of a range of flood management options, including:

- Impacts of geometry;
- The impact they could have on other flood risk areas;
- The impacts on the defended area of floods that exceed the design standard;
- The implications of the flood management options for providing a consistent threshold risk of flooding.

Flood walls/embankments
Flood walls and embankments are used to prevent flood water entering discrete flood risk areas. The defence standard provided depends on the top level of the defence and therefore the height above ground. Typical applications of flood walls and embankments include:

- Coastal defences, where the defence is provided to prevent inundation by high tidal water levels and wave action;
- Defences on estuaries and other tidal reaches, where defence is provided to prevent inundation by high tidal water levels, often in combination with high levels caused by fluvial flows;
- Defences on non-tidal rivers, where defence is provided to prevent inundation by high fluvial water levels. These include defences of urban

areas, where the standard is normally high, and agricultural areas, where the standard is often low.

Flood defences are most economic where the floodplain is wide and the area defended per unit length of defence is large, for example in Figure 3.2(b). Flood defences become an expensive option where the floodplain is narrow and the area defended per unit length of defence is small, for example in Figure 3.2(a).

Flood defences can worsen flooding in other areas, particularly in the following cases:

- The construction of flood defences on estuaries can cause an increase in flood levels upstream in some circumstances;
- Flood defences on rivers remove storage from the floodplain, causing an increase in flood flows and levels downstream;
- Flood defences on rivers block floodplain flow, causing an increase of water levels. This normally extends from the downstream limit of the defence, reaches a maximum at the upstream limit, and dissipates within the backwater length of the river further upstream.

It therefore follows that:

- Flood defences will increase water levels elsewhere, particularly upstream on rivers where part of the floodplain has been blocked by the defences;
- Fluvial flood defences will increase water levels on the opposite side of the river.

Other important factors to consider when using flood defences include:

- The impact on local drainage systems, as flooding can be caused behind the defences because local drainage water cannot discharge. Storage areas and/or pumps are often used in these circumstances;
- Seepage can occur under defences. Where flood defences are the only option, a cut-off wall below ground level may be required to prevent seepage. This can be very expensive.

When floods occur that exceed the defence level, water can overtop the defences leading to rapid flooding. This can be exacerbated by a failure of part of the defence system. Thus the construction of flood defences can lead to a more hazardous situation than the pre-defence conditions.

The rate at which a defended area fills depends on a number of factors including:

- Height of water level above the defence, as this controls the rate of flow per unit length of defence;
- Length of defence;
- Duration of flood;

- Area/volume of floodplain.

The impact of duration and level is illustrated on Figure 3.6.

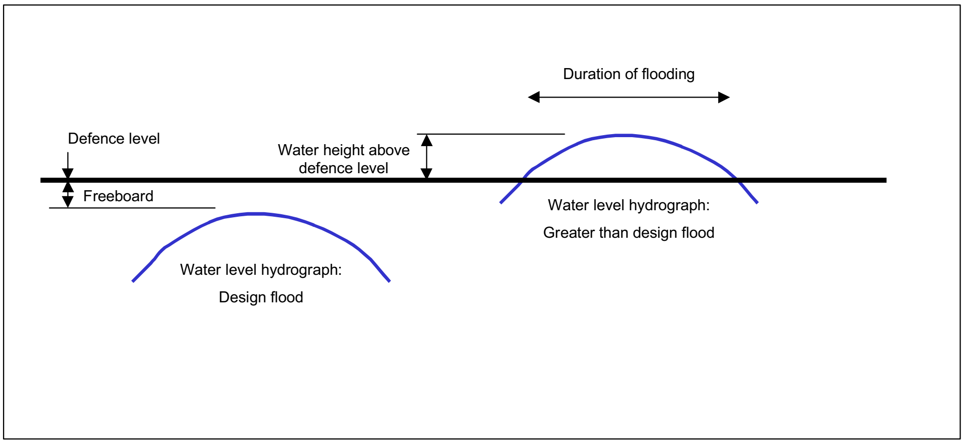


Figure 3.6 Impact of flood duration and level on inundation

The following general conclusions can be drawn regarding floodplain inundation:

- On large rivers, the duration of inundation is long and the amount of floodwater is large. Conversely, on small rivers, the duration of inundation is short and the amount of floodwater is normally smaller. The volume of floodwater in tidal situations depends on the number of tide cycles where flooding occurs;
- Small narrow floodplains on large rivers are likely to completely fill with water when defences are overtopped;
- Large floodplains on small rivers will only partially fill, and the defences will provide a residual degree of protection;
- Defences on the coasts and estuaries normally provide a considerable degree of residual protection when overtopping or breaching occurs because flooding is limited by volume of water.

With regard to the achievement of consistent threshold risk of flooding, flood defences offer considerable flexibility in flood defence design because individual cells can be provided with a specific threshold standard. There are however limits on the standard that can be provided caused by physical constraints and the associated financial limitations, for example the high cost of defending long narrow floodplains or building defences in intensive urban areas.

Flood storage
Flood storage involves storing flood water at a location upstream of the area to be protected. The storage may either be 'on-line', where the downstream flow is controlled by an outlet structure from the storage area, or 'off-line, where the upper part of the flood hydrograph is diverted to the storage area. In this case the downstream flow is limited to the flow corresponding to the threshold level of

the offtake structure. In both cases, the maximum flow in the river channel downstream of the storage area is limited to a pre-determined amount which is less than the flow needed to cause flooding in the design situation.

Typical applications of flood storage include:

- Storage areas just upstream of flood risk areas. These can be on-line (for example, Tonbridge) or off-line (for example, Lincoln);
- Strategic storage areas that may be remote from the flood risk area. This provides benefit to a whole catchment rather than a local area.

Flood storage areas require a volume of potential flood storage. Thus they require land that can be flooded during an extreme event. Engineering works are needed to maximise the depth of storage (for example, embankments and dams) and to limit the extent of storage.

The impact of flood storage schemes is to reduce the peak flow downstream. This reduces downstream flood risk. Discharge of the stored water changes the shape of the flood hydrograph (often lengthening it) and this can worsen flooding in some circumstances. For example, if the storage area is on a tributary, the changed hydrograph shape could lead to higher overall peak flows on the main river. There is a need to optimise the use of storage schemes so that the flood mitigation benefit is maximised. This may include, for example, delaying the time when water enters a storage area so that the reduction of the peak flow is maximised.

Storage areas are vulnerable to larger than design events that exceed their storage capacity. Once the storage area is filled, the downstream flow increases sharply as shown in Figure 3.7. A storage area will have some residual flood defence benefit because of attenuation in the reservoir even though it is full.

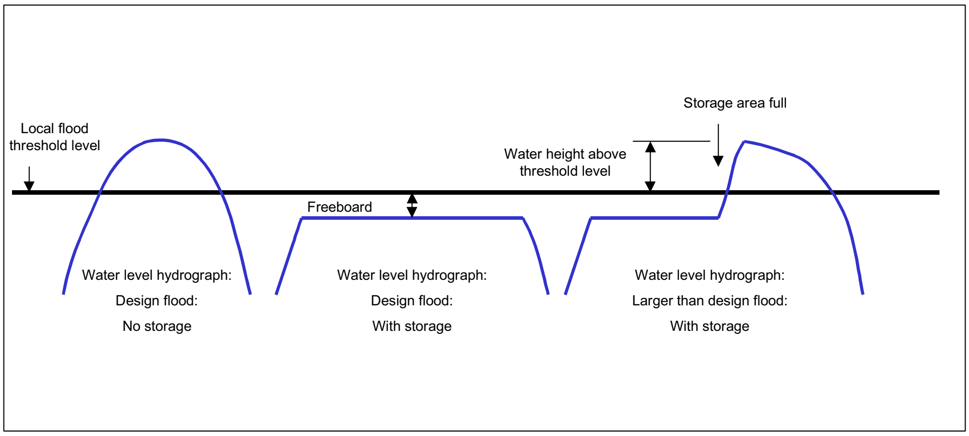


Figure 3.7 Impact of extreme events on flood defence using flood storage

Thus if a larger than design flood occurred, there will be a rapid rise in river flow and water levels leading to flooding in the flood risk areas. Whilst the key hydrological design criterion for a scheme involving walls or embankments is peak flow, flood volume is the main factor in the design of storage schemes.

Storage schemes are vulnerable in the type of flooding that occurred in autumn 2000, where the rainfall duration was long and river flows were high for an extended period. In such cases there is a danger that storage schemes will fill and lose their effectiveness.

With regard to the achievement of consistent threshold risk of flooding, storage schemes provide the same peak river flow to all flood risk areas. The onset of flooding becomes a function of the local threshold level in each flood risk area. If all flood risk areas have the same threshold standard, they will all have the same threshold flood risk.

Storage schemes are often constructed in combination with works on the downstream channel and walls to ensure the desired standard of defence is provided at all locations.

Bypass channel
A bypass channel involves diverting part of the flood flow away from the flood risk area in a separate channel. The maximum flow in the river channel in the design situation is limited to a pre-determined amount which is less than the flow needed to cause flooding.

The most important requirement for a bypass channel scheme is a suitable corridor of land to accommodate the channel. As this is rarely available in urban areas, the number of schemes of this type is small.

The impact of a bypass channel is to reduce the attenuation of the flood wave by preventing floodplain flow and channelling the flood water into two channels (the river and the bypass). This causes an increase in peak flood flows and levels downstream, although the effect is normally small (less than 50mm even for large schemes).

If the capacity of the scheme is exceeded:

- There will be a gradual rise in river flow and water levels, leading to flooding which starts with the most vulnerable areas (i.e. those with the lowest flood threshold level);
- New flood risk areas might be created along the bypass channel route.

With regard to the achievement of consistent threshold risk of flooding, bypass channels provide the same peak river flow to all flood risk areas. The onset of flooding becomes a function of the local threshold level in each flood risk area. If all flood risk areas have the same threshold standard, they will all have the same threshold flood risk. It is also necessary to ensure that areas adjacent to the bypass channel have the required threshold risk of flooding.

Increase of channel capacity
The objective of increasing the channel capacity is to contain all flows within the river channel so that the maximum water level is lower than the level needed to cause flooding. This approach has been used in numerous flood alleviation schemes throughout the UK, particularly for small watercourses in urban areas.

Channel capacity is increased by widening or deepening the river, or providing flood berms (lowered areas of the floodplain adjacent to the river, which have the advantage of not damaging the existing low flow channel). The scope for widening and deepening a river in an existing urban area is limited by the presence of development and the risk of undermining existing river walls and associated structures.

The impact of increasing channel capacity is to reduce the attenuation of the flood wave by preventing floodplain flow and channelling the flood water into the river channel. This causes an increase in peak flood flows and levels downstream, although the effect is normally small for urban schemes of limited length.

If the capacity of the scheme is exceeded there will be a gradual rise in river flow and water levels leading to flooding which starts with the most vulnerable areas (i.e. those with the lowest flood threshold level).

With regard to the achievement of consistent threshold risk of flooding, the increase of channel capacity provides the same peak river flow to all flood risk areas. The onset of flooding becomes a function of the local threshold level in each flood risk area. If all flood risk areas have the same threshold standard, they will all have the same threshold flood risk.

In practice local variations in water levels occur caused by waves, super-elevation, turbulence, etc. This is one reason why a ‘freeboard’ allowance is provided in the design of such schemes.

Floodproofing
Floodproofing includes:

- Measures to prevent water entering individual properties;
- Measures to reduce (but not prevent) the amount of water entering individual properties;
- Measures to reduce the amount of pollution caused by flooding to individual properties. This involves blocking holes (doors, etc), allowing water to enter through walls and floors, collecting water in a sump, and pumping it out;
- Temporary walls to prevent flooding of groups of properties (but not ‘demountable’ defences, as these are considered to be permanent works).

The common feature of floodproofing measures is that they are implemented locally. The use of sandbags is a common example of a floodproofing measure.

Floodproofing is a potentially popular option for a number of reasons including:

- It can be applied to any property including those in remote locations;
- Costs can be relatively low compared with a flood alleviation scheme;

- Theoretically it might be the most appropriate solution if a criterion of equal cost per property were applied (see Section 5.4.3).

However, practical experience to date has indicated numerous problems with floodproofing, including the following:

- Measures to completely prevent water entering properties are very expensive;
- The blocking of doors, windows, air bricks, etc. does not prevent water entering properties through walls and floors (i.e. flooding will still occur, although damage will be less);
- Walls could collapse under a differential head of more than one metre. Measures to prevent flooding to individual properties are therefore not effective for flood depths greater than one metre, and there is the potential to cause more damage to a property than the flood would have done;
- Temporary walls require community action and co-ordination to erect;
- All measures require flood warning, particularly temporary walls;
- Considerable effort will be needed to supply floodproofing equipment to individual properties and advise on safe use.

If the flood exceeds the maximum defence level provided by a floodproofing measure, flooding will obviously occur.

With regard to consistent standards, floodproofing is associated with consistent treatment of properties rather than providing a consistent threshold risk of flooding.

Measures to manage energy on the coasts
Measures to manage energy on the coasts include:

- Energy attenuation (e.g. saltmarshes)
- Energy absorption (e.g. big beaches)
- Energy resistance (e.g. sea walls).

These works are primarily concerned with managing wave energy and the associated flooding caused by overtopping and failure of coastal defences.

The scope for energy attenuation depends on the availability of suitable environments (saltmarshes, wetlands, etc) and the extent to which these can be created (for example, by managed realignment). Energy absorption and energy resistance structures can be designed to provide a required standard of protection. Thus the standard of protection partly depends on natural features and partly on defence interventions.

Energy management works are vulnerable to events that exceed the design standard because this not only leads to flooding but also to potential failure of structures and erosion of the foreshore. Thus a flexible approach is needed to develop design options that can be readily adapted to changing conditions.

With regard to the achievement of consistent threshold risk of flooding, energy management works offer considerable flexibility in flood defence design because individual cells can be provided with a specific threshold standard. However there are more variables and uncertainties associated with the design of coastal works compared with river and estuary defences.

Flood warning
Flood warning is perhaps the most important 'non-structural' measure that can be associated with consistent standards of flood defence. This is because it is within the control of the Environment Agency, and can lead directly to a reduction in flood impacts.

Flood warning involves providing people in a flood risk area with a warning of impending flooding. Currently the Agency uses a minimum warning time of 2 hours (1 hour in some areas), which automatically means that those at risk of flash flooding (warning time less than one hour) do not receive a warning.

In practice there are a number of difficulties with providing flood warnings that produce effective mitigation actions, including:

- Reliability of warning. It is not always possible to provide a reliable flood warning for a variety of reasons including poor information and uncertainty in predictions;
- Warnings may not be received for a variety of reasons, for example people may not be at home to receive the warning;
- Co-ordination of the flood response, which involves a range of different organisations.

There is however scope to improve the flood warning service by increased investment (and therefore the involvement of more people and resources). In the past, this has been difficult to justify economically but, if there was a change in policy emphasis towards protecting population rather than assets, this option could become more attractive.

3.8 What are 'wrong' choices?

If we are deciding upon a criterion to determine the 'right' choices, it is necessary to be clear what might constitute the 'wrong' choices. The ideal criterion is one which always results in, firstly, a decision to undertake a scheme to a specified standard when that is the right choice and, secondly, results in the rejection of schemes or standards when to undertake those works would be wrong. Any criterion may therefore result in one of two forms of errors (Table 3.2):

- **Type 1** errors occur when a decision is made not to undertake the works when given perfect knowledge those works should have been undertaken;
- **Type 2** errors are those when works are undertaken when perfect knowledge would have lead to those works not being undertaken.

Table 3.2 Type 1 and Type 2 errors resulting from the application of a particular decision criterion

Outcome of applying decision criterion	'Reality'	
	Undertake	**Do not undertake**
Undertake		Type 2 errors
Do not undertake	Type 1 error	

Inconsistent design standards of protection within a community are cited as an example of a Type 1 error with the existing criterion. In addition, the following can be suggested as other forms of Type 1 errors that may result from the existing criterion.

The flood risk has increased as a result of development higher up on the catchment so that a community is now exposed to a significantly higher risk but it is not efficient to provide them with flood defence and so it is not provided; Important non-economic efficiency criteria are excluded (e.g. issues of socio-economic regeneration and social exclusion);

The impact on the viability of a community of the loss of community facilities (e.g. a village shop) is ignored (e.g. if a mobile home development moves out of a community, the reduction in demand may mean that local shops etc. cease to be viable);

It has been argued that it is easier to justify flood alleviation works for the rich than for the poor.

We might define potential forms of Type 2 errors as occurring when the scheme:

- Worsens flood problem up or downstream;
- Has significant net negative environmental impacts;
- Will fail to deliver the anticipated flood alleviation benefits;
- Entails an excessive cost (e.g. the cost of the scheme exceeds the value of the property protected);
- Negatively impacts upon the performance of the catchment as a whole;
- Is implemented because of political pressure.

The first four of these are embodied in Defra's stated requirement that schemes are satisfactory in engineering, environmental and economic terms. The fifth follows from the principles of Integrated Water Resource Management as embodied both in the Water Framework Directive and in Defra policy guidance.

Figure 3.8 illustrates the results of applying three different hypothetical criteria to the same hypothetical set of 140 possible schemes and options.

		reality	
		do	do not
Criterion	Do	90	29
	do not	20	1

		reality	
		do	do not
criterion	Do	70	10
	do not	40	20

		reality	
		do	do not
Criterion	Do	60	1
	do not	50	29

Figure 3.8 Application of different criteria to a set of possible schemes/options

Of the 140 schemes considered, if we had perfect knowledge, we would know that 110 should be undertaken and 30 should not be built. In each case, the criterion results in the correct outcome being identified about 65% of the time in the particular set of schemes and options used (i.e. 91/140 in the first case, 89/140 in the second case and 90/140 in the third case) but the performance of each criterion is actually very different.

The first is quite successful at identifying those schemes that should be undertaken but only at the cost of mistakenly identifying most of those schemes that really should not be undertaken as being desirable. Of the 110 schemes that should in reality be undertaken, it identifies 90 of those schemes. But of the thirty schemes that should not in practice be undertaken, it correctly rejects only one of those schemes. The second criterion is very successful at identifying those schemes that should not be undertaken but only at the cost of mis-classifying many of the truly desirable schemes as undesirable. The third criterion is successful in classifying the schemes about 2/3rds of the time. It draws the correct conclusions about 70 of the 110 schemes that should be undertaken, and 20 of the 30 schemes that should not be undertaken. We might reasonably have preferences between the different criterion in terms of proportions of type 1 and type 2 errors that result from each criterion. It is important to decide the balance of type 1 and type 2 errors that can be tolerated from a criterion, given that it would be unrealistic to expect any criterion to have a zero rate of misclassification.

In addition, it should be recognised that some schemes or options are truly marginal; the reasons for and against that scheme or option being equally balanced. So, for example, a benefit-cost ratio of one indicates that the choice between the proposed option and the current situation is exactly balanced.

4. Potential criteria

The obvious starting point is one where central government does not provide any grant aid for flood defence at all. Provided that there are no exceptions to this rule, it provides equality of treatment. However, control would still be necessary over works undertaken by individuals or local communities so that the works they undertook did not simply shift the risk on to others (e.g. in the USA in the nineteenth century, levee districts on opposite banks of a river engaged in competitive dike raising) or cause environmental damage. The importance of the no funding option is then as a baseline; it is necessary to persuade those who are not at risk of flooding, that they both ought to be prepared to contribute to the costs of protecting others from flooding, and that the decision criterion adopted is an appropriate one when their interests are taken into account.

We can then either specify an alternative criterion with the aim of ensuring equality of treatment, equality of outcome or equality of condition; either people should be treated equally or each should be given the same, or they should be raised to the same standard.

A range of possible approaches can be identified under each category:

Approach	Possible criterion
Equality of treatment	No government funding of any flood or sea defence scheme
	Economic efficiency criterion
	Uniform spending allowance per capita, per property or per household
Equality of condition	Uniform design standard of defence
Equality of outcome	All households to be left with the same level of vulnerability after intervention
	All households to be left with the same residual flood losses
	No household shall experience more than a specified depth of flooding

Sen (1992) warns that it will not usually be possible to achieve all forms of equality simultaneously and this is the case here. The choice of a decision criterion forces us to decide what form of equality is most important, given the resulting positive and negative effects.

Sections 4.1 to 4.9 briefly describe and discuss a range of potential criteria for defining Consistent Standards. The nine criteria are summarised in Appendix 1 in terms of their implications and their key advantages and disadvantages.

4.1 Economic efficiency

The criterion currently applied is that of economic efficiency. The problems with this approach are:

It results in different standards of protection being provided between schemes and hence between regions and also, in some cases, within communities;

Economic efficiency is not the only, nor perhaps the most important, objective that we bring to choices and these other objectives are omitted when economic efficiency is the sole consideration;

In particular, concerns such as social-economic regeneration cannot be readily included into an economic efficiency cost-benefit analysis. The counter-argument is that there exist other budgets which are specifically intended to fund socio-economic regeneration and associated with those budget are the appropriate decision criteria;

The standard of protection that is adopted is determined partly by the shape of the valley and partly by the density of value per unit area;

When flooding is very frequent so that the capitalised value of future flood losses exceeds the market value of the property then the latter is taken as the limit of the benefits. However, there are very marked differences in the market prices of dwellings between regions (Table 4.1). In turn, this implies that in these extremes, there will be inequalities in the standard of flood protection provided between regions although these effects may be somewhat muted after these market values have been weighted by the income factors set out in the most recent edition of the Treasury's 'Green Book' (H M Treasury 2003).

Table 4.1 Current market prices of dwellings by region

Region	detached	semi-detached	terraced	flat/maisonette
East Anglia	211,581	134,984	114,411	100,630
East Midlands	195,374	111,193	88,726	97,008
Greater London	520,023	287,070	271,187	222,147
North	184,938	100,812	69,738	84,661
North West	210,735	114,038	67,183	110,382
South East	329,396	193,006	157,659	132,144
South West	259,651	158,163	135,150	127,812
Wales	170,837	98,861	76,017	99,381
West Midlands	231,375	124,123	96,144	105,210
Yorks and Humber	193,355	104,612	74,742	105,786

(Source: Land Registry February 2004)

Once the depth-damage curves are weighted with the factors from the Treasury's 'Green Book' (H M Treasury 2003), there is a slight loading against the protection of dwellings in social class AB;

So-called ‘intangible’ flood losses continue to be difficult to evaluate in economic terms and hence are excluded in whole or in part from the cost-benefit analysis. R&D is currently in progress to address this issue;

Economic efficiency analysis takes no account of whether those at risk knowingly choose the risk to which they are exposed, or whether the risk was later imposed upon them through the actions of others (e.g. the risk has increased as a result of changes in land use practice and hence in runoff);

A secondary issue is that the current approach (Defra 1999) requires the optimisation of the design standard within the indicative range. The driver behind this requirement is that the benefits and costs of the different options may well rise as a non-linear function of the design standard of protection. Hence, a comparatively small change in the design standard of protection may provide a much better ‘buy’. The label ‘optimisation’ should perhaps be avoided since it begs the question of in what sense is a solution ‘optimal’. Secondly, the problem with seeking optimisation is that it requires that we know everything important, and we know it both reasonably accurately and precisely. Since we do not know everything and what we do know, we know neither accurately nor precisely, it might be better to abandon the term ‘optimisation’.

4.2 Population efficiency

The concept of population efficiency is that it is desirable to defend the maximum number of people per pound spent. The application of this approach would be to determine flood defence requirements by the number of people at risk and the standard to which they are protected at present (everyone in the floodplains is at risk for an event which exceeds the design standard of their defences). A defence standard is required which is sufficient so that people in defended areas feel ‘secure’. The analysis covered later in this report was applied using the 1% and 0.2% annual probabilities of flooding.

Population efficiency will in practice produce similar outcomes to the economic efficiency approach as the number of people per house is unlikely to vary dramatically across the country. It will avoid the pitfalls of variable house prices, but will not take account of damage to commercial and industrial properties.

Population efficiency is not considered to be a practical approach in some cases because of the obvious need to defend industrial and commercial areas.

4.3 Equal cost per property

A major inequality at present is the amount spent per property in order to provide flood alleviation works. So, an obvious alternative to the present criterion is to provide a fixed amount in grant aid per property where this amount could be related to the minimum or average spend at present. This would be the amount that the responsible authority would then be provided with as grant aid for the works and the scheme undertaken, and the resulting design standard of protection would be possible within the available amount.

The disadvantages of this criterion are:

- It takes no account of the influence of the shape of valleys; in so far as site specific features influence the cost of undertaking works, the result will be inequalities in the resulting design standard of protection;
- It will similarly take no account of regional differences in the cost of works although this could be remedied by adopting regional weighting factors;
- It takes no account of the initial level of risk although weighting factors could be introduced to allow for such differences;
- It would be necessary to have a formal definition of the area at risk so as to identify those properties for which the sum per property would be payable;
- It does not take account of social inclusion concerns although the lump sum per property could be adjusted to take account of the marginal value of income by the use of the Treasury's income weights (H M Treasury 2003);
- A rule would be necessary to determine what amount would be payable for non-domestic properties e.g. for a factory or a shop. In particular, it would be necessary to develop a rule which defined the amounts payable with regard to those properties in which the government has an interest e.g. schools, hospitals, universities;
- If a house were converted into two flats, then the amount that would be available as grant aid would immediately double. It would also tend to reward increases in development intensities;
- The approach promotes a mechanistic approach rather than thought, when the purpose of project appraisal is actually to aid thought and to provide insight into the nature of the choice that must be made.
- Perhaps the main disadvantage of this approach is that it would result in money being spread thinly between flood risk areas, leading to inappropriate/ineffective solutions.

A variant of this approach would be one where grant aid was limited to this sum but the local community could spend more if it so wanted and raised that money. The disadvantage is then that differences in wealth between areas would determine the standard of protection provided.

Overall, the approach would seem to combine the crudity of the 'house equivalents' model with a rigid rule based approach. It has most of the disadvantages of the economic efficiency approach without any of the flexibility of a cost-benefit approach to take account of specific local differences.

4.4 A consistent design standard; equality of threshold risk

There are five possible variations of this approach:

- Nobody is protected at all;
- Nobody in the community is protected to a higher standard than the best that can be justified for any single individual. This is a lowering down approach and by implication if the protection of everyone in the community cannot be justified, then nobody is protected;
- Everyone in a community is protected to the same design standard where this standard is fixed across the catchment or the country;
- Everyone in a community is protected to the same design standard where this standard is the highest that can be justified for any single property i.e. a levelling up approach;
- In the final variant, the economic efficient option is first determined in terms of the optimum design standards for the different groups of properties. The capitalised cost of this option defines the limit on the costs of undertaking a scheme which provides a uniform standard of protection to all properties in the community.

All five options ensure equality of outcome within a community and if that is the sole concern, then there is no basis on which to choose between the five possibilities. In practice, it is not thought that those who argue for a consistent standard of protection approach are proposing that a lower standard of protection for some should be accepted if it means that others in the community can then be protected. Nor that a community should refuse flood protection if it is only possible to protect some people in the community. The virtue of the fifth variant is that directly engages the local community in the choice.

The problems with adopting one version or another of this criterion are:

- What is a community?
- For the purposes of the definition, is London a single community or many?
- If a consistent standard applies within a community, should not that standard apply across the catchment as a whole? Or, across the country as a whole?

It is likely that there will continue to be an inconsistency in approach between flooding from rivers and sewers, together with continued arguments as to whose flood it is and hence the standard of protection any individual household receives will depend upon whether the flooding is deemed to have been the result of a problem with the sewer or with a watercourse.

For example, one house may be flooded because the sewer has an inadequate capacity and the house is flooded by water flowing overland down to the watercourse. The neighbouring house may then be flooded by the watercourse overflowing its banks as a result of the water flowing overland through the house next door. Consequently there will be inconsistency in the standard of protection provided to different households within a community as a result of differences in the cause of flooding unless the same design standard of protection is applied to both causes of flooding.

The current target decision standard of protection against flooding for sewers is for the 10 year return period flood and around 7,000 properties are flooded, on average, each year. The equivalent asset value of the sewer system is £107 billion, many times the value of the fixed flood defence assets for river and sea flooding. The costs of providing protection from flooding from sewers are borne by the charge payers for the regional sewerage plc. rather than by the general taxpayer as is the case for river and coastal flooding.

One option therefore, would be to fund all riparian flood defence through a charge on wastewater or on runoff rather than through general taxation and to apply a consistent approach to all forms of rainfall derived flooding. It is likely that investment would have to shift away from flooding from rivers towards flooding from sewers; of the 7,000-10,000 properties flooded in the Autumn 2001, a significant fraction appear to have been flooded as a result of surface water drainage problems or problems with sewers. The disadvantage of this approach is that wastewater charges would have to rise substantially when it is likely that a significant increase in water and wastewater charges will be required in the next price round in order to meet other obligations.

Either the standard adopted must be defined from the available budget or it will be necessary to prioritise between schemes within that budget. Dividing this budget between proposed schemes would then determine the design standard of protection that could be afforded for each. If the budget is increased or decreased from year to year, then different standards of protection will be afforded from year to year.

In practice, in extreme floods, it is necessary to determine which areas will be sacrificed in order to protect other more critical areas. If a 500 year return period flood occurs in a community protected to a 200 year design standard, where in one half of the community there exists a district hospital and major factory while in the other half of the community there are 40 homes, then efforts will almost certainly be focused on protecting the hospital and factory. Desperate attempts will be made to strengthen the defences protecting the hospital and factory.

In those areas where there are significant risks to life, the country may well wish to ensure that a higher standard of protection is provided.

The predicted increases in the risks of flooding as a result of climate change are likely to mean that it will be necessary to retire the defence lines in some areas. Any sort of guaranteed design standard of protection will create problems since it would be inconsistent to withdraw protection from those properties that have it at present and adopt a consistent standard of protection approach. Such a move risks creating the illusion of an entitlement to be protected where legally no such right exists.

If the entire community is entitled to a consistent standard of defence, but a consistent standard is not applied between communities, then defining individual communities becomes critical. In particular, it will be critical for individual households whether or not they are deemed to be part of a particular community and which community they are deemed to be a member.

It assumes that it is always physically possible to provide a uniform standard of protection to everyone in a community.

It has been presumed thus far that the consistent standard approach applies only to dwellings. If this is not the case, then the question must be addressed as to whether the approach should be extended to all types of property or only to categories of property designated on some basis. In particular, it is assumed that the approach applies neither to farmland as a whole nor to individual farms.

At present, agricultural land is frequently used for flood storage either formally as ‘washlands’ or informally by the absence of flood defences other than for land drainage purposes. A consistent standard approach would require careful framing if farms and farmland are not to be included, since farms are part of rural communities, but if a consistent standards approach resulted in embankments being extended in the flood plains then it would be strongly opposed by many on environmental grounds. Equally, it would result in the sacrifice of important flood storage and would also increase flood risk downstream.

Conceptually, a consistent standards approach involves fixing one element in a choice that involves both multiple objectives and multiple constraints. It prohibits trade-offs between other objectives and the objective of providing the designated standard of protection. Equally, it overrides those other constraints with the exception of its international obligations.

4.5 Equal vulnerability

Vulnerability has been defined in a number of different ways but it is best understood in interactive terms since it always carries with it the implicit associations of ‘to’ and ‘because’. It is then widely argued that individuals or households differ in their vulnerability to floods and a given individual’s or household’s vulnerability will differ between floods. Therefore, one possible decision criterion is to seek to achieve equal vulnerability between individuals or households between different flood contexts. Thus, to increase interventions in those floods that pose particularly demanding challenges or in those populations that are particularly unable to cope with the challenge posed by a particular form of flooding.

Unfortunately, it has not yet proved possible to differentiate rigorously between the possible combinations of floods and populations to identify all of the factors and the interactions that influence vulnerability. So, for example, in the recent study of the health impacts of flooding, neither the socio-demographic characteristics of the affected population nor the characteristics of the flood which they experienced nor the interaction between those characteristics proved particularly good predictors of the health damage suffered as a consequence of the flood. Two possibilities are that personality factors or recent life experiences are important determinants of the vulnerability of an individual or household in relation to a particular flood. If this proves to be the case, then it will be difficult to provide a useful measure of vulnerability. But in the meantime, it is not presently possible to provide a sufficiently robust and reliable measure of vulnerability for use as a decision criterion.

4.6 An equal reduction in flood losses

A narrow criterion would be to seek to achieve a consistent reduction in the expected value of the loss between households. The major disadvantage of this approach is:

- It would be biased against those who are most at risk of flooding since a reduction of, say, £20,000 in the capitalised value of expected future flood losses would only be sufficient to reduce the risk of those at high risk of flooding by a small amount. Conversely, achieving the same reduction for those already at a comparatively small risk of flooding would require a very large reduction in the future risk of flooding.

This seems a sufficiently significant disadvantage not to consider this option any further.

4.7 Equality of residual flood loss

A related approach would seek to reduce the residual expected flood losses of a household to below some threshold value. For example, the criterion might be that no household should be exposed to a capitalised expected value of future flood losses of £15,000. The threshold value might be set such that it would be economically viable for the household then to either undertake flood proofing for the residual risk or to undertake works that would reduce the loss in future flooding. The disadvantages of this possible criterion are:

- The criterion value would need to be weighted by the income level of the household otherwise it would be biased in favour of high income households;
- We do not wish households to install flood proofing if the depth of flooding is likely to exceed about 1 metre or the velocity of flow is significant in order to avoid partial or complete structural failure of the dwelling.

Again, this does not look to be a very promising criterion.

4.8 An equal depth of flooding

An alternative is to set the criterion as the maximum depth of flooding that shall be experienced in any property in some extreme flood. This depth could be defined as that which will not result in partial or complete structural failure of the dwelling if the dwelling is flood proofed. The disadvantages of this approach are that:

- It is still necessary to define the probability of the event in which this depth of flooding will occur;
- It directs attention towards specific flood risk management options which may be desirable, but those options will not always be practical. In particular, it is difficult to see how this criterion could be applied to flood embankments or flood walls since the criterion would apply for events more extreme than the notional design standard of protection of those embankments or walls.

Therefore, it is not thought that this is a practical option.

4.9 Payment equality

The principle of this option is that everyone gets the service that they are willing to pay for. This approach can however only apply where flood defence and other works are funded locally, or flood defence is included in an overall budget that covers a range of services allowing communities to make choices. In this case, people would have to choose between flood defence and other services, and many people may not be defended (unless they have been flooded recently).

This option would not be practical within the funding arrangements for flood defence in England and Wales, and is not considered further.

4.10 Summary

The nine criteria discussed above are summarised in Appendix 1, including comment on the main advantages and disadvantages. Summary comments on the nine criteria are given in Table 4.2 below.

Table 4.2 Potential criteria: summary

Criterion	Comment
4.1 Economic efficiency	Current approach
4.2 Population efficiency	
4.3 Equal cost per property	
4.4 Equality of threshold risk	
4.5 Equal vulnerability	
4.6 Equal reduction in flood losses	Not an acceptable option
4.7 Equality of residual flood loss	Not an acceptable option
4.8 Equal depth of flooding	Not a practical option
4.9 Payment equality	Not a practical option

Whilst the choice of which options to pursue is a matter for the stakeholders, in the first instance Defra and the Environment Agency, the above discussion and summary indicates that five of the potential criteria are worth considering further. This includes economic efficiency, the current approach.

4.11 Factors for stakeholders to consider

There is a wide range of possible options and this report can only define the issues and make suggestions; it is up to the stakeholders to decide which decision criterion to adopt. There is no self-evident best option and the issue is the almost circular one of deciding a basis by which to choose a criterion for making other choices. In making the choice as to a criterion, the particular points that recommended that the stakeholders bear in mind are:

- The first priority in flood risk management is managing those situations in which floods present a significant risk to life;
- This is a time of rapid change in the context of flood risk management and the criterion adopted needs to be forward adaptive to the future context rather than looking backward to the past or tied to a transitory present;
- That flood risk management must now be considered in the context of the Water Framework Directive introduces an integrated approach to catchment management not just between different water functions but also between land and water management;
- One consequence is that a marked difference in the criteria for making choices when dealing with flooding from rivers and from sewers would be likely to become increasingly problematic;
- The increasingly central role of regional assemblies in planning and possibly in other matters as well;
- A decision criterion can either follow from some more widely established policy of flood risk management or the effect of the decision criterion will determine what that policy will be;
- It is unclear and generally difficult to determine whether the risk of flooding to some particular area has increased as a result of changes in land use upstream in the catchment;
- The requirements of the government and its duties under the Aarhus convention for public involvement in environmental decision making and their right to environmental information. The form of these requirements has already been defined for local authorities. The Environment Agency is currently developing the requirements for their use;

- The different issues of the different stakeholders, notably those who are currently flooded, those who will bear the costs of any scheme, and those who will be otherwise positively or negatively affected by the consequences of the scheme. In turn, the criterion must fulfil two purposes: it must enable the choice of the appropriate option and it must ensure accountability by being transparent and rigorous;

- Any criterion has two purposes: to accept some options and to reject others. It is therefore important to consider in what conditions it is desirable or appropriate to reject a scheme or an option. The Habitats Directive requires that schemes or options be rejected in some circumstances, and schemes or options may be undesirable on environmental grounds in additional circumstances. Similarly, the Water Framework Directive implies that a scheme or an option should be rejected if it is inconsistent with the intention of achieving good ecological quality for a river. An option or scheme should be rejected if it simply has the effect of shifting the problem up - or downstream;

- In considering any criterion, the likelihoods of both type 1 and type 2 errors should be considered;

- It is increasingly recognised that we should seek to manage all floods and not just some, that we need to consider in advance both how we will cope with extreme events and what will be done if an element of a scheme fails on demand;

- Climate and other changes are increasing the risks of flooding and it may become necessary to retreat defences in order to provide additional flood storage;

- Local conditions, including the cross-sectional form of the river valley, have important implications for the options that can be adopted and the costs of those options;

- Neither the **economic efficiency** criterion nor the **consistent design standard** approach are consistent with the principle of managing all floods and not just some. Both are misleading in that they ignore the problems of responding when the scheme fails either in service or as the result of an extreme event.

5. Case studies

5.1 Introduction

The overall purpose of the project as stated in the CSG7 is:

“To examine the advantages and disadvantages of adoption of a policy of consistent standards of flood alleviation for communities, make recommendations for any changes in future appraisal guidance and identify any further research required to reduce areas of uncertainty.”

It is intended that the case studies are used to assess the impacts of a policy of consistent standards in order to understand the advantages and disadvantages, and develop recommendations.

Seven case studies have been selected. Whilst they are based on actual cases, they are numbered A to G. Actual data has been used in the analysis of case studies where it is available, but where data are missing or not available, estimates have been made.

The following criteria for Consistent Standards have been applied to the case studies:

- Economic efficiency
- Population efficiency
- Equal cost per property
- Equality of threshold risk
- Equal vulnerability

These criteria are discussed in Appendix 1 including the possible implications for flood defence and an initial assessment of the advantages and disadvantages.

This section sets out the approach used to apply these criteria to the case studies, and the results. The case study analyses are contained in Appendix 2. It should be noted when comparing results that different standards will provide defence for a different number of properties. For example, a 10% annual probability of flooding standard will protect part of the floodplain to this standard whereas a 1% annual probability of flooding standard will protect a larger area of floodplain to a higher standard, and therefore more properties.

5.2 Indicators for comparison of case study results

The following indicators have been used, and are based on Government sustainability objectives:

Objective: PUT PEOPLE AT THE CENTRE

Flooding disrupts homes and lives. Indicators for individual people are:

- Number of residential properties in community protected;
- Number of residential properties in community not protected;
- Percentage of residential properties in community not protected;
- Number of residential properties that suffer from increased flooding, and by how much;
- Vulnerable people: how many people who cannot easily evacuate themselves are protected/not protected.

Indicators for a community are:

- Number of non-residential properties in community protected;
- Number of non-residential properties in community not protected;
- Number of major infrastructure items protected (main roads, railways, etc.);
- Number of major infrastructure items not protected;
- Number of key community functions protected (hospitals, fire stations, etc);
- Number of key community functions not protected.

Objective: LONG TERM PERSPECTIVE

Flooding is likely to get worse. Flood protection has an impact on the long-term sustainability of a community. Indicators are:

- Impact of a larger than design event flood.

Objective: COST AND BENEFITS

Public funding is limited. Indicators are:

- Economic benefit (expressed in terms of benefit-cost ratio)
- Cost per residential property
- Cost per property (residential and non-residential).

Objective: POVERTY AND SOCIAL EXCLUSION

Flooding could create blight, particularly frequent flooding. It has been suggested (Flood Hazard Research Centre, verbal communication) that the only evidence of property blight as a result of flooding occurs at low return periods, perhaps the 20% annual probability of flooding standard. A 10% standard has been adopted here as data for this standard are readily available. The indicators are:

- Number of residential properties in community protected to 10% annual probability standard;

- Number of residential properties in community not protected to 10% annual probability standard;
- Percentage of residential properties in community not protected to 10% annual probability standard.

Objective: ENVIRONMENTAL LIMITS

Flooding should not be increased. With regard to the developed environment, indicators are:

- Number of properties that suffer from increased flooding, and by how much (see putting people at the centre, above).

No consideration has been given in this analysis to standards for the natural and rural environment, including agriculture.

5.3 The case studies: base data

In order to undertake the analysis of case studies outlined in Section 5.4, certain base data are needed. These included:

- Map of the flood risk area showing the floodplains and flood cells, and particular layout characteristics (e.g. long narrow cells, depressions in the floodplain, etc);
- Number of residential and non-residential properties at risk for a range of flood frequencies;
- Population at risk for a range of flood frequencies, if available (in all case studies, two people per house were assumed);
- Threshold probability of flooding for different cells;
- The benefits and costs for each cell for all the return periods examined;
- The benefits and costs for the whole ‘community’ for all the return periods examined, although this could be determined from the individual cell data;
- Final scheme cost (where a scheme has been implemented);
- An estimate of social vulnerability in terms of concentrations of vulnerable people (i.e. those who cannot evacuate themselves, generally old people and the disabled);
- Key infrastructure and key community functions (for example, fire stations, hospitals, etc) in the flood risk areas.

Data were collected from Environment Agency project managers and, in some cases, local authority staff.

5.4 Methodology

Economic efficiency

The economic efficiency criterion is the current approach to project appraisal. It is normally applied to each flood cell (although it could be applied to the group of flood cells that covers a ‘community’). The analysis is generally applied to each cell in each community in order to achieve the most economically efficient solution.

Method of selection of schemes to be implemented
The method of selecting schemes for implementation using the economic efficiency criterion is:

Adequate benefit-cost ratio
Priority score (based on a national assessment of all schemes).

Population efficiency

This criterion is based on providing schemes to protect the greatest number of people. This criterion does not state what standard of protection would be applied. It is assumed that all properties in a community will be protected, although comment is made on locations where the marginal cost of including individual properties is high.

This criterion is most appropriate to national planning, where schemes would be prioritised according to the population at risk of flooding. In the case studies, this criterion has been applied by protecting the main areas of population to the 1% and 0.2% standards.

Method of selection of schemes to be implemented
The method of selecting schemes for implementation using the population criterion is to prioritise nationally according to magnitude of population protected.

Equal cost per property

An average cost per property is required. The Agency average is £7k per property. Values of £5k and £10k per residential property have been applied.

The process is:

- Calculate the available funding for flood defence for the community based on the cost per property;
- Compare this with the amount actually spent on the schemes;
- Consider flood defence option(s) that could be achieved for the available money.

There are a number of options with this approach:

- Try to achieve a consistent threshold standard for all properties using the available money;
- Invest an equal amount of money for each property. Groups of properties in a flood cell would have a flood defences whereas individual isolated properties could be provided with separate flood mitigation measures to the value of the available amount for each property.
- Alternatively, the cost could be a "community top up cost" if a contributions policy were adopted.

This criterion is generally applied by community in the case studies, but in some cases application to each cell was also investigated.

Equality of threshold risk

A range of threshold standards have been considered including a low standard (say 10% annual probability of flooding, equal to the standard for sewer flooding), a median standard (the 2% standard) and a high standard (1% or 0.5%). The exact standards used depended on the standards used in the appraisal of each case study. This approach could lead to the protection of individual properties where the marginal cost of protection is very high.

This criterion was applied by community as the public expectation will be that everyone is exposed to the same minimum risk.

Method of prioritisation
The selection of the best schemes for implementation could be by benefit cost analysis or by population protected.

Equal vulnerability

Vulnerability is defined as those who cannot evacuate themselves (generally old people and the disabled). It is assumed that children would be evacuated/looked after by their parents/guardians.

The following methods were considered for estimating the number of vulnerable people:

- The Social Flood Vulnerability Index in the MDSF (which gives a measure of vulnerability by enumeration district). This was however too crude to locate vulnerable groups;
- By asking project managers about the vulnerability of people in flood risk areas. This was adopted, although the awareness of project managers of social vulnerability issues was variable;
- Identifying the location of vulnerable people from maps (for example, nursing homes, etc). This provided some information but was not comprehensive;

- Using the EIA assessment. There was very little information in the EIA documents on social vulnerability.

This criterion was applied by flood cell so that the protection provided is directly related to the beneficiaries, although in the majority of cases no specific areas of vulnerable people were identified. If this criterion was developed further, local authorities and associated charity organisations should be involved in identifying the locations of vulnerable people.

Method of prioritisation of schemes
Schemes could be prioritised based on the social vulnerability calculated using factors for each category of vulnerability and the numbers of people in each category (for example, disabled, old, etc).

5.5 Review of case studies

When developing the criteria for consistent standards, the perceived key advantages and disadvantages were identified, as listed in Appendix 1. The advantages and disadvantages of the different criteria arising from the case studies are listed in the final tables of each case study. These are reproduced in Tables 5.1 to 5.5 below, for each of the five criteria examined in the case studies, together with some conclusions on advantages and disadvantages of each criterion.

The following notes apply to Tables 5.1 to 5.5:

- The advantages and disadvantages in the 'case study' section apply to specific case studies;
- The numbers in brackets refer to the number of times the specific advantage/disadvantage occurred in the seven case studies; and
- For reasons of clarity, the tables only include the most important advantages and disadvantages.

Table 5.1 Economic efficiency

Source	Advantages	Disadvantages
Initial assessment (see Appendix 1)	Economically efficient	Different minimum standards within and between communities
		Intangible losses neglected
Case studies	Best b/c ratio and cost/property	Not all areas protected (5)
		Some areas not protected in 10% flood (and possible at risk of blight)
	Best cells have best b/c ratio and low cost/property	Unprotected areas subject to increase in risk (2)
	Best b/c ratio (4)	Different standards between cells
Conclusions	Provides best b/c ratio except where, in some cases but not others, other criteria lead to a low defence standard (see Case Studies B and E).	Not all areas protected; There can be an increase in risk in unprotected areas (particularly where one river bank is protected and the other not); Different standards occur between different cells within a community.

Table 5.2 Population efficiency

Source	Advantages	Disadvantages
Initial assessment (see Appendix 1)	Areas with high population at risk are defended	Commercial / industrial areas excluded
Case studies	All population protected to specified standard	Very expensive, b/c ratio <1 No protection if not enough funds
	Most or all population protected to specified standard (2)	Not all areas protected (particularly commercial)
	Good b/c ratio Reasonable cost/property	
		More expensive than economic efficiency but more properties protected (and cost/property similar)
		Increase in flood risk elsewhere Not all community protected
Conclusions	Most of population protected;	Cells with mostly non-residential properties excluded
	Good b/c ratio and cost/property in some cases but not others.	Expensive in some cases (low b/c ratio, high cost/property)

Table 5.3 Equal cost per residential property

Source	Advantages	Disadvantages
Initial assessment (see Appendix 1)	Everyone at risk receives same budget	Money spread too thinly: Inappropriate / ineffective solutions
Case studies	Low cost (5)	Minimal protection (floodproofing only) (3)
	Highest b/c ratio but low defence standard (2)	Low standard (2) Floodproofing for most cells if cell by cell approach adopted
		Very low b/c ratio Variable protection standard by cell Very low standard by community
	Viable scheme at equitable cost High protection standard	Use of resources not optimised
Conclusions	Low cost compared to actual schemes except Case Study G, where a large number of properties are protected.	Generally either very low defence standard or no defences possible (and floodproofing is the only structural option).
	High b/c ratio but low standard in some cases (Case Studies B and E). This depends on threshold standards in each cell.	Low b/c ratio in some cases (for example, Case Study D).
	Good scheme in one case (Case Study G, where there are a large number of properties).	Fixed amount per property leads to sub-optimal expenditure. In some cases money may be spread too thinly to provide effective solutions.

Table 5.4 Equal threshold risk

Source	Advantages	Disadvantages
Initial assessment (see Appendix 1)	Everyone gets a consistent minimum standard of defence	No flexibility to provide higher standards for strategic assets.
		Large communities (eg cities) have low standard of protection: catastrophes more likely.
Case studies	Everyone has same minimum standard (7)	Inefficient use of money if every property protected.
	Standard can be similar to urban drainage	Flooding will be relatively frequent for low standard
	High standard of protection for whole community	Expensive. All properties protected and cost/property high
		More expensive than economic efficiency but more properties protected and cost/property similar (3)
		More expensive than economic efficiency and cost/property higher
	Options are economically efficient (flood storage and channel improvement)	

Table 5.4 Equal threshold risk (continued)

Source	Advantages	Disadvantages
Conclusions	Same minimum standard for all.	Requires flexible approach to take account of strategic assets. For example, London has a consistent minimum threshold standard of 0.1%.
	Standard can be low or high. Low standards are consistent with urban drainage, but not suitable for large floods where a 'catastrophe' scenario could occur. High standards have high cost.	
	Can be economically efficient, for example: Case study G, involving flood storage and channel improvement; Case Studies C and F, where savings have been made by implementing all cells in one scheme	Generally more expensive than the economic efficiency criteria, as follows: More properties protected but cost/property similar (Case Studies C, E, F); More properties protected but cost/property higher (Case Studies A,B,D).

Table 5.5 Equal vulnerability

Source	Advantages	Disadvantages
Initial assessment (see Appendix 1)	Vulnerable people are protected	Difficult to 'ring fence' vulnerable groups
		Objective definition of 'vulnerable' currently not possible
Case studies	Community functions protected at least cost	Most of community not protected
		Low b/c ratio and high cost/property
Conclusions	Protects vulnerable people (or, if desired, key community functions).	Most of community may not be protected
		Unlikely to be economically efficient
		Difficult to define and identify vulnerable groups (although this could be done in liaison with Local Authorities and associated organisations)

In addition to the above advantages and disadvantages of the different criteria, the following general observations are made regarding the application of the criteria to the case studies:

- Several of the case study schemes appear vulnerable to future increases in flood risks and/or larger than design events, in particular:
  - Flood defences create a serious hazard if they are overtopped or breached. In some cases, flooding could occur very quickly, for example Case Study A where there is a narrow defended floodplain on a large river,
  - Flood storage schemes, where the downstream flow increases quickly when the capacity is exceeded,
  - Schemes where the river is throttled, for example at the bridge crossing sites in Case Studies B and D. In these cases it would be difficult and expensive to further improve the standard of protection;

- Where insufficient funds are available to implement a scheme under the equal cost/property criterion, floodproofing has been suggested. There are many doubts regarding this approach, as discussed in Section 3.7.3.

More work is needed to assess the practicality of this option, where it is suitable, and what the benefits are;

If some but not all of flood cells are defended, there is a risk of an increase in flood risk at the others; There is a high cost/property in some cases, as discussed further in Section 6

- It appears desirable to protect cells that cover the centre of towns on opposite sides of a river for the following reasons:
    - Economically efficient solution (Case Study E)
    - Community function (Case Study F), and/or
    - To avoid an increase in risk in part of the town centre (Case Study D);

- Small outlying cells have a marginal impact on the analysis (for example, Case Studies C and F).

6. Conclusions

The driver for this study was the possibility that changing the decision criterion would remove, or significantly, reduce the problems of making choices as to whether flood alleviation works should be provided and, if so, as to what standard of flood protection should be provided. The overall conclusion is that no such simple and painless solution exists to the problem. But in addition a number of lessons and conclusions have been drawn as to the policy issues involved in flood risk management and those lessons may turn out to yield a better way forward.

Choices are always difficult, precisely because adopting one option necessarily precludes simultaneously adopting an alternative course of action. Those choices also become particularly sharp when the choice involves individuals suffering and we know the suffering that flooding causes to those affected. In consequence, we may seek to gain a better understanding of what a choice involves, and we may hope to find a better option, but it is less likely that we will be able to make choices easier, solely by adopting a different decision criterion.

The problem of choosing a decision criterion is somewhat circular in that we need decision criteria by which to select the decision criterion. In discussing the basis for selecting a criterion, it was argued that a balance has to be struck between type 1 errors - not undertaking a scheme when one should have been undertaken - and type 2 errors - undertaking a scheme when one should have not been undertaken. There it was suggested that there might be four conditions which resulted in a type 1 error:

The flood risk has been increased by development higher up the catchment: no clear examples of this case were found but in several cases, the scheme undertaken will increase the risk to other properties. Here, it is not the criterion but the scheme, and more particularly the nature of the option adopted, that results in this error;

Non-economic efficiency criteria. No direct evidence of concerns as to socio-economic regeneration were evident in the case studies;

In one of the case studies, there is a clear social and economic connection between the different areas. The economic efficiency criterion fails to take account of that connection.

That a criterion may discriminate against the poor and in favour of the better off. That it is density of loss per unit length of defence that has a major influence on the economic viability of a scheme tends to argue against this claim. regions.

It was suggested that Type 2 errors occur when a scheme:

Worsens a flood problem up or downstream. A number of the proposed schemes would do so, although the impact is generally small. Only the economic efficiency criterion could directly take account of those impacts;

Has significant net negative environmental impacts. No reports of such effects were found. Only the economic efficiency criterion has the potential to take account of both negative and positive environmental impacts;

Will fail to deliver the anticipated flood alleviation benefits. Concerns were expressed about the reliability of one scheme which depends upon manually installed flood proofing measures. The incorporation of reliability engineering techniques into the analysis is most readily done when the economic efficiency criterion is applied;

Entails an excessive cost. Local data on property prices was not obtained but a cost per property in one instance of £200,000 is suggestive that this cost would exceed the value of the property protected. Criteria other than the economic efficiency criterion would require auxiliary rules to take account of excessive costs;

Negatively impacts upon the performance of the catchment as a whole. Not surprisingly, no scheme was in the form of a 1960s 'river improvement' which converted rivers into a culverts. Conversely, none of the schemes can be claimed to have contributed directly towards the achievement of the objectives of the Water Framework Directive. A number of the schemes further fix existing throttle points in the system in place. None of the criteria directly take account of such concerns;

Is implemented because of political pressure. Severe flooding, particularly if it is unexpected, can produce a very powerful local reaction for the provision of flood alleviation works even though they may be difficult to justify compared with other flood risk areas. This is particularly a problem when a large event exceeds the capacity of existing flood defences.

It was argued earlier that the decision criterion must be capable of consistent application. The vulnerability criterion is weak in these terms because of the problems of defining exactly what is vulnerability. It is open to the argument that someone else is also vulnerable.

The general conclusions that can be drawn from the case studies are:

- There are a number of generic options for riparian flood defence (source control, storage, increasing conveyance of flood flows, separation between river and property);
- In each case study area, a range of such options were considered but for reasons of feasibility or cost, the option selected in the majority of cases was a flood wall or embankment;
- This non-random sample of schemes implies that dikes or flood walls will often be the best or only viable option.

It would helpful to determine whether the apparent preponderance of dikes/walls over other methods (i.e. source control, storage and improvements in conveyance) is a consequence of the comparative effectiveness of the different methods, their relative cost or financing issues, physical constraints, limitations within the framework of project appraisal, or result from treating a local problem rather than taking a catchment perspective.

Those other methods have advantages both in terms of managing all floods rather than just some and in providing a reduction of risk to most of those at risk of flooding. They would remove many of the problems of providing a consistent standard of flood defence within a community but the differences within a catchment and between catchments would probably remain. Some of the problems just listed can be fixed (e.g. with the framework of project appraisal, adopting a catchment approach rather than a local approach, in financing) relatively easily. But physical constraints and comparative effectiveness cannot;

The physical reality of different exposure to flooding in different parts of any catchment means that it is difficult to achieve equality of standard. There are uncertainties in hydrological design and water level prediction during different events as well as physical constraints and environmental and social factors;

The impact of 'larger than design' floods varied between the case studies. Narrow protected areas on large rivers would flood quickly and completely once the design standard was exceeded. Wide floodplains on smaller rivers would only partially flood, and there would be a high level of residual protection for many properties. The majority of the protected areas in the case studies were small compared with the size of the river;

In considering the flood plain, three distinct regions can be distinguished:

- Throttles: narrow points which limit the maximum flow and create backwater effects
- Other sections of the floodway
- Flood storage areas

A number of the flood problems in the case studies occur at a throttle point and there is consequently a danger of fixing the throttle point at a time when it might be argued that adapting to climate change will probably require widening throttle points. A major problem in adapting will be historic areas, including conservation areas, and particularly old bridges.

Culverts are a further type of throttle that are susceptible to higher flood risks in the future, particularly bearing in mind the risk of blockage.

Schemes studied which involved dikes or walls did have the effect of increasing the depth of flooding to be expected elsewhere on the catchment, generally by a quite small amount (i.e. 50 mm) but in one case by 300 mm. In this latter case, providing protection to one part of a community would increase the depth of flooding to the other part of the community which was to be left unprotected. What the implication in terms of changing the probability of flooding was not assessed. It is implicit in FCD PAG3 that such effects should be included as a cost in assessing the proposed flood alleviation scheme, but the wider issue of equity is obvious;

The potential increase in flood loss as a result of 50 mm increase in depth of flooding varies, for the average house, between £120 and £10,000 – the larger figures being for situations where the 50 mm increase will result in flooding now occurring just above floor level (Figure 6.1). This means that an increase in the number of properties that flood in a particular event has a much greater influence on event losses than an increase in depth of flooding to properties that already flood in more frequent events.

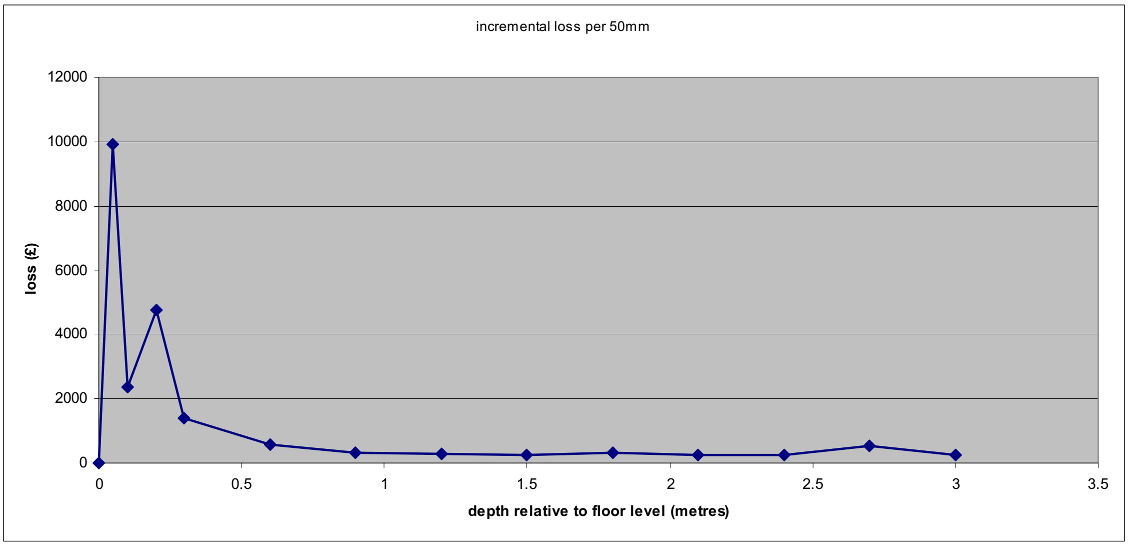


Figure 6.1 The incremental flood loss arising from an increase in the depth of flooding of 50mm

In a number of cases, development has occurred relatively recently and the granting of planning for that development must be questioned;

As a result of the high costs of protection observed in the first case studies undertaken, in the subsequent studies we used flood proofing as a fallback option, subject to the concerns that we discussed in Section 3.7.3. Whilst this appears to be a convenient option, particularly as it encourages ‘self-help’, there are many pitfalls;

When the cells that were not provided with protection are considered, the problem is not a lack of benefits but the extent of the costs of providing protection. In many cases, the costs of protection would be very high indeed (in excess of £70,000 per property). For comparison, the cost of a hip replacement averaged £3,755 in 1998/1999 (National Audit Office 2000). Allowing for inflation in health care costs, a rough figure of £4,000 per hip replacement is not an unreasonable. Hence, to justify some of the proposed projects, it has to be argued that reducing the flood risk to a property is 15-20 times more effective in reducing suffering than undertaking a hip replacement.

In some cases, it would almost certainly be cheaper to buy and demolish those properties rather than provide flood defence. These costs are high even in some cells where it was economically efficient to undertake works. Table 6.1 summarises the results and Table 4.1 gives the current market prices of dwellings in different regions. Table 6.2 provides an indication of the effectiveness of flood defences in the case studies.

Table 6.1 Cost per property by standard of protection that would be offered

Case study	Cost per property (£'000)		Standard of protection offered (%)	Region
	Residential	All		
A	80-115	60-90	1.0-2.0	West Midlands
B	16-23	13-17	0.5-1.0	South East
C	44	37	1.0	South East
D	16-17	14-15	0.5-2.0	Yorks and Humber
E	120	90	1.3	Yorks and Humber
F	230-250	60-70	0.5-1.0	Yorks and Humber
G	5.3	4.6-5.2	1.0-2.5	North West

Table 6.2 Costs and effectiveness of flood defences

Case study	Region	Length of e (km)	Cost per nit (£m / km)	Properties f defence
A	West Midlands	**0.6**	**17.3**	**287**
B	South East	**0.7-1.5**	**5.3 – 6.2**	**350 – 410**
C	South East	**2.7**	**1.9**	**52**
D	Yorks and Humber	**3.3**	**1.5**	**110**
E	Yorks and Humber	**1.0**	**4.9**	**53**
F	Yorks and Humber	**2.05**	**2.7**	**45**
G	North West	**N/A**	**-**	**-**

The next obvious question is: why are costs so high in these cases? Although statistical analysis of the full data set has not yet been completed, Figure 6.2 does show the importance of loss per unit length of a dike or wall in determining the cost per property. The cost of works varied over the range of about £1,000 to £7,000 per linear metre; in consequence, the density of properties per unit length has to be quite high if the cost per property is not to be very high;

The cost per property as the standard of protection was increased varied between the schemes; most commonly, there was a high fixed cost of installing any standard of protection, the incremental cost of adopting a higher standard then tending to fall. But, in a few cases, it was cheap to provide a low standard of defence but costs rose markedly if a higher standard defence was to be proposed;

Town centres were often covered by more than one cell in the case studies, usually because they were either side of a river crossing point. Consideration might be given to protecting cells that cover the centre of towns on opposite sides of a river for a variety of reasons including economic efficiency (Case Study E), community function (Case Study F), and avoiding an increase in risk in part of the town centre (Case Study D).

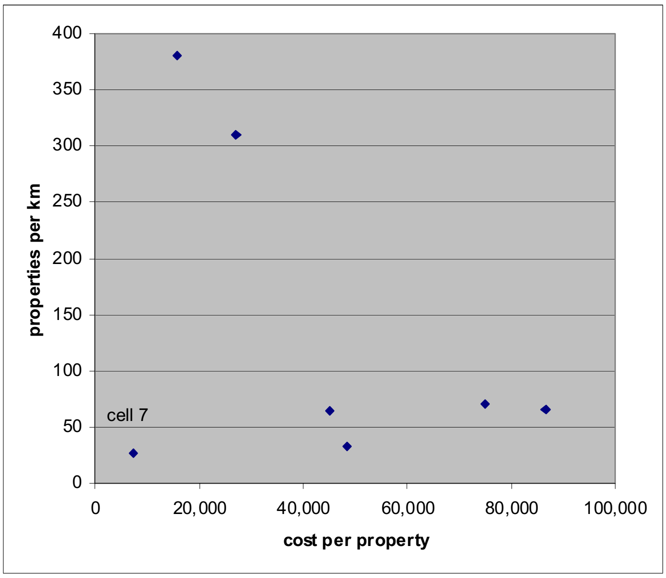


Figure 6.2 Case study B: costs per property by cell

Opportunities exist for local funding to support flood defence funding, particularly in Case Study G which has large areas for potential regeneration involving both the local authority and developers;

The case studies did not cover the issue of whether some properties would flood as a result of surcharges from sewers, or whether flooding as a result of local drainage problems would continue within areas protected from flooding from the river. Schemes were generally designed to avoid an increase in flooding from this source;

In none of the case studies was there clear evidence that land use changes elsewhere on the catchment had resulted in a marked increase in the risk of flooding. The important parameters here are the proportion of the catchment across which that change takes place and the location within the catchment of the land where the change occurs. Intuitively, therefore, such a change is most likely to be found in small catchments, particularly small urbanising catchments.

At this wider level, two policy concerns emerged:

- In some cases, particularly around throttle points, providing flood defence in the long run is likely to be unsustainable;
- The unit costs of providing conventional defences in some areas are very high and can exceed the market value of the property concerned.

Neither of these concerns is directly addressed by the choice of the decision criterion; both need addressing.

7. Suggestions

In this context, it is not appropriate to make recommendations to the stakeholders but it is appropriate to try to clarify what we consider to be the lessons learnt so far.

Defining a decision criterion to determine the design standard of protection to be provided in a particular area is a classic example of what Rittel and Webber (1973) described as a ‘wicked problem’. One aspect of a ‘wicked problem’ is that it can be defined in a number of quite different ways, “the information needed to understand the problem depending upon one’s idea for solving it”; another, that ‘solving’ one problem can simply result in another aspect coming to the fore. Hence, a useful strategy can be to seek to define the problem and hence the solution in a different way. Amongst such options are:

If communities could part fund flood alleviation through their own resources then the question of a consistent community standard would not arise. It arises precisely because any works are currently funded directly or indirectly through the general taxpayer. The problem would not change but the community itself would have to confront the problem of whether to provide different standards in different areas or increase the charges they imposed upon themselves. The current review of local government funding provides one route to establishing such a means of local financing;

A hypothecated charge for catchment management is an alternative model. In neither case would the charge be specifically for flood risk management; in the former case, it would be available for the local authority to spend as it saw fit and in the latter case, it could be spent upon any aspect of catchment management that would contribute towards the achievement of the objectives of the Water Framework Directive which does refer to flooding. The simultaneous advantage and disadvantage of this approach would be that it forces the difficult decision on to the community itself.

There is a danger of being trapped into a cycle of protecting what is there where undertaking that protection becomes increasingly more difficult and expensive as flood flows increase as a result of climate change. The implication is that we should decide now which parts of the flood plain will have to be evacuated in order, in particular, to ease throttle points. The difficulties relieving with throttle points is that in some cases, those throttle points occur at the historic points of settlement and, in others, the local community lacks land that can be developed outside the flood plain.

Achieving the good ecological quality objective of the Water Framework Directive depends not just upon water quality but also upon both the flow regime and the geomorphological form of the channel. Achieving a geomorphological form that will support a diverse ecosystem requires space; the sheet piled banks or concrete trapezoidal channels have been forced on flood defence engineers in part because constricted space in urban areas does not allow any other options. Therefore, it may become necessary to buy some buildings on the flood plain, demolish them, and convert that land to a use that allows the river to be managed more readily.

The problem is finding an acceptable mechanism to fund such works whilst simultaneously avoiding ‘planning blight’. In areas qualifying for structural funds, it may be possible to acquire land in this way as part of a strategy of regeneration. However, in some of the case study areas, there is a shortage of land that is not on a steep slope. As the size of commercial properties increases, the average size of a large warehouse now being 50,000 square metres, the pressure on flat land will increase so that communities which lack any useable flat land will decline. That flat land tends to be on flood plains. Hence, banning all development on flood plains and abandoning existing development may mean the decline of some established communities;

There is a move to encourage flood awareness and self help amongst the public in flood risk areas. One aspect of this initiative is the use of flood proofing for individual properties (or groups of properties, using ‘pallet barriers’). An approximate figure for the cost of flood proofing a domestic property is £2,000 per room. In some parts of the case study areas, flood proofing would almost certainly be a cheaper option that the options considered. In this approach, the general option would be to provide flood proofing with other options only be adopted if they provide better value for money. There are problems with flood proofing, notably that a difference in the water head of more than about a metre is sufficient to cause partial or complete structural failure of a masonry constructed building. Thus, potentially flood proofing may create a risk to life and in the USA, it is recommended that evacuation accompanies flood proofing. Flood shields and similar devices should therefore be labelled with a safety warning as to the dangers of seeking to modify them to provide protection against a greater depth of flooding.

Secondly, putting barriers across openings requires labour (and takes time so requiring a significant warning lead time) and around 15% of the population have mobility difficulties. In turn, the reliability of flood proofing may be quite low. Thirdly, if the duration of flooding or ground conditions are such that water starts to enter through the ground and up through the floor, then flood proofing will not provide complete protection. Fourthly, it provides a consistent standard of protection against the depth of flooding but it does not provide a consistent standard of protection in terms of the probability of flooding;

Alternatively, the ABI commissioned research from BRE on the additional costs that would result from repairing flooded dwellings in such a way as to reduce the susceptibility of those buildings to flood damage. Given the very high cost of some of the options considered in the case studies, such reconstruction may be a cheaper response;

The move to integrated catchment approaches and catchment flood management planning may lead to new approaches to flood defence and flood risk management. For example, the use of strategic flood storage and flood warning may be preferred to local solutions. This provides opportunities for greater consistency in flood defence standards although, for reasons given elsewhere in this report, consistent standards over a wide area are very difficult to achieve;

The prioritisation of funding between new schemes and existing defences will depend both on the needs associated with existing defences and policies for future flood management. As existing defences come to the end of their design lives, options exist to upgrade, downgrade or maintain the standard of defence. Such decisions will depend on the outcome of this and other studies into flood risk management. The criteria developed in this study would be equally applicable to such situations. The results of this study indicate that there will not be a single approach that achieves an optimal solution in every case.

When a choice between alternatives is easy, it is no longer a choice. Equally, because a choice involves sacrificing one thing for another, it is necessarily painful. We can decide what pain is worth bearing for what gain to whom but we cannot escape the pain which must be borne by someone. Consequently, there is no criterion which can be mechanically applied and which will result in universal happiness.

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Appendices

Appendix 1

Potential criteria for Consistent Standards (Sheet 1 of 4)

Principle: shorthand (numbers refer to criteria in Section 4)	**Principle: What is the "fundamental truth" and what it means to the customer**	**Application to flood defence**	**Implications for flood defence policy**	**Implications for consistency**	**Key Advantages**	**Key Disadvantages**
4.1 Economic efficiency	Equality of (economic) consideration: everyone gets the service that is economically efficient to deliver	The standard of defence is related to what benefits it delivers to you and your community	Different standards for different people and/or communities, based on benefit-cost results	The standard is consistent for all those who benefit equally	Economically efficient	Different minimum standards within and between communities Intangible losses neglected
4.2 Population efficiency	Equality of (population) consideration: Everyone gets the service that protects the most people	Whether or not communities are defended depends on the number of people protected	Communities with high populations at risk are defended. Others get no defence.	The standard is consistent for individual defended areas (but not necessarily between areas).	Areas with high population at risk are defended.	Commercial / industrial areas excluded
4.3 Equal cost per property	Equality of expenditure on all those at risk.	The flood defence budget is divided equally between all those at risk of flooding	Different standards for different people and/or communities depending on their location	The standard is consistent for all those who live in physically similar areas	Everyone at risk receives same budget	Money spread too thinly: Inappropriate / ineffective solutions.

Potential criteria for Consistent Standards (Sheet 2 of 4)

Principle: shorthand (numbers refer to criteria in Section 4)	Principle: What is the "fundamental truth" and what it means to the customer	Application to flood defence	Implications for flood defence policy	Implications for consistency	Advantages	Disadvantages
4.4 Equal threshold risk	Everyone gets the same service ranging from no protection to the highest that could be justified for a single property.	The standard of defence is the same for everyone. It is likely that the standard will be low if applied nationally.	Uniform standards; no benefit-cost analysis	The standard is consistent because the standard is the same for all.	Everyone gets a consistent minimum standard of defence	No flexibility to provide higher standards for strategic assets. Large communities (e.g. cities) have low standard of protection: catastrophes more likely.
4.5 Equal vulnerability	Equality of vulnerability: Everyone gets the service that they need.	The standard of defence is related to your need as gauged by your exposure and your vulnerability.	Different standards for different people and/or communities based on a needs assessment; probably no benefit-cost analysis.	The standard is consistent for all with similar needs	Vulnerable people are protected	Difficult to 'ring fence' vulnerable groups Objective definition of 'vulnerable' currently not possible.

Potential criteria for Consistent Standards (Sheet 3 of 4)

Principle: shorthand (numbers refer to criteria in Section 4)	Principle: What is the "fundamental truth" and what it means to the customer	Application to flood defence	Implications for flood defence policy	Implications for consistency	Advantages	Disadvantages
4.6 Equal reduction in flood losses	Limit on reduction in flood losses. Everyone will get the same reduction in losses.	The standard of defence is intended to provide an equal reduction in losses.	Defence standard will depend on AAD and the works needed to reduce it by a fixed amount.	The standard is consistent for similar properties in similar locations.	Everyone receives the same reduction in potential losses.	Biased against those at greatest risk of flooding, who will continue to be at high risk. Not considered to be an acceptable option.
4.7 Equality of residual flood loss	Limit on maximum AAD. Everyone will not suffer more damage than a specified amount.	The standard of defence is related to the potential damages of individual properties/communities	Different standards for properties with different potential damages. Need to assess AAD for all properties.	The standard is consistent for all those with similar property/contents values	Ceiling on maximum damages incurred	Biased against poorer households. Not considered to be an acceptable option.

Potential criteria for Consistent Standards (Sheet 4 of 4)

Principle: shorthand (numbers refer to criteria in Section 4)	Principle: What is the "fundamental truth" and what it means to the customer	Application to flood defence	Implications for flood defence policy	Implications for consistency	Advantages	Disadvantages
4.8 Equal depth of flooding	Limit on maximum depth of flooding at any property.	The standard of defence is linked to a maximum depth of flooding for any property for a specified event.	Defence standards will be linked to the maximum depth of flooding in a defended area.	The standard will be consistent for properties with similar threshold levels.	Ceiling on maximum flood depth.	Difficult to apply in practice as specified event will exceed defence standard. Not considered to be a practical option.
4.9 Payment equality	Everyone gets the service that they pay for.	The standard of defence is related to how much you and your community pays for it (whether the floodplain dwellers or the people in your 'revenue region')	Different standards for different people and/or communities, based on actual payments for that service.	The standard is consistent with the beneficiaries' willingness to pay for the service	People get what they pay for	Not appropriate where flood defence funding provided centrally. Not considered to be a practical option.

Notes:
No consideration is given to the provision of a 'consistent' flood warning/emergency planning/emergency response service
Floods from rivers and the sea are covered, but not urban drainage, groundwater, etc.

Appendix 2 Case studies

Case Study A

A.1 Background to the scheme

Case Study A is a town that is divided into two parts by a large river. There is a flood cell on each bank, connected by a road bridge. There are properties on both banks of the river. The town suffers a problem common to many riverside towns in that it has relatively narrow floodplains with long river frontages. As a result, the cost of providing flood defences is relatively high.

A wide range of options were considered for flood defence including:

- Creating upstream storage lakes;
- Dredging the river;
- Building a dam;
- Bypass channels or tunnels;
- Creating underground storage;
- Building flood defences in the town itself.

This case study is a small town on a very large river. Any changes to the river itself would have to be very significant and are therefore unlikely to be economic to implement. Such options might only be viable if they provided flood relief to other communities.

The options were appraised using standard FCDPAG3 appraisal techniques. The preferred option is flood defences in the town itself. The use of existing reservoirs was considered for flood storage, but these are too far from the site to be effective. The enhancement of an existing flood storage area upstream would not be economically viable and would have negative impacts on floodplain land use. Dredging the river would require major excavations in the river bed to be effective, and this would not be environmentally or economically acceptable. A dam was discounted because of the lack of suitable sites and the serious impacts that flood storage would have on the floodplains. There is no obvious route for a bypass channel without massive excavation, and a tunnel was discounted on cost grounds. Similarly underground storage would not be practicable because of the huge volume of storage required.

A.2 The proposed scheme

The final solution consists of the construction of flood defences in the town on one bank of the river only. Because of the historic nature and attractiveness of the town, demountable defences are to be used so that the walls are only erected during flood periods.

A viable scheme has been developed for the west bank where most of the properties at risk of flooding are located and there is a quay along the river which facilitates construction work. It was not possible to develop a viable scheme for the east bank because of the smaller number of properties at risk. In addition, the east bank does not have a quay wall and construction conditions would be more difficult. The scheme is summarised in Table A.1.

Table A.1 Proposed scheme

Scheme	Details of flood risk area				Defence standards (annual probability of flooding)		Scheme cost (£M)
	No residential properties	Area (ha)	Population (estimate)	Vulnerable people (based on % of population)	Pre-scheme	Proposed scheme	
Cell 1	130	4.5	260	Normal	50%	1%	10.4
Cell 2	28	2.4	60	Normal	50%	50%	-
All cells	158	6.9	320		50%		10.4

As only one bank of the river will be defended, there will be different standards of flood defence on each bank. The issue of inconsistent standards of defence was recognised during the appraisal process but there was very little scope for developing a scheme with the same defence standard on both sides of the river because of the low benefit-cost ratio for works on the east bank.

The scheme cost is £10.4 million. The cost is high because permanent walls are unacceptable and demountables have been selected. In addition, elaborate drainage works are needed to control local drainage during a river flood event. The length of defences is about 800m.

A.3 The flood problem

A.3.1 Properties at risk

Property flooding occurs on both banks of the river. Flooding is frequent, and the start of property flooding has a 50% annual probability of occurrence flooding. The number of properties affected by the flood with a 1% annual probability of occurrence are as follows:

West bank: 130 residential and 42 non-residential
East bank: 28 residential and 3 non-residential

Total properties at risk are given in Table A.2.

Table A.2 Properties at risk

Cell	Residential/ non-residential	Annual probability of flooding					
		10%	5%	2%	1%	0.5%	0.2%
1	Residential	109	126	128	130	130	135
	Non-residential	17	26	38	42	43	43
2	Residential	21	25	26	28	28	29
	Non-residential	2	2	2	3	3	3
Total	Residential	130	151	154	158	158	164
	Non-residential	19	28	40	45	46	46
	All	149	179	194	203	204	210

Major infrastructure affected by floods is as follows:

Cell 1 Main road that links cells 1 and 2
Cell 2 Main road that links cells 1 and 2

A.3.2 The physical environment

The floodplain is flat and relatively narrow. The dimensions of the floodplain within the affected community are as follows:

West bank: 500m long (parallel to the river) x 70-150m wide
East bank: 400m long (parallel to the river) x 50-70m wide

The land rises quite steeply from the edge of the floodplain. This case study is a typical example of a small town in a valley with a narrow developed floodplain parallel to the river.

The layout of the flood risk area is shown on Figure A.1.

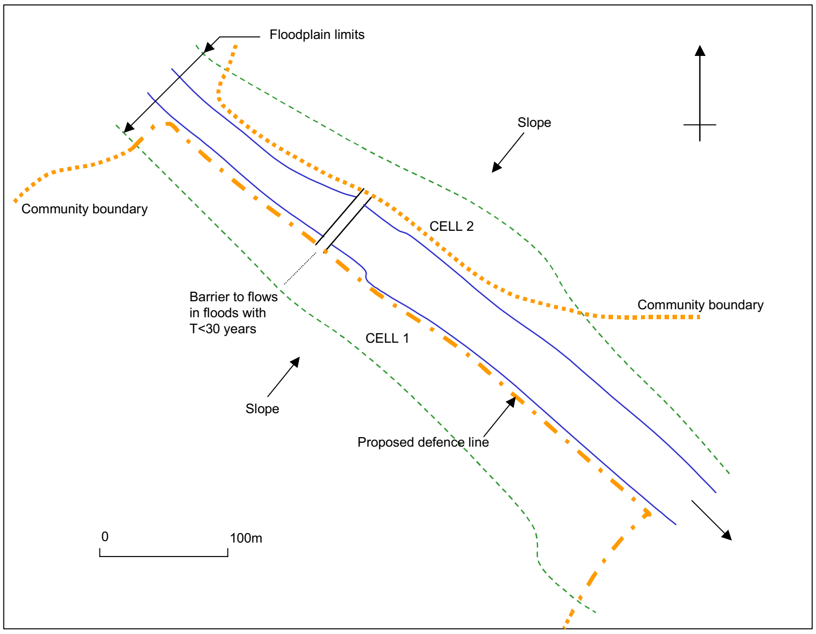


Figure A.1 Case Study A: Site layout

A.3.3 Appraisal results

Costs and benefits of options involving flood defences for both cells individually and combined are given in Table A.3. The costs adjusted to 2003 prices. All benefits are based on Multi-Coloured Manual (2003).

Table A.3 Appraisal results

a} Scheme costs

Annual probability of flooding (%)	Appraisal results - Scheme cost for cell (£ million):	
	1	2
10	6.4	5.8
5	8.1	7.3
2	9.3	8.4
1	10.4	9.4
0.5	11.5	10.4
0.2	13.0	11.7

b} Scheme benefits

Annual probability of flooding (%)	Appraisal results - Benefits for cell (£ million):	
	1	2
10	3.7	0.7
5	7.8	1.4
2	12.2	2.2
1	14.0	2.5
0.5	15.9	2.9
0.2	17.0	3.1

c} Benefit-cost ratios by cell

Annual probability of flooding (%)	Appraisal results - Benefit : cost ratio for cell:	
	1	2
10	0.58	0.12
5	0.96	0.19
2	1.31	0.26
1	1.35	0.27
0.5	1.38	0.28
0.2	1.31	0.26

d} Benefit-cost ratios by community

Annual probability of flooding (%)	Appraisal results – Benefit : cost ratio for the cluster of cells
10	0.36
5	0.60
2	0.81
1	0.83
0.5	0.86
0.2	0.81

A.3.4 Socio economic conditions

Many of the houses are small listed buildings. Repair costs are therefore high. The main economic functions of the town are tourism and the provision of accommodation for people working in nearby cities. The population in the flood-risk area is of mixed age group and is predominately middle-class. There are no particular social vulnerability issues.

In addition to property damage, floods last for several days and have the following impacts:

- Closure of local shops;
- Closure of the main road through the community. A significant diversion is needed to travel from one side of the community to the other;
- Closure of a local school because of access problems.

A.4 Application of Methods

A.4.1 Introduction

Application of the different criteria for Consistent Standards is described below in Sections A.4.2 to A.4.6. The results are summarised in Section A.5.

A.4.2 Economic efficiency

The current appraisal method was applied to each individual cell and the whole community. For each cell, the PAG3 rule will result in cell 1 being protected to the 1% annual probability of flooding standard. Works for cell 2 cannot be justified.

The whole community analysis (cells 1 and 2) produced a benefit-cost ratio of less than one, and works covering both cells cannot be justified.

Results are therefore only presented for cell 1. The implications are as follows:

- Cell 1 is protected to the 1% annual probability of flooding standard;
- Cost per residential property is about £80,000;
- Water levels in the river increase by about 30mm for the 1% flood because flow is constricted by the flood defence;
- The commencement of flooding in cell 2 will continue to have a 50% annual probability;
- Flood risk in cell 2 will increase slightly because of the increase in river levels;
- If a larger than 1% flood occurs, the new defences in cell 1 will overtop. Flooding will be rapid because the floodplain is narrow.

A.4.3 Population efficiency

The population efficiency criterion is intended to maximise the population protected from flooding. As there is a significant population on both banks of the river, the interpretation of this criterion is as follows:

- Protection provided for both cells;

- Defence standards of 1% and 0.2% annual probability applied.

The implications of this approach are as follows:

- Cost per residential property is about £120,000 for the 1% standard, which is much higher than the economic efficiency approach;
- Water levels in the river increase by about 50mm for the 1% flood because flow is constricted by the flood defences. This will not affect the defended areas but will increase flood risk for other properties in the vicinity;
- If a larger than 1% flood occurs, the new defences will overtop. Flooding will be rapid because the floodplain is narrow.

If the community has a high enough population to justify protection based on national prioritisation, the whole community would be protected to a selected standard. However the cost per member of population protected is high, about £60,000 based on two people per house.

A.4.4 Equal cost per property

The cost per residential property that would be needed to provide protection for the 1% annual probability flood is given in Table A.4. The equivalent figures of cost per property (residential and non-residential) are given in Table A.5. The figures are high and, as stated in Section A.4.2, works for cell 2 cannot be justified economically.

Table A.4 Cost per residential property for 1% standard defence

Cell	Cost per residential property (£)
1	80,000
2	330,000

Table A.5 Cost per property for 1% standard defence

Cell	Cost per property (£)
1	60,000
2	300,000

This criterion provides a fixed amount of funding of either £10,000 or £5,000 per residential property. Funding of £10,000 per residential property would provide funds of:

- £1.3 million (cell 1)
- £0.3 million (cell 2)
- £1.6 million (whole community)

These figures are far below the cost for even a 10% standard scheme (see Table A.3 (a)). This reflects the high initial costs needed for foundations and local drainage.

Options for measures using this budget may be as follows:

- Some dredging of the river. This would require ongoing maintenance and is not a sustainable or very effective option;
- Continue to maintain, including existing flood warning service. This would not relieve the flooding problem;
- Provide properties with floodproofing equipment and advice. If floodwater was excluded from individual properties there is a danger that buildings would collapse because of the high differential head on the walls. Some benefit could be achieved using panels on openings as this could reduce water levels in buildings and prevent silt entering buildings.

Small permanent walls along the river would not be affordable because of the need for a cut-off (to prevent seepage under the defences) and drainage works to prevent flooding from local drainage.

It appears therefore that some floodproofing of buildings is the only option possible with this level of funds. This will not prevent flooding but will reduce the consequences.

A.4.5 Equal design standards of protection

Equal design standards of protection of 10%, 5%, 2% and 0.5% are applied to both cells and the results are summarised in Table A.6.

Table A.6 Equal design standards: Results

Protection standard for all properties (annual probability of flooding, %)	B/C ratio	NPV (£ million)
10	0.37	-7.8
5	0.60	-6.2
2	0.81	-3.3
0.5	0.86	-3.1

In this case, the population efficiency criterion has the same effect (ie both cells are protected to the same standard). The implications of this approach are as follows:

- Cost per residential property varies from about £90,000 to £140,000;

- Water levels in the river increase because flow is constricted by the flood defences. This will not affect the defended areas but will increase flood risk for other properties in the vicinity;
- If a larger than design standard flood occurs, the new defences will overtop. Flooding will be rapid because the floodplain is narrow.

A.4.6 Equal vulnerability

In this case, there are no concentrations of vulnerable people and this option is not applicable.

A.5 Results

The results are summarised in Tables A.7 and A.8. The implications of the results are considered Table A.9.

Table A.7 Results summary

Criterion	Residential properties protected	People protected (2)	Standard	Vulnerable people protected	Standard (years)	Costs (£m)	B/C ratio
Economic efficiency by cell	130	260	1%	Normal proportion		10.4	1.3
Population efficiency Cells 1 and 2	158	320	1%	Normal proportion		19.8	0.85
	164	330	0.2%	Normal proportion		24.7	0.83
Equal cost per property (£10k)	0	0		None		1.8	(1)
Equal cost per property (£5k)	0	0		None		0.9	(1)
Equality of threshold risk Cells 1and 2	130 151 154 158	260 300 310 320	10 20 50 200	Normal proportion		12.2 15.4 17.7 21.9	0.37 0.61 0.87 0.89

Notes: 1. Floodproofing: Benefits not calculated
2. Based on two people per house

Table A.8 Indicators

Indicator	Criterion: Standard (% annual probability):	Economic Efficiency	Population efficiency		Equal Cost £10k	Equal Cost £5k	Equal threshold			
		1	1	0.2	50	50	10	5	2	0.5
PEOPLE										
Residential properties protected		130	158	164	0	0	130	151	154	158
Residential properties not protected		28	0	0	158	158	0	0	0	0
% residential properties not protected		18	0	0	100	100	0	0	0	0
Residential properties with increased risk		28 30mm	0	0	0	0	0	0	0	0
Vulnerable people protected (1)		6	7	8	0	0	6	7	7	7
Vulnerable people not protected (1)		1	0	0	0	0	0	0	0	0
COMMUNITY (note: no key community functions in flood risk area)										
Non-residential properties protected		42	45	46	0	0	19	28	40	46
Non-residential properties not protected		3	0	0	45	45	0	0	0	0
Infrastructure protected		0	1	1	0	0	1	1	1	1
Infrastructure not protected		1	0	0	1	1	0	0	0	0
LONG-TERM PERSPECTIVE										
Rate of flooding: larger flood		Rapid inundation	Rapid inundation		Slow inundation		Rapid inundation			
COSTS AND BENEFITS										
B/C ratio		1.3	0.83	0.81	N/A	N/A	0.37	0.60	0.81	0.86
Cost/residential property (£'000)		80	125	150	N/A	N/A	94	102	115	138
Cost/property (£'000)		60	98	118	N/A	N/A	82	86	91	107
POVERTY & SOCIAL EXCLUSION										
Residential properties protected (10% flood)		109	130	130	0	0	130	130	130	130
Residential properties not protected (10% flood)		21	0	0	130	130	0	0	0	0
% residential properties not protected (10% flood)		16	0	0	100	100	0	0	0	0

Notes: Based on one person per twenty houses. There are no specific concentrations of vulnerable people in this area.

Table A.9 Implications

Criterion	Implications
Economic efficiency by cell	<u>Hydraulic:</u> Increase in flood levels throughout the community at all return periods, affecting undefended areas *(n.b. increases typically small, say 0.03m)* Rapid inundation of cell 1 in floods > 100-year <u>Advantages:</u> Best benefit/cost ratio and cost/property <u>Disadvantages:</u> Not all areas protected (18% of properties unprotected) Some properties not protected during the 10% flood <u>Winners:</u> Cell 1 has improved protection <u>Losers:</u> Cell 2 has no protection and an increase in risk Undefended properties in vicinity of scheme have a small increase in risk
Population efficiency: all population affected	<u>Hydraulic:</u> Increase in water level upstream (backwater) and downstream. Rapid inundation of defended areas in extreme floods (greater than scheme standard) <u>Advantages:</u> All population protected to a specified standard <u>Disadvantages:</u> Very expensive. Benefit/cost ratio < 1. Danger that no protection provided if not enough funds. <u>Winners:</u> Whole community if the scheme can be afforded <u>Losers:</u> Whole community if scheme cannot be afforded Properties in vicinity that are undefended, as risk would slightly increase Communities elsewhere in the country with lower population at risk that would be defended under present system
Equal cost per property	Hydraulic: No impact. Advantages: Low cost

Criterion	Implications
	Disadvantages: Minimal protection (floodproofing only) Winners: Communities elsewhere in the country Losers: Everyone will flood relatively frequently Wider community will suffer relatively frequently due to disruption of town
Equality of threshold risk Low standard	Hydraulic: Slight increase in water level upstream (backwater) and downstream. Advantages: Everyone has same minimum standard Similar to standards provided by urban drainage Disadvantages: Inefficient use of money if every property in the community is protected Flooding will be relatively frequent and could occur rapidly when defences overtop Winners: Everyone gets something Losers: Everyone will still flood relatively frequently Wider community will suffer relatively frequently due to disruption of town
Equality of threshold risk High standard	Hydraulic: Increase in water level upstream (backwater) and downstream. Rapid inundation of defended areas in extreme floods Advantages: Everyone has same minimum standard High standard provided for whole community Disadvantages: Expensive. Inefficient use of money (particularly if every property in the community is protected). Winners: Everyone gets high standard of protection Losers: High investment will mean there is less money for communities elsewhere Properties in vicinity that are undefended, as risk would slightly increase.

A.6 Conclusions

- The economic efficiency approach only protects one of the two cells, and slightly increases flood risk in the other;
- Application of the population efficiency criterion is effectively the same as equal threshold of flooding because there is a significant population in each cell;
- The equal threshold criterion provides protection to all properties but the cost is high;
- If a larger than design standard flood occurred, the cells would flood quickly to river level because the floodplain is narrow;
- Equal cost per residential property of £10,000 and £5,000 would not provide enough money for flood defences, and flood proofing would be the only option. Complete prevention of water entering houses would not be affordable or desirable because flood depths exceed 1m.

Case Study B

B.1 Background

Case Study B is a medium sized town where development has taken place in the floodplain. Proposals for flood defence measures for the town have been developed following the serious flooding of October 2000. The flooding was caused by a fluvial event with an estimated return period well in excess of 100 years (annual probability of occurrence < 1%) and is probably of the order of 200-years (annual probability of occurrence 0.5%). The flood overwhelmed the existing defences, which have an approximate standard of 50 years (annual probability of occurrence 2%).

Flooding occurred in eight hydraulic cells. The cells are listed in Table B.1 below.

Table B.1 Flood cells

Cell number	Description	Comments
1	Commercial development (1950s to 1970s). Mainly factory units and warehouses. Housing round the edge. Flooding from river. Secondary flooding in NW corner from playing field. Saucer shaped area which floods quickly (max depth 3.6m).	Relatively short frontage and therefore low cost for high level of protection.
2	Historic core of the town. Commercial (north) and residential (south). Main shopping street. Many listed buildings.	Protection expensive because of historic buildings on river frontage and probable need to reconstruct some existing river walls.
3	Mostly commercial including main shops and law courts. Railway station flooded from the north of the town via a tunnel.	
4	Commercial, with factories and warehouses.	
5	Dense terraced housing.	Flood water crosses fields to the north.
6	1950s housing estate. About 45 houses flooded in 2000.	
7	Severe flooding of a small number of houses next to the river.	
8	Corner of a 1960s-70s estate, most of which is above flood level. About 12 houses flooded in 2000.	

A total of 13 options were considered for flood defence including:

- Wall raising;
- Wall raising plus upstream storage;
- Wall raising plus downstream storage;
- Wall raising plus upstream and downstream storage;
- River widening;
- River diversion in town;
- Bypass through adjacent chalk cliff;
- Longer bypass to the east of the town;
- Tidal barrier.

The options were appraised using standard FCDPAG3 appraisal techniques. The preferred scheme consisted of flood walls and embankments. River widening and a river diversion in the town were ruled out because of heritage and cost considerations. Other bypass options were ruled out on cost. Barrier options (including upstream storage) were also ruled out on cost grounds.

B.2 The proposed scheme

The recommended scheme consisted of flood walls and embankments, with the defence standards listed in Table B.2.

Table B.2 Recommended defence standards

Cell number	Defence standard (annual probability of flooding)	Comments
1	0.5% (Recommended scheme)	
2	1.0% (Recommended scheme)	1% standard under FCDPAG3. Possible future increase in standard if downstream storage implemented.
3	2.0% (Implement if funding available)	2% standard under FCDPAG3. Possible future increase in standard if downstream storage implemented.
4	0.5% (Implement if funding available)	2% standard under FCDPAG3. Combined with cell 5 to achieve higher standard
5	0.5% (Implement if funding available)	Combined with cell 4
6	About 2.0%	Present standard. Improvement

		not economic.
7	1.0% (Implement if funding available)	
8	0.5% (Implement if funding available)	

The scheme is summarised in Table B.3.

Table B.3 The proposed scheme

Scheme	Details of flood risk area				Defence standards (annual probability of flooding, %)		Scheme cost (£M)
	Non residential properties	Area (ha)	Population (estimate) (1)	Vulnerable people (based on % of population)	Pre-scheme	Proposed scheme	
Cell 1	237	25	480	Normal	2	0.5	3.7
Cell 2	166	11	330	proportion	2-5	1.0	5.6
Cell 3	2	6	4		2-5	2.0(2)	-
Cells	24	12	50		2-5	0.5(2)	-
4&5	18	2	36		2-5	2-5	-
Cell 6	4	1	10		2-5	1.0(2)	-
Cell 7	13	<1	26		2-5	0.5(2)	-
Cell 8							
	403	36	800		2-5	5-0.5	9.3
Cells							
1&2	464	58	940		2-5	5-0.5	21.1
All cells except 6							

(1) Based on two people per house
(2) If funding available

The defence standards vary because of the appraisal process, for the following specific reasons:

- The town is divided into hydraulically independent cells;
- The standard of protection has been determined independently for each cell using the FCDPAG3 decision process. Some cells were not economically viable and will not be protected.

Concerns regarding Consistent Standards were raised during the consultation process by the local District Council and County Council. Views expressed included the following:

- The town centre (cells 2 and 3) has a lower standard than areas largely occupied by factory units and warehouses (cells 1 and 4). This area has significant social, cultural and economic importance for both the town and the surrounding district;
- Some important residential areas (which are occupied continuously) have a lower standard than areas occupied by factory units and warehouses (which are mostly occupied only during working hours);

- The town centre (cells 2 and 3) would still flood in a repeat of the October 2000 flood event;
- Defence is not provided for some isolated areas (i.e. cell 6).

B.3 The flood problem

B.3.1 Properties at risk

Property flooding occurs on both banks of the river. Existing flood defences provide protection against floods with a 5% to 2% annual probability of occurrence. Whilst the majority of the defended area has a 2% standard, some work is needed to raise low spots and repair parts of the defences. The number of properties affected by the flood with a 1% annual probability of occurrence are as follows:

Residential: 425
Non-residential: 228
Total: 653

The distribution of properties at risk is given in Table B.4.

Table B.4 Properties at risk

Cell	Number of properties at risk for different annual probabilities of flooding Res: residential; Non-res: non-residential									
	10%	5%	2%		1%		0.5%		0.2%	
			Res	Non-res	Res	Non-res	Res	Non-res	Res	Non-res
1	0	0	142	46	218	46	237	50	250	55
2	0	0	149	52	166	83	230	93	250	100
3	0	0	2	23	2	37	137	42	150	50
4	0	0	0	50	0	59	0	59	0	59
5	0	0	0	0	6	1	24	1	30	1
6	0	0	1	1	18	2	40	3	50	5
7	0	0	3	0	4	0	4	0	4	0
8	0	0	5	0	11	0	13	0	15	0
Total	0	0	302	172	425	228	685	248	749	270

B.3.2 The physical environment

The floodplain upstream and downstream of the town is wide and flat, but the town is built at a point where the floodplain is narrow and has steep valley sides.

Cells 1 to 4 are in the main river valley where continuous development has taken place across the floodplain, and cells 5, 6 and 8 are on the periphery of the floodplain. The floodplain cells vary considerably in shape, and the ratio of properties protected per unit length of defence also varies, as shown in Table B.5.

Table B.5 Properties protected per unit length of defence

Cell	Properties protected (1% flood)	Defence length (m)	Properties per km defence
1	264	700	380
2	249	800	310
3	39	600	65
4/5	66	1000	66
6	20	600	33
7	4	150	27
8	11	150	70

The layout of the flood risk area is shown on Figure B.1.

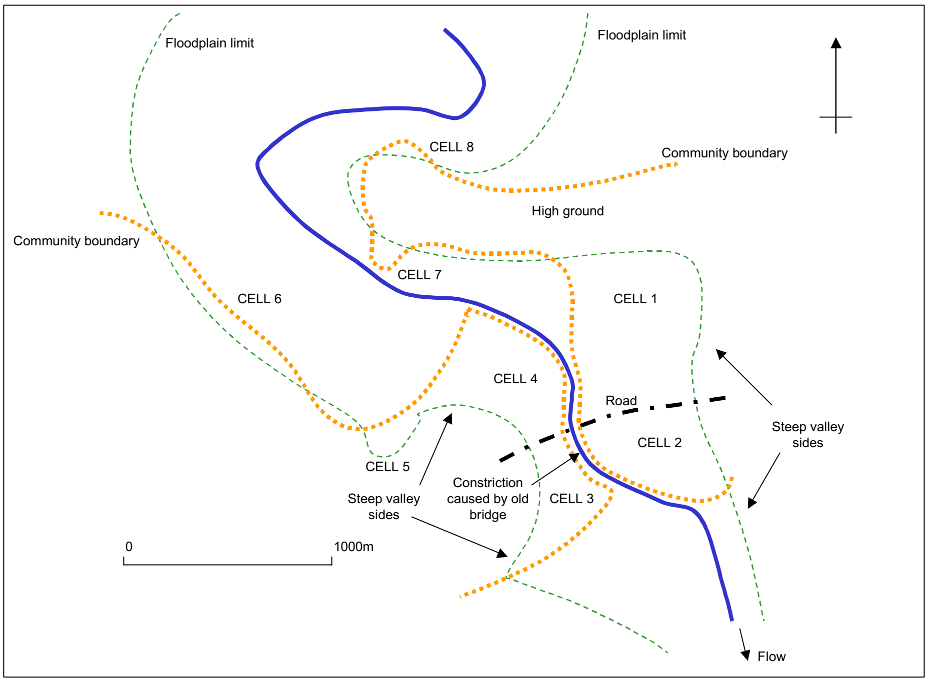


Figure B.1 Case Study B: Site layout

B.3.3 Appraisal results

Costs and benefits of options involving flood defences for individual cells are given in Table B.6. The costs adjusted to 2003 prices. All benefits based on Multi-Coloured Manual (2003).

Table B.6 Appraisal results

a} Scheme costs

Annual probability of flooding (%)	Appraisal results - Scheme cost for cell (£ million):								
	1	2	3	4	5	4&5	6	7	8
10									
5									
2	0.4	5.0	3.7	4.1	0.8	4.5	0.4	0.3	0.2
1	3.0	5.6	4.8	5.8	0.9	5.8	0.8	0.3	0.2
0.5	3.7	7.2	6.5	6.6	0.9	6.5	1.1	0.4	0.2
0.2	4.8	9.5	9.0	7.8	1.0	7.8	1.5	0.4	0.3

b} Scheme benefits

Annual probability of flooding (%)	Appraisal results - Benefits for cell (£ million):								
	1	2	3	4	5	4&5	6	7	8
10									
5									
2	31.7	12.7	9.7	20.8	0.1	20.8	-	0.4	0.2
1	40.1	15.4	11.6	25.9	0.2	25.9	0.1	0.5	0.3
0.5	45.1	17.5	13.3	29.3	0.2	29.4	0.3	0.5	0.3
0.2	49.0	19.5	15.0	33.0	0.3	33.0	0.5	0.6	0.4

c} Benefit-cost ratios by cell

Annual probability of flooding (%)	Appraisal results - Benefit : cost ratio for cell:								
	1	2	3	4	5	4&5	6	7	8
10									
5									
2	79.3	2.53	2.63	5.08	0.16	4.61	0	1.40	0.90
1	13.2	2.75	2.43	4.48	0.18	4.43	0.19	1.46	1.21
0.5	12.2	2.42	2.05	4.46	0.25	4.50	0.31	1.42	1.40
0.2	10.2	2.05	1.67	4.23	0.30	4.23	0.30	1.40	1.40

d} Benefit-cost ratios by community

Annual probability of flooding (%)	Appraisal results – Benefit : cost ratios for clusters of cells:		
	Cells 1 and 2	**All cells except 6**	**All cells**
10			
5			
2	8.2	5.4	5.2
1	6.5	4.8	4.6
0.5	5.7	4.3	4.2
0.2	4.8	3.7	3.5

B.3.4 Socio economic conditions

The flood risk areas contain extensive commercial and residential areas. The flood risk area includes part of the historic centre of the town and contains a large number of listed buildings. Property repair costs in these areas are therefore high.

There are no specific issues regarding the vulnerability of people to flooding. There are two old peoples' homes in the flood risk area, but these are multi-storey buildings. During the 2000 floods, residents were moved to upper floors and were not threatened by the flood.

Infrastructure and public services in the flood risk areas are as follows:

- Railway station (cell 3)
- Railway (cell 3), also flooded in undefended part of floodplain north of cell 6
- Main road connecting the east and west parts of the town (cells 1 and 4)
- Fire station (cell 3).

B.4 Application of Methods

B.4.1 Economic efficiency

The analysis is undertaken for each cell and for the whole community. For each cell, the PAG3 rule will result in:

- Cell 1 0.5% standard, b/c ratio of 12.2, very high priority score
- Cell 2 1.0% standard, b/c ratio of 2.75
- Cell 3 % standard, b/c ratio of 2.63
- Cells 4& 5 0.5% standard, b/c ratio of 4.50

- Cell 6 No works, b/c ratio < 1.0
- Cell 7 1.0% standard, b/c ratio of 1.46
- Cell 8 0.5% standard, b/c ratio of 1.40

The analysis is carried out for the following three cases:

- Cell 1
- Cells 1 and 2 with the above standards
- All cells except cell 6 with the above standards

The general impacts of these options are as follows:

- Increased protection of part of the floodplain will cause a small increase in flood levels and therefore flood risk elsewhere for large flood events;
- It is estimated that protection of cell 1 and cell 2 might increase levels by about 50mm during the 1% event. The frequency of occurrence of the present 1% flood level would be 1.1% (ie the flood level would occur more often as a result of defending part of the floodplain);
- The flood cells already have defences, and inundate rapidly when the defences are overtopped.

B.4.2 Population efficiency

If the community has a high enough population to justify protection based on national prioritisation, the whole community would be protected to a selected standard. Approximate values of cost per person protected are given in Table B.7.

Table B.7 Cost per person

Cells	Annual probability of flooding (%)	Cost per person (£'000)
1 and 2	1	11
	0.2	17
All except 4 (where there are no residential properties)	1	16
	0.2	18

This criterion is applied for the above four cases.

B.4.3 Equal cost per residential property

The cost per residential property for schemes that provide protection for the 1% annual probability flood is given in Table B.8. The equivalent figures of cost per property (residential and non-residential) are given in Table B.9.

Table B.8 Cost per residential property

Cell	Cost per residential property (£'000)
1	14
2	34
3	2400
4/5	960
6	80
7	55
8	20
All	48

Table B.9 Cost per property

Cell	Cost per property (£'000)
1	11
2	23
3	150
4/5	90
6	38
7	55
8	20
All	29

This criterion provides a fixed amount of funding of either £10,000 or £5,000 per residential property. Applying these values to individual cells would provide the flood mitigation measures outlined in Table B.10. The defence standards indicated in the table are approximate. For simplicity the funds have been calculated for the number of properties at risk in the 1% annual probability event.

Table B.10 Application of fixed funding per residential property

Cell	Available funds (£'000)		Flood mitigation measures	
	£10,000 /property	£5,000 /property	£10,000 /property	£5,000 /property
1	2180	1090	Defence: 1.2% standard	Defence: 1.4% standard
2	1660	830	Defence: 3% standard	Defence: 4% standard
3	20	10	Floodproofing	Floodproofing
4/5	60	30	Floodproofing	Floodproofing
6	180	90	Floodproofing	Floodproofing
7	40	20	Floodproofing (but deep water)	Floodproofing (but deep water)
8	110	55	Floodproofing	Floodproofing
All	4250	2125	Defence for whole community: 3% standard	Defence for whole community: 4% standard

The impacts of this approach are summarised below:

- The funding is insufficient to fund any of the works identified in the economic efficiency approach;
- Some cells could be defended to a relatively low standard. The existing defences for cells 1 and 2 require a limited amount of work to achieve a consistent standard of defence. The resulting benefit cost ratio is high but the standard is relatively low.
- If assessed individually, floodproofing is the only option for the remaining cells. Doors, windows and other openings should be blocked but water should still be allowed to enter properties through walls and floors to prevent excessive heads developing, causing structural damage;
- A low standard defence could be provided for the whole community by raising low spots in defences, repairing walls, etc.

B.4.4 Equal design standards of protection

Equal design standards of protection of 10%, 5%, 2%, 1% and 0.5% were applied to all cells and the results are summarised in Table B.11.

Table B.11 Results

Protection standard (annual probability of flooding, %)	B/C ratio	NPV (£ million)
10	Below existing standard	Below existing standard
5	Below existing standard	Below existing standard
2	5.2	61
1	4.6	73
0.5	4.2	81

It can be seen that an economically viable scheme can be achieved in all cases.

B.4.5 Equal vulnerability

In this case, there are no concentrations of vulnerable people and this option is not applicable.

B.5 Summary

The results are summarised in Tables B.12 and B.13. The implications of the results are considered in Table B.14.

Table B.12 Results summary

Criterion	Option	Residential properties protected	People protected	Standard (%)	Cost s (£m)	B/C ratio
Economic efficiency	Cell 1	237	480	0.5	3.7	12.2
	Cells 1 and 2	403	800	0.5/1.0	9.3	6.5
	All cells except 6	446	900	Variable	6.5	4.8
Population efficiency	Cells 1 and 2	384	770	1	8.6	6.5
		500	1000	0.2	14.3	4.8
	All cells except 4	425	850	1	15.6	4.4
		749	1500	0.2	26.5	3.2
Equal cost per property (£10k)	Cell by cell	290	580	3-1.2	4.25	?
	Whole community	300	600	3	4.25	>10
Equal cost per property (£5k)	Cell by cell	<290	<580	4-1.4	2.13	?
	Whole community	<300	<600	4	2.13	>15
Equality of threshold risk	Whole community	302	600	2	14.5	5.2
		425	850	1	20.5	4.6
		685	1400	0.5	25.6	4.2

Table B.13 Indicators

Indicator / Criterion:	Economic Efficiency			Population efficiency				Equal Cost £10k		Equal Cost £5k		Equal threshold		
Cells:	1	1,2	All - 6	1,2	1,2	All - 4	All - 4	By cell	All	By cell	All	All	All	All
Standard (%)	0.5	Var	Var	1	0.2	1	0.2	3 - 1.2	3	4 - 1.4	4	2	1	0.5
PEOPLE														
Residential properties protected	237	403	446	384	500	425	749	290	300	<290	<300	302	425	685
Residential properties not protected	207	41	18	41	249	0	0	10	0	<10	0	0	0	0
% residential properties not protected	47	9	4	10	33	0	0	3	0	3	0	0	0	0
Residential properties with increased risk	207	41	18	41	249	0	0	3	0	3	0	0	0	0
COMMUNITY														
Non-residential properties protected	50	133	230	129	155	169	211	120	98	<120	<98	172	228	248
Non-residential properties not protected	182	99	2	99	115	59	59	50	74	<50	<74	0	0	0
Infrastructure protected	0	0	2	0	0	1	1	0	2	0	2	2	2	2
Infrastructure not protected	2	2	0	2	2	1	1	2	0	2	0	0	0	0
LONG-TERM PERSPECTIVE														
Rate of flooding: larger flood	Cells will be inundated in turn according to defence standard			Defended cells will overtop at the same time and fill quickly				All cells will flood during relatively small events except cell 1.				Cells will overtop at the same time and fill quickly		
COSTS AND BENEFITS														
B/C ratio	12.2	6.5	4.8	6.5	4.8	4.4	3.2	>10	?	>15	?	5.2	4.6	4.2
Cost/residential property (£'000)	16	23	47	22	29	37	35	15	14	8	7	48	48	37
Cost/property (£'000)	13	17	31	17	22	26	28	11	10	6	5	31	31	27
POVERTY & SOCIAL EXCLUSION: results for 10% flood														
Residential properties protected	Not applicable: All cells have standard > 10%													
Residential properties not protected														
% residential properties not protected														

Table B.14 Implications

Criterion	Implications
Economic efficiency	Hydraulic: Increase in flood levels throughout the community at all annual flood frequencies <2%, affecting undefended areas. Increase typically 0.05m but depends on cells protected. Rapid inundation cells in floods greater than design standard Advantages: Best cells have best benefit/cost ratio and low cost/property Disadvantages: Not all areas protected. Unprotected areas subject to increase in risk Winners: Defended cells have improved protection Losers: Cells without improved defences have an increase in risk Undefended properties in vicinity of scheme have a small increase in risk
Population efficiency	Hydraulic: Increase in flood levels throughout the community at all annual flood frequencies <2%, affecting undefended areas. Rapid inundation of defended areas in extreme floods (greater than design standard) Advantages: Most or all population protected to a specified standard. Good benefit/cost ratio (best for 1% standard) Reasonable cost/property Disadvantages: Not all areas protected including cell 4, which is purely commercial. Winners: Whole community if the scheme can be afforded Losers: Whole community if scheme cannot be afforded Properties in vicinity that are undefended, as risk would slightly increase
Equal cost per property	Hydraulic: Little impact. Advantages: Highest benefit cost ratio because works can only be afforded that provide a consistent (but low) standard of defence

Criterion	Implications
	Disadvantages: Low standard: flooding will still occur every 25-30 years on average. Minimal protection (floodproofing only) for most cells if cell by cell approach adopted. Winners: Communities elsewhere in the country Losers: Everyone will flood relatively frequently Wider community will suffer relatively frequently due to disruption of town
Equality of threshold risk	Hydraulic: Slight increase in water level upstream (backwater) and downstream. Rapid inundation of defended areas in extreme floods Advantages: Everyone has same minimum standard. High standard provided for whole community Disadvantages: Expensive. All properties protected and cost per property relatively high. Winners: Everyone in community is protected Losers: High investment will mean there is less money for communities elsewhere Properties in the vicinity that are undefended, as risk would slightly increase.

B.6 Conclusions

Broad conclusions are as follows:

- Case study B already has protection to a standard of 5% to 2% annual probability of flooding;
- There is pressure to provide a high standard following the 2000 floods (estimated annual probability about 0.5 to 0.7%);
- A cost-effective scheme could be provided for all cells. Overall cost is high and cost/property is high for marginal cells;
- Schemes involving protection of cells 1 and 2 only are more cost effective than schemes covering a larger number of cells, but flood risk in other cells would be increased by a small amount;

- Cost effectiveness reduces with increasing flood magnitude. The most cost-effective schemes are those which provide a low but consistent standard of protection. A low standard may not be acceptable following the recent floods.

Case Study C

C.1 Background

Case Study C is a small town on the margins of a river valley at the confluence of two rivers. The community is divided into three main areas by the rivers, and these are connected by road bridges.

C.2 The proposed scheme

Case Study C is an example where Consistent Standards have been applied within the appraisal framework. It is a relatively small scheme which has four flood cells. The initial appraisal showed that two of the four cells were economically viable. However this analysis was based on individual schemes. As a result, set up and general costs were repeated. By combining the schemes, costs could be saved and the overall viability of the scheme improved.

It was therefore decided to base the analysis on the marginal increases in cost of including all four cells in one scheme. The results showed that a third cell was economically viable on this basis, and the Benefit Cost ratio of the fourth cell was 0.88. To make the fourth cell viable would require an increase in benefits of £150,000 or some £10,000 per annum. A summary of the scheme is given in Table C.1 and the benefit-cost ratios for the four cells are shown in Table C.2.

Table C.1 Proposed scheme

Scheme	Details of flood risk area				Defence standards (annual probability of flooding)		Scheme cost (£M)
	No residential properties	Area (ha)	Population (estimate)	Vulnerable people (based on % of population)	Pre-scheme	Proposed scheme	
Cell 1	25	1.8	50	Normal proportion	>20	1	1.14
Cell 2	32	2.0	64		>20	1	1.36
Cell 3	1	0.2	2		>20	1	0.27
Cell 4	16	1.6	32		>20	1	0.76
All cells	74	5.6	148		>20	1	3.18

Table C.2 Case Study 1: Benefit-cost ratios

Cell	Benefit-cost ratios	
	Initial analysis (4 separate schemes)	Revised analysis (one scheme)
1	2.3	2.34
2	1.5	1.68
3	0.9	1.68
4	0.6	0.88

In this marginal case the decision was taken to include all four cells in the scheme. This decision was justified on the grounds that intangibles are not taken into account in the analysis, and damage values would substantially increase when the FLAIR data is updated. Whilst it is a special case, it demonstrates the benefits (in terms of avoiding cost duplication) of including several cells in a single scheme and taking into account the marginal increase in cost of adding additional cells.

The Consistent Standard of protection is provided for all four cells in the scheme of 100-years (1%). Although a 200-year standard had a higher benefit-cost ratio, the argument for the 100-year standard is that the land is in Land Use Class B (indicative standard 25 to 100 years), which applies to "typically less intensive urban areas". In addition, the risk based approach in PPG25 indicates the 100-year standard as the area does not contain any essential infrastructure (hospitals, fire stations, etc), which would have justified a higher standard of protection.

If the appraisal process had been strictly followed, the scheme would have provided a 1% standard for two cells but no additional protection for the other two cells. These have a risk of flooding in the range of 5-years to 20-years, depending on the individual property. In this case inconsistent standards would have arisen for the following specific reasons:

- The town was divided into hydraulically independent cells;
- If each cell were appraised independently, some cells would be economically viable whereas the others would not.

In a small community, the provisions of different standards of flood defence could have a serious negative impact on those who are not protected. It was possible to achieve Consistent Standards primarily on economic grounds using the marginal cost argument outlined above. All four cells would be viable if appraised using the new Multi-Coloured Manual damage data.

The consequences of inconsistency would have been a large difference in defence standards in a small town. This would be difficult to accept socially and politically. It could have a divisive effect on the town in which the unprotected areas suffer relative blight compared with the protected areas.

In this case, the implications of applying Consistent Standards were to:

- Provide a more socially and politically acceptable solutions;
- Avoid the risk of causing economic divisions in the community. House prices in the unprotected areas may be affected and there may be increased difficulties obtaining insurance. Thus the unprotected areas may suffer from relative blight compared to the protected areas;
- The application of Consistent Standards could reduce the benefit-cost and priority scoring for the overall scheme based on the present appraisal system, thus reducing the chances that the scheme(s) will proceed. However as the differences are marginal, the scheme was considered to be satisfactory on both counts.

The final scheme will cost significantly more than the cost estimates because of problems that have arisen during construction. The viability of the scheme will be reduced because of this, although the use of Multi-Coloured manual data would lead to an increase in benefits.

C.3 The flood problem

C.3.1 Properties at risk

The distribution of properties at risk is given in Table C.3.

Table C.3 Properties at risk

Cell	**Number of properties at risk for different annual probabilities of flooding Res: residential; Non-res: non-residential**											
	20%		**4%**		**2%**		**1%**		**0.5%**		**0.2%**	
	Res	**Non -res**	**Res**	**Non -res**	**Res**	**Non -res**	**Res**	**Non -res**	**Res**	**Non -res**	**Res**	**Non -res**
1	12	3	23	4	23	5	25	5	25	5	25	6
2	24	1	30	3	31	5	32	5	35	6	40	7
3	1	0	1	1	1	1	1	1	1	1	1	1
4	7	0	13	0	15	2	16	4	25	5	30	7
All	44	4	67	8	70	13	74	15	86	17	96	21

Major infrastructure affected by floods is as follows:

Road between cells 1 and 2 (cell 1 and 2)
Road between cells 2 and 4 (cells 2 and 4)

C.3.2 The physical environment

Table C.4 Properties protected per unit length of defence

Cell	Properties protected (1% flood)	Defence length (km)	Properties per km defence
1	*30*	*0.55*	*55*
2	*37*	*0.40*	*90*
3	*2*	*0.17*	*12*
4	*20*	*0.58*	*35*

The layout of the flood risk area is shown on Figure C.1.

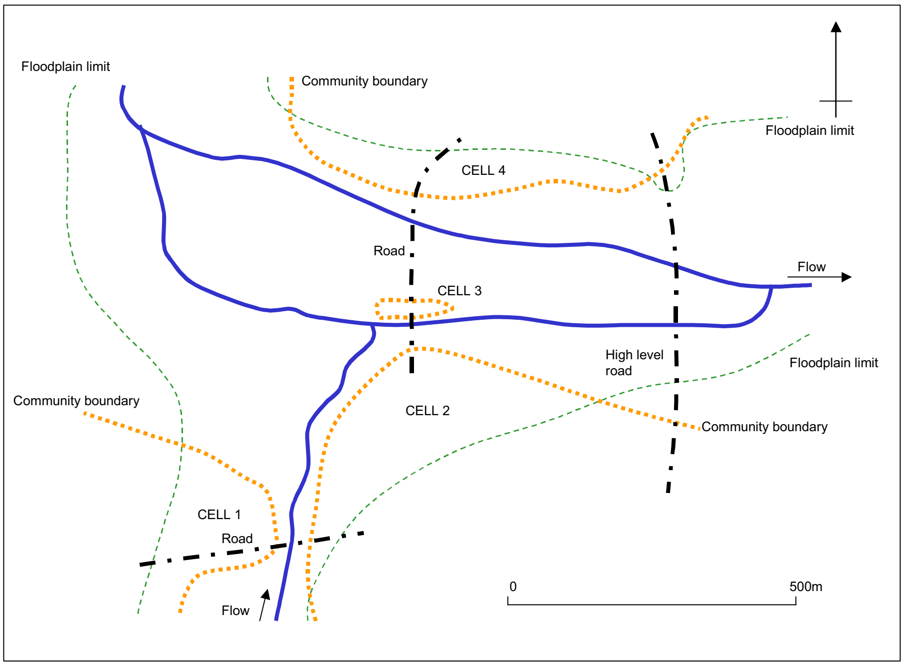


Figure C.1 Case Study 1: Site layout

C.3.3 Appraisal results

Costs and benefits of schemes for both cells individually and combined are given in Table C.5. Flood damages have been assessed using the FLAIR data. All damages and costs have been calculated for January 2002. The final costs exceeded these costs due to difficulties in construction.

Table C.5 Appraisal results

a} Scheme costs

Annual probability of flooding (%)	Appraisal results - Scheme cost for cell (£ million):				
	1	2	3	4	Community (all cells)
20	0.97	1.05	0.22	0.47	2.32
4	1.06	1.27	0.24	0.68	2.92
2	1.11	1.32	0.26	0.71	3.06
1	1.14	1.36	0.27	0.76	3.18
0.5	1.20	1.46	0.28	0.81	3.39
0.2	1.30	1.60	0.30	0.90	3.70

b} Scheme benefits

Annual probability of flooding (%)	Appraisal results - Benefits for cell (£ million):				
	1	2	3	4	Community (all cells)
20	1.05	1.10	0.01	0.18	2.39
4	2.25	1.80	0.16	0.37	4.64
2	2.51	1.96	0.21	0.43	5.17
1	2.62	2.02	0.23	0.46	5.39
0.5	2.88	2.17	0.29	0.57	5.96
0.2	3.20	2.40	0.35	0.70	6.70

c} Benefit-cost ratios

Annual probability of flooding (%)	Appraisal results - Benefit : cost ratio for cell:				
	1	2	3	4	Community (all cells)
20	1.09	1.04	0.06	0.39	1.03
4	2.12	1.42	0.70	0.55	1.59
2	2.27	1.49	0.83	0.60	1.69
1	2.30	1.49	0.88	0.61	1.69
0.5	2.40	1.49	1.02	0.70	1.76
0.2	2.46	1.50	1.15	0.80	1.80

The incremental cost savings from combining the cells produced a viable scheme covering all four cells.

C.3.4 Socio economic conditions

The area has a relatively high standard of living and there are not particular social vulnerability issues.

There are two locally important roads crossing the floodplain which connect the different parts of the community. It is not practicable to protect these roads where they cross the floodplain, and gates will be provided at both ends of each bridge. Thus these infrastructures will remain at risk whatever scheme is adopted.

C.4 Application of Methods

C.4.1 Economic efficiency

Using the PAG3 decision rule, protection of cells 1 and 2 to the 0.5% annual flood risk standard could be justified. However, because the area is not intensely urbanised the 1% standard was adopted. Thus the application of this is criterion involves protecting cells 1 and 2 to the 1% standard.

C.4.2 Population efficiency

This criterion involves protecting the main centres of residential population. Cells 1, 2 and 4 all have a significant population. This criterion was applied by providing cells 1, 2 and 4 with flood defence. Two standards have been used: the 1% and 0.2% annual probability of flooding. The approximate cost per person protected is about £20,000 for the 1% standard and £18,000 for the 0.02% standard, based on two people per house.

C.4.3 Equal cost per property

The cost per residential property for schemes that provide protection for the 1% annual probability flood is given in Table C.6. The equivalent figures of cost per property (residential and non-residential) are given in Table C.7.

Table C.6 Cost per residential property

Cell	Cost per residential property (£'000)
1	46
2	42
3	270
4	48
All	43

Table C.7 Cost per property

Cell	Cost per property (£'000)
1	38
2	37
3	135
4	38
All	36

This criterion provides a fixed amount of funding of either £10,000 or £5,000 per residential property. Applying these values to individual cells and the whole community would provide the funding shown in Table C.8. For simplicity, the calculation is done using properties at risk for the 1% annual probability event.

Table C.8 Equal cost per property: available funds

Funding per residential property	Available funds by cell number (£'000)				
	1	2	3	4	All
£10,000	250	320	10	160	740
£5,000	125	160	5	80	370

These figures are far below the estimated costs for even a 20% annual standard scheme (total cost £2,320,000 from Table C.5 (a). Thus the only option would be to provide properties with floodproofing equipment and advice.

Flood depths are generally less than one metre for the 1% annual probability flood event (maximum about 1.5m for four properties). Opportunities exist for complete exclusion of water from properties although the floodproofing measures would have to be investigated in detail. Generally £5,000 or even £10,000 per property may not be enough to provide a system that excludes floodwater.

C.4.4 Equal design standards of protection

The results of applying equal design standards to all cells are summarised in Table C.9.

Table C.9 Results

Protection standard (annual probability of flooding, %)	Residential properties	Costs (£ million)	Benefits (£ million)	B/C ratio	NPV (£ million)
20	44	2.32	2.39	1.03	0.07
4	67	2.92	4.64	1.59	1.72
2	70	3.06	5.17	1.69	2.11
1	74	3.18	5.39	1.69	2.21
0.5	76	3.39	5.96	1.76	2.57

It can be seen that a viable scheme could be developed for all standards of protection.

C.4.5 Equal vulnerability

In this case, there are no concentrations of vulnerable people and this option is not applicable.

C.5 Summary

The results are summarised in Tables C.10 and C.11. The implications of the results are considered Table C.12.

Table C.10 Results

Criterion	Option	Residential properties protected	People protected (1)	Standard (%)	Costs (£m)	B/C ratio
Economic efficiency	Cells 1 and 2	60	120	0.5	2.66	1.90
		57	114	1.0	2.50	1.86
Population efficiency	Cells 1, 2 and 4	73	146	1.0	3.26	1.56
		95	190	0.2	3.80	1.66
Equal cost per property (£10k)	Flood proofing	None	None	N/A	0.74	N/A
Equal cost per property (£5k)	Flood proofing	None	None	N/A	0.37	N/A
Equality of threshold risk	All cells	44	88	20.0	2.32	1.03
		67	134	4.0	2.92	1.59
		70	140	2.0	3.06	1.69
		74	148	1.0	3.18	1.69
		76	152	0.5	3.39	1.76

Notes 1. Based on two people per house.

Table C.11 Indicators

Indicator	Criterion:	Economic Efficiency		Population efficiency		Equal Cost (£10k and £5k)		Equal threshold				
	Cells:	1,2	1,2	1,2,4	1,2,4	All	All	All				
	Standard (%)	1.0	0.5	1	0.2	N/A	N/A	20.0	4.0	2.0	1.0	0.5
PEOPLE												
Residential properties protected		57	60	73	95	0	0	44	67	70	74	76
Residential properties not protected		17	26	1	1	All	All	0	0	0	0	0
% residential properties not protected		23	30	1	1	100	100	0	0	0	0	0
Residential properties with increased risk		17	26	1	1	0	0	0	0	0	0	0
COMMUNITY (note: no key community functions in flood risk area)												
Non-residential properties protected		10	11	14	16	0	0	4	8	13	15	17
Non-residential properties not protected		5	6	1	1	All	All	0	0	0	0	0
Infrastructure protected		0	0	0	0	0	0	0	0	0	0	0
Infrastructure not protected		2	2	2	2	2	2	2	2	2	2	2
LONG-TERM PERSPECTIVE												
Rate of flooding: larger flood		Rapid inundation of defended areas				Slow rise		Rapid inundation of defended areas				
COSTS AND BENEFITS												
B/C ratio		1.86	1.90	1.56	1.66	N/A	N/A	1.03	1.59	1.69	1.69	1.76
Cost/residential property (£'000)		44	44	45	40	10	5	53	44	44	43	45
Cost/property (£'000)		37	37	37	34	8	4	48	39	37	36	36
POVERTY & SOCIAL EXCLUSION: results for 20% flood												
Residential properties protected		36	36	43	43	0	0	44	44	44	44	44
Residential properties not protected		8	8	1	1	All	All	0	0	0	0	0
% residential properties not protected		18	18	2	2	100	100	0	0	0	0	0

Table C.12 Implications

Criterion	Implications
Economic efficiency	Hydraulic: There will be a minimal increase in flood levels throughout the community at all return periods, affecting undefended areas. *(nb increases typically small and not measurable).* Rapid inundation of cell 1 in floods > 1% annual probability Advantages: Best benefit/cost ratio Disadvantages: Not all areas protected (23% of properties unprotected for 1% flood) Winners: Cells 1 and 2 have improved protection Losers: Cells 3 and 4 have no protection (and a minimal increase in risk)
Population efficiency:	Hydraulic: There will be a minimal increase in flood levels water level upstream (backwater) and downstream. Rapid inundation of defended areas in extreme floods (greater than scheme standard) Advantages: Almost all population protected to a specified standard Disadvantages: More expensive than economic efficiency but more properties protected (and cost per property similar). Winners: Cells 1, 2 and 4 if the scheme can be afforded Losers: Cell 3, which has no protection. Whole community if scheme cannot be afforded
Equal cost per property	Hydraulic: No impact. Advantages: Low cost Disadvantages: Minimal protection (flood proofing only) Winners: Communities elsewhere in the country Losers: Everyone will flood relatively frequently
Equality of threshold risk	Hydraulic: There will be a minimal increase in flood levels water level upstream (backwater) and downstream. Rapid inundation of defended areas in

	extreme floods (greater than scheme standard). Advantages: Everyone has same minimum standard. Disadvantages: More expensive than economic efficiency but more properties protected (and cost per property similar). Winners: Everyone gets protection. Losers: Higher investment will mean there is less money for communities elsewhere.

C.5 Conclusions

Broad conclusions are as follows:

This flood risk area comprises two large cells that can be provided with viable flood protection, and two smaller cells that on their own are not viable based on economic efficiency.

Whilst the economic efficiency approach provides the best benefit/cost ratio, the differences with the equal threshold and population efficiency approaches are marginal. Costs per property protected are similar for all three approaches.

In this case, where differences in key indicators are marginal, a consistent standards approach was adopted. This has the advantage that all properties in the community will be protected;

The cost of protecting each residential property is about £44,000. Thus it is not possible to provide protection for sums of £10,000 or £5,000 per property.

Case Study D

D.1 Background

Case Study D consists of three urban areas that make up a single conurbation and community albeit with separate parishes. The highest known floods in the past 120 years were in 1947, 1999 and 2000 whilst significant events also occurred in 1892, 1931, 1960, 1963 and 1982. Flood events affect local through roads at the 10% annual probability flood and a main line railway at the 5% annual probability flood.

The threshold for the onset of property flooding is the 20% annual probability flood with more than 200 properties incurring flood damage at the 1% annual probability flood. These are divided up into three flood cells. Property numbers at risk in the 1% annual probability event are as follows:

54 properties in flood cell 1, on the right bank of the river
72 properties in flood cell 2, on the right bank of the river
239 properties in flood cell 3, on the left bank of the river

The land use banding is category A, with corresponding indicative standard in the range of the 50 to 200 year return period.

All three urban areas are heritage Conservation Areas and the river corridor is designated as an Area of Landscape Protection for the purpose of development control. The river is a candidate Special Area of Conservation under the Habitats Directive, a Site of Special Scientific Interest and a 700m length of the river between cells 2 and 3 is designated as a non statutory Site of Importance for Nature Conservation.

The economic benefit, from the prevention of damage from flooding, is calculated at £7 million. These are in addition to benefits that are not included in currently accepted economic assessment techniques, future business stability, and reduction of anxiety associated with flooding and improvements to habitat.

D.2 The proposed scheme

A scheme has been developed to protect all three areas. The scheme comprises flood protection embankments and walls on both banks of the river. The scheme includes pumps for two Ordinary Watercourses, to discharge local drainage behind the defences.

The benefit cost analysis of independent hydraulic flood cells has led to significantly different standards of protection being selected within the same community. The preferred option has a 0.5% annual probability of flooding standard of defence for cell 1 and a 2% standard of defence for cells 2 and 3. The benefit cost ratio for the preferred scheme is 1.55.

The reason for the inconsistencies is due to the geography of the river in relation to the communities. The high standard for cell 1 could be justified because the area only requires a relatively short simple defence and therefore the costs are relatively small. For cells 2 and 3 the economic analysis was marginal and a Listed Bridge caused a hydraulic restriction in the channel. To increase the standard above the 2% standard would require major expenditure on the bridge. This would further reduce the benefit-cost ratio and would have a very low incremental benefit-cost ratio. The benefit-cost ratios are given in Table D.1, which clearly shows the impacts of the Listed Bridge on the viability of defending cells 2 and 3.

Table D.1 Benefit-cost ratios

Cell	Benefit Cost ratios for different flood defence standards		
	2%	1%	0.5%
1	1.69	1.87	2.03
2	1.71	0.97	1.02
3	1.32	1.00	1.07

The 2000 flood had an annual probability of between 2% and 1%. It is estimated that this flood would be contained within the freeboard allowance for the schemes for cells 2 and 3.

Following detailed studies for the scheme, the overall benefit-cost ratio for the scheme reduced to 1.14. This is a consequence of fast-tracking the scheme because of intense political pressure following two recent and severe floods. As the benefit-cost ratio is still positive and intangibles (which will be large) are not included in the appraisal, the scheme is still considered to be justifiable.

The case study, which is for illustrative purposes, is based on the original benefit-cost ratios.

The urban areas form one contiguous area which relies on the same services and other amenities. It can therefore be considered as a single community. The proposed scheme provides different standards of defence. Cells 2 and 3 will flood during events with annual probabilities between 2% and 0.5% whereas cell 1 will be protected. For larger events, all three cells will flood.

The base data for the scheme is summarised in Table D.2.

Table D.2 Base data

Scheme	Details of flood risk area				Defence standards (annual probability of flooding, %)		Scheme cost (£M)
	No residential properties	Area (ha)	Population (1)	Vulnerable people (based on % of population)	Pre-scheme	Proposed scheme	
Cell 1	49	4	100	Normal	20	0.5	
Cell 2	50	5	100	Normal	20	2.0	
Cell 3	214	35	430		20	2.0	
All cells	313	44	630				

(1) Estimate, based on two people per house

D.3 The flood problem

D.3.1 Properties at risk

The distribution of properties at risk is given in Table D.3.

Table D.3 Properties at risk

Cell	Number of properties at risk for different annual probabilities of flooding Res: residential; Non-res: non-residential											
	10%		5%		2%		1%		0.5%		0.2%	
	Res	Non-res	Res	Non-res	Res	Non-res	Res	Non-res	Res	Non-res	Res	Non-res
1	8	1	18	2	40	3	49	5	55	6	60	8
2	25	2	35	15	45	20	50	22	52	28	55	30
3	80	10	150	15	195	20	214	25	232	28	250	30
All	113	13	203	32	280	43	313	52	339	62	365	68

D.3.2 The physical environment

The floodplain is typically 500m wide but it varies in width. The layout of the flood risk area is shown on Figure D.1. The three cells have very different layouts, as follows:

- Cell 1 consists of a narrow valley approximately at right angles to the river. During a flood, water rises up the main street, flooding properties on both sides;
- Cell 2 is parallel to the river and is generally not more than 100m wide;
- Cell 3, which is by far the largest cell, has a width of up to 400m and a gently sloping valley side.

Defending cells 1 will have a very small impact on flood levels in the river. Defending cell 2 will have a slightly greater impact, although still small. Defending cell 3 will have a larger impact because of a high proportion of the flow area will be cut off. It is estimated that the increase could be of the order of 0.3m, although the exact amount will depend on the extent to which floodplain flow is blocked by buildings and other obstructions.

The most upstream of the two bridges between cells 2 and 3 is a listed structure that causes significant blockage to the flow. This has a significant impact on the scheme design, as discussed in Section D.2.

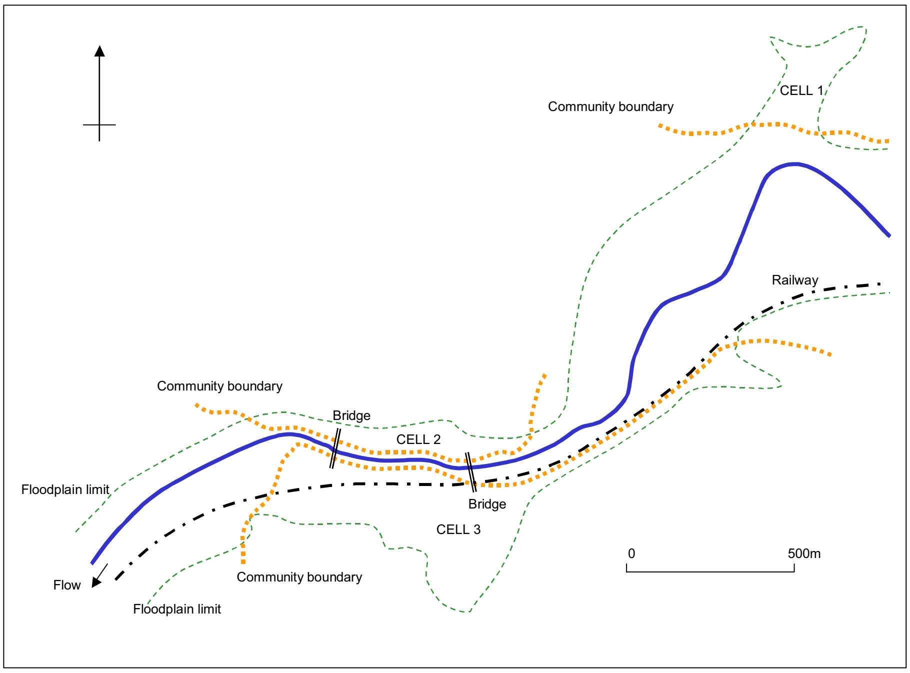
Properties protected per unit length of defence are given in Table D.4. The figure for cell 3 excludes a long length of defence that protects the railway. The figures clearly show the impact of floodplain shape on effectiveness of defence.

Table D.4 Properties protected per unit length of defence

Cell	Properties protected (1% flood)	Defence length (km)	Properties per km defence
1	54	0.30	180
2	72	1.10	65
3	239	1.90(1)	125

Excludes defences specifically for the railway

Figure D.1 Case Study 1: Site layout



D.3.3 Appraisal results

Costs and benefits of schemes for individual and combined cells are given in Table D.5. Flood damages have been assessed using the FLAIR data. All damages and costs have been calculated for 2000.

Table D.5 Appraisal results

a} Scheme costs

Design standard of protection (%)	Appraisal results - Scheme cost for cell (£ million):		
	Cell 1	Cell 2	Cell 3
10	0.10	1.09	2.52
5	0.13	1.17	2.87
2	0.15	1.33	3.32
1	0.17	2.86	5.04
0.5	0.19	2.90	5.30
0.2	0.23	3.00	5.60

b} Scheme benefits

Design standard of protection (%)	Appraisal results - Benefits for cell (£ million):		
	Cell 1	Cell 2	Cell 3
10	0.06	0.68	1.35
5	0.16	1.51	2.97
2	0.25	2.27	4.40
1	0.31	2.60	5.02
0.5	0.39	2.96	5.67
0.2	0.50	3.30	6.30

c} Benefit-cost ratios by cell

Design standard of protection (%)	Appraisal results - Benefit : cost ratio for cell:		
	Cell 1	Cell 2	Cell 3
10	0.57	0.62	0.54
5	1.20	1.29	1.03
2	1.69	1.71	1.32
1	1.87	0.91	1.00
0.5	2.03	1.02	1.07
0.2	2.17	1.10	1.12

d} Benefit-cost ratios by community

Design standard of protection (%)	Appraisal results – Benefit : cost ratio for the cluster of cells
10	0.56
5	1.11
2	1.44
1	0.98
0.5	1.08
0.2	1.14

D.3.4 Socio economic conditions

The flood risk area is mixed. It includes listed buildings in the town centre and a range of housing. The only particular social vulnerability issue is a nursing home in cell 3.

Major infrastructure affected by floods is as follows:

Road to railway station between cells 2 and 3 (cells 2 and 3)
Main road connecting cells 2 and 3 (cells 2 and 3)
Through road in cell 1 (cell 1)
Railway line (cell 3)

Community functions protected by floods include:

Fire station (cell 2)
Railway station (cell 3)
Nursing home (cell 3)

D.4 Application of Methods

D.4.1 Economic efficiency

Using the PAG3 decision rule, protection of cell 1 to the 0.5% annual flood risk standard and cells 2 and 3 to the 2.0% standard could be justified, and this is the scheme that was adopted. However the benefit-cost ratios for all three cells are generally less than 2 for all flood events.

D.4.2 Population efficiency

All three cells have significant population and therefore all should be protected using the population criterion. Options for protecting all three cells to the same standard are considered further in Section D.4.4. A variant would be to consider the protection of cell 3 only, as this contains about 70% of the population (and a nursing home, see Section D.4.5). Thus protection is provided for cell 3 only, to the 2% standard.

D.4.3 Equal cost per property

The cost per residential property for schemes that provide protection for the 2% annual probability flood is given in Table D.6. The equivalent figures of cost per property (residential and non-residential) are given in Table D.7.

Table D.6 Cost per residential property

Cell	Cost per residential property (£'000)
1	4
2	30
3	17
All	17

Table D.7 Cost per property

Cell	Cost per property (£'000)
1	3.5
2	20
3	15
All	15

This criterion provides a fixed amount of funding of either £10,000 or £5,000 per residential property. Applying these values to individual cells would provide the flood mitigation measures outlined in Table C.8. The defence standards indicated in the table are approximate. For simplicity the funds have been calculated for the number of properties at risk in the 1% annual probability event.

Table D.8 Application of fixed funding per residential property

Cell	Available funds (£'000)		Flood mitigation measures	
	£10,000 /property	£5,000 /property	£10,000 /property	£5,000 /property
1	490	245	<0.2% scheme	0.2% scheme
2	500	250	Floodproofing	Floodproofing
3	2140	1070	12% scheme	Floodproofing
All	3130	1565	12% scheme	Floodproofing

The equal cost per property criterion would therefore result in:

- A very high standard of defence for cell 1 if the criterion is applied by cell;
- A very low standard of defence for cell 3 if £10,000 per residential property is applied by cell, with flooding occurring more frequently than once in ten

years on average. A scheme would not be possible if £5,000 per property were available;

- A scheme would not be affordable for cell 2.

D.4.4 Equal design standards of protection

The results of applying equal design standards to all cells are summarised in Table D.9.

Table D.9 Results

Protection standard (annual probability of flooding, %)	Residential properties	Costs (£ million)	Benefits (£ million)	B/C ratio	NPV (£ million)
10	113	3.71	2.09	0.56	-1.62
5	203	4.17	4.64	1.11	0.47
2	280	4.80	6.92	1.44	2.12
1	313	8.07	7.93	0.98	-0.14
0.5	339	8.39	9.02	1.08	0.63
0.2	365	8.83	10.10	1.14	1.27

D.4.5 Equal vulnerability

An option involving the protection of cell 3, where there is a nursing home, is covered in Section D.4.2. In terms of protecting vulnerable people, it would be more effective to provide defences around the nursing home only, although this option has not been considered.

D.5 Summary

The results are summarised in Tables D.10 and D.11. The implications of the results are considered Table D.12.

Table D.10 Results

Criterion	Option	Residential properties protected	People protected (1)	Standard (%)	Costs (£m)	B/C ratio
Economic efficiency	Cells 1 to 0.5%, cells 2 and 3 to 2%	295	590	2.0 - 0.5	4.84	1.46
Population efficiency	Cell 3	195	390	2.0	3.32	1.33
Equal cost per property (£10k)	By cell: Cells 1 (0.2%) and 3 (12%) protected	160	320	12 - 0.2, Flood proofing	3.13	0.48(2)
Equal cost per property (£5k)	By cell: Cell 1 (0.2%) protected	60	120	0.2, Flood proofing	1.57	0.32(2)
Equal cost per property (£10k)	Whole community	100	200	12.0	3.13	0.48(2)
Equal cost per property (£5k)	Whole community	0	0	Flood Proofing only	1.57	0(2)
Equality of threshold risk	All cells	113	230	10	3.71	0.56
		203	410	5	4.17	1.11
		280	560	2	4.80	1.44
		313	630	1	8.07	0.98
		339	680	0.5	8.39	1.08
		365	730	0.2	8.83	1.14

Notes:

1 Based on two people per house
2 Floodproofing benefits not assessed

Table D.11 Indicators

Indicator	Criterion	Economic Efficiency	Population Efficiency	Equal Cost (£10k)		Equal Cost (£10k)		Equal threshold					
	Cells	All	3	1,3	All	1	Nil	All	All	All	All	All	All
	Standard (%)	2.0 - 0.5	2.0	0.2, 12	12	0.2	12	10	5	2	1	0.5	0.2
PEOPLE													
Residential properties protected		295	195	120	100	60	0	113	203	280	313	339	365
Residential properties not protected		0	850. 3m	20	0	60	100	0	0	0	0	0	0
% residential properties not protected		0	30	14	0	50	100	0	0	0	0	0	0
Residential properties with increased risk		0	40	20	0	0	0	0	0	0	0	0	0
COMMUNITY													
Non-residential properties protected		46	20	15	10	8	0	13	32	43	52	62	68
Non-residential properties not protected		0	23	2	0	9	10	0	0	0	0	0	0
Infrastructure protected		4	1	2	4	1	0	4	4	4	4	4	4
Infrastructure not protected		0	3	2	0	3	4	0	0	0	0	0	0
Community function protected		3	2	2	3	0	0	3	3	3	3	3	3
Community function not protected		0	1	1	0	3	3	0	0	0	0	0	0
LONG-TERM PERSPECTIVE													
Rate of flooding: larger flood		Generally, cells 1 and 2 will fill quickly to the river level if defences are overtopped. Cell 3 will fill more slowly and will provide residual protection to properties at the edge of the cell.											
COSTS AND BENEFITS													
B/C ratio		1.46	1.33	.48	.32	.48	0	.56	1.11	1.44	0.98	1.08	1.14
Cost/residential property (£'000)		16	17	26	31	26	N/A	33	21	17	26	25	24
Cost/property (£'000)		14	15	23	28	23	N/A	29	18	15	22	21	20
POVERTY & SOCIAL EXCLUSION: results for 10% flood													
Residential properties protected		113	80	8	0	8	0	113	113	113	113	113	113
Residential properties not protected		0	33	105	113	105	113	0	0	0	0	0	0
% residential properties not protected		0	41	93	100	93	100	0	0	0	0	0	0

Table D.12 Implications

Criterion	Implications
Economic efficiency	Hydraulic: There will be a large increase in flood levels in the reach between cells 2 and 3 (of the order of 0.3m for large floods). This will affect undefended areas, particularly upstream. Rapid inundation of cell 2 in floods > 2% annual probability. Cell 3 is larger and would fill more slowly. Advantages: Best benefit/cost ratio Disadvantages: Different standards between cells 1 and 2/3 Winners: All cells have improved protection but cell 1 has best protection. Losers: Areas within the backwater influence, where there is an increase in flood risk.
Population efficiency: Cell 3 protected	Hydraulic: If cell 3 is protected there will be a significant increase in flood risk for cells 1 and 2 (of the order of 0.3m increase in levels). There will also be an increase in flood levels water level upstream (backwater) and downstream. Advantages: No significant advantage compared with economic efficiency. Disadvantages: Increase in flood risk elsewhere Not all community protected Winners: Cell 3 Losers: Cells 1 and 2, where there is an increase in flood risk. Areas within the backwater influence, where there is an increase in flood risk.
Equal cost per property By cell	Hydraulic: Small impact on flood levels for low return period flood when cell 3 defended to 12% standard Advantages: Low cost Disadvantages: Benefit cost ratio <<1

Criterion	Implications
	Protection standard very variable (from 0.2% in cell 1 to floodproofing) Winners: Cell 1, very high standard Some improvement for cells 2 and 3 but very limited Communities elsewhere in the country as more funds available Losers: Cells 2 and 3 flood relatively frequently
Equal cost per property By community	Hydraulic: Small impact on flood levels when cells defended to 12% standard (£10,000 per property scenario) Advantages: Low cost Disadvantages: Benefit cost ratio <<1 Protection standard very low (12%) Winners: Minor improvement over existing condition Communities elsewhere in the country as more funds available Losers: Community has a much lower standard than with other approaches and floods relatively frequently
Equality of threshold risk	Hydraulic: There will be significant increases in flood levels upstream (backwater) and downstream. Rapid inundation of cells 1 and 2 in floods > threshold. Cell 3 is larger and would fill more slowly. Advantages: Everyone has same minimum standard Disadvantages: More expensive than economic efficiency and cost per property is higher. Note that a 2% standard gives very similar results to economic efficiency because cell 1 (which has a higher standard for economic efficiency criterion) is small. Winners: Everyone gets protection Losers: Areas within the backwater influence, where there is an increase in flood risk. Higher investment needed for 1% standard and above. There will be less money for communities elsewhere

D.6 Conclusions

Broad conclusions are as follows:

- 85% of properties are in cells 2 and 3. A different standard for cell 1 has a marginal impact on indicators;
- It is desirable to protect cells 2 and 3 to the same standard because:
  - Protection of cell 3 has a large impact on flood levels in the river. If cell 2 was not protected it would flood even more frequently than at present.
  - Cells 2 and 3 are both affected by the throttle at the bridge. Any works to the bridge would affect both cells equally;
- The £10,000 per residential property criterion would provide a very high standard for cell 1, a very low standard for cell 3, and floodproofing only for cell 2 if applied by cell;
- The £10,000 per residential property criterion would provide a very low standard if applied to the whole community (less than the 10% standard);
- The equal cost/property criterion provides a very low benefit cost ratio, although the benefits of floodproofing are not included;
- For the equal threshold criterion, cost per property is high at low standards of defence and for the 1% standard and above because of the throttle at the bridge. The optimum value occurs at the 2% standard.

Case Study E

E.1 Background

Case study E is a town on a small river that suffers from flooding at a number of locations. The town centre suffers flooding during events with an annual probability of 20 to 10%. The threshold of flooding for properties further downstream is the 4% annual probability event. The total number of properties at risk in the 1% annual probability event is 65 (52 residential).

E.2 The proposed scheme

A scheme was proposed that protects the town centre but not the properties further downstream. This was rejected by the community, who requested a consistent standard of defence throughout the community. An additional £1.1 million was needed to protect a further 12 houses. This was included in the final scheme to provide protection for the 'community'. The final scheme protects 52 residential and 13 non-residential properties to a 1.3% annual probability of flooding standard. Defra guidelines indicated that a 2% standard was appropriate but the higher standard was adopted for insurance reasons. Both options had the same benefit-cost ratio.

It was considered that the best approach to consistent standards would have been to provide a 4% standard, as no works would be needed for the downstream properties. This is a lower standard than the recent floods of 1999 and 2000, and was considered to be unacceptable by the community.

The final scheme was recently rejected by the Environment Agency as representing poor value for money. Details of the scheme are shown on Table E.1.

Table E.1 Proposed scheme

Scheme	Details of flood risk area				Defence standards (annual probability of flooding)		Scheme cost (£M)
	No residential properties	Area (ha)	Population (estimate)	Vulnerable people (based on % of population)	Pre-scheme	Proposed scheme	
Cell L1	30	1.8	60	Normal proportion	5 -10	1.3	4.3 (L1/R1)
Cell R1	11	3.0	22		10	1.3	
Cell R2	0	2.0	0		5 -10	1.3	0.6
Cell LG	0	0.4	0		1	1	0
Cells L2/R3	11	2.0	24		4	1.3	1.1
All cells	52	9.2	106			1.3	6.0

The benefit of adopting consistent standards was that the whole community would receive protection to the same standard. However the scheme would be considerably more expensive than a scheme to protect the town centre, which would have been advised using the PAGN decision rule. As noted above, the relatively poor value for money resulted in the scheme not going ahead in its present form.

E.3 The flood problem

E.3.1 Properties at risk

The distribution of properties at risk is given in Table E.2.

Table E.2 Properties at risk

Cell	Number of properties at risk for different annual probabilities of flooding Res: residential; Non-res: non-residential											
	10%		2.5%		2%		1.3%		1%		0.5%	
	Res	Non-res	Res	Non-res	Res	Non-res	Res	Non-res	Res	Non-res	Res	Non-res
L1	10	2	30	5	30	5	30	5	30	5	35	6
R1	4	2	11	2	11	2	11	2	11	2	12	4
R2	0	2	0	5	0	5	0	5	0	5	0	6
LG	0	0	0	0	0	0	0	0	0	0	0	1
L2/ R3	0	0	11	1	11	1	11	1	11	1	15	1
All	14	6	52	13	52	13	52	13	52	13	62	18

E.3.2 The physical environment

The floodplain is typically 100m wide and the flood risk areas consist of generally narrow strips of land on either side of the river. The layout of the flood risk area is shown on Figure E.1. Cells L1, R1 and R2 for a continuous flood risk area in the centre of the town. Cells L2 and R3 form a continuous flood risk area further downstream.

Defending cell L1 and R1 independently will cause a significant increase in water level in the river which increases flood risk in undefended cells. The same would apply to the independent defending of cells L2 and R3.

If cells L1/R1/R2 were protected but L2/R3 were not, there would be a tiny increase in flood water level at cells L2/R3 caused by the loss of floodplain storage. This would however only be millimetres, and would not be measurable. Water level increases would be much more severe upstream, caused by the backwater effect of blocking the floodplain.

Properties protected per unit length of defence are given in Table E.3.

Table E.3 Properties protected per unit length of defence

Cell	Properties protected	Defence length (km)	Properties per km defence
L1	34	0.3	110
R1	13	0.4	30
R2	5	0.3	15
LG	1	0.06	15
L2/R3	12	0.3	40

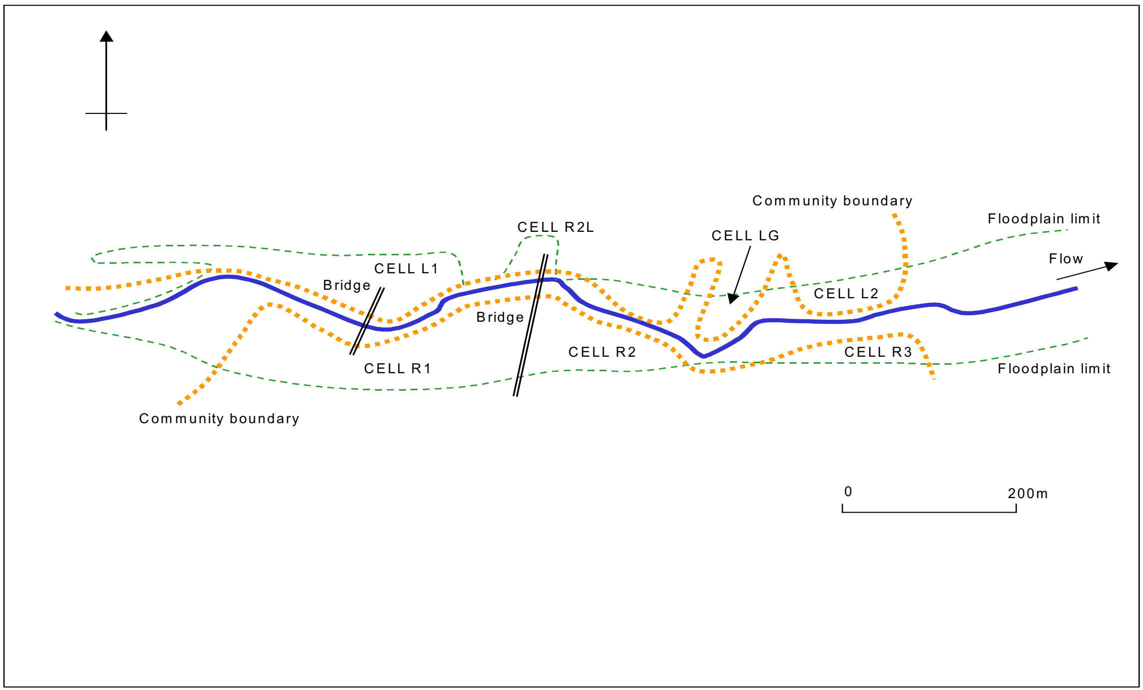


Figure E.1 Case Study 1: Site layout

E.3.3 Appraisal results

Costs and benefits of schemes for both cells individually and combined are given in Table E.4. The appraisal has been carried out by a group of cells rather than individual cells. All damages and costs have been calculated for September 2003.

Table E.4 Appraisal results

a} Scheme costs

Annual probability of flooding (%)	Appraisal results - Scheme cost for cell (£ million):		
	L1 and R1	L1, R1 and R2	Community (all cells)
10	0.3	0.4	0.4
2.5	4.0	4.6	5.5
2	4.1	4.7	5.6
1.3	4.3	4.9	6.0
1.0	4.5	5.0	6.2
0.5	5.0	5.5	7.0

b} Scheme benefits

Annual probability of flooding (%)	Appraisal results - Benefits for cell (£ million):		
	L1 and R1	L1, R1 and R2	Community (all cells)
10	0.8	1.2	1.2
2.5	5.0	7.0	7.2
2	5.1	7.2	7.4
1.3	5.4	7.6	7.8
1.0	5.7	7.7	8.0
0.5	7.0	9.0	9.5

c} Benefit-cost ratios

Annual probability of flooding (%)	Appraisal results - Benefit : cost ratio for cell:		
	L1 and R1	L1, R1 and R2	Community (all cells)
10	2.7	3.0	3.0
2.5	1.3	1.5	1.3
2	1.3	1.5	1.3
1.3	1.3	1.6	1.3
1.0	1.3	1.6	1.3
0.5	1.4	1.6	1.4

E.3.4 Socio economic conditions

Case study E is an attractive and historic market town. Commercial properties near the centre of the town would be affected by flooding together with transport links. Major infrastructure affected by floods is as follows:

- Road between cells L1 and R1 (cell L1 and R1)
- Road between cells L1 and R1 (cell L1 and R1)

Community functions affected by floods include:

Railway station (cell L1)

There are no particular social vulnerability issues.

E.4 Application of Methods

E.4.1 Economic efficiency

Using the PAG3 decision rule, protection of cells L1, R1 and R2 would be the preferred option, with a benefit-cost ratio of 1.6. This option is therefore included in the analysis.

E.4.2 Population efficiency

The overall population is small, although over 50% reside in cell L1. This criterion involves protecting the main centres of residential population. Cells L1, R1 and R3 contain the vast majority of the population. Costs for these cells were not available individually and, in view of the small population, an analysis in terms of maximising the population protected was not carried out.

E.4.3 Equal cost per property

The cost per residential property for schemes that provide protection for the 1% annual probability flood is given in Table E.5. The equivalent figures of cost per property (residential and non-residential) are given in Table E.6.

Table E.5 Cost per residential property

Cell	Cost per residential property (£'000)
L1/R1 (to raise standard from 20/10% to 1.3%)	105
R2 (to raise standard from 20/10% to 1.3%)	N/A
L2/R3 (to raise standard from 4% to 1.3%)	100
All	115

Table E.6 Cost per property

Cell	Cost per property (£'000)
L1/R1 (to raise standard from 20/10% to 1.3%)	90
R2 (to raise standard from 20/10% to 1.3%)	120
L2/R3 (to raise standard from 4% to 1.3%)	90
All	90

This criterion provides a fixed amount of funding of either £10,000 or £5,000 per residential property. Applying these values to individual cells and the whole community would provide the funding shown in Table E.7.

Table E.7 Equal cost per residential property: available funds

Funding per residential property	Available funds by cell number (£'000)		
	L1, R1	L1, R1, R2	All
£10,000	410	410	520
£5,000	205	205	260

£10,000 per property would be adequate to ensure that a 10% standard would be available to all properties. At present some flooding does occur at this flood frequency and the NPV of damages is £1.2 million. This option provides a higher-benefit cost ratio than the preferred option, but is far below the indicative standard for urban areas and would not be accepted by the community. £5,000 per property would not be enough to provide any flood defence, and could only be used for flood proofing and non-structural flood mitigation measures.

E.4.4 Equal design standards of protection

The results of applying equal design standards to all cells are summarised in Table E.8.

Table E.8 Results

Protection standard (annual probability of flooding, %)	Residential properties	Costs (£ million)	Benefits (£ million)	B/C ratio	NPV (£ million)
10.0	14	0.4	1.2	3.0	3.0
2.5	52	5.5	7.2	1.3	1.7
2.0	52	5.6	7.4	1.3	1.8
1.3	52	6.0	7.8	1.3	1.8
1.0	52	6.2	8.0	1.3	1.8
0.2	62	7.0	9.5	1.4	2.5

It can be seen that a viable scheme could be developed for all standards of protection.

E.4.5 Equal vulnerability

In this case, there are no concentrations of vulnerable people and this option is not applicable.

E.5 Summary

The results are summarised in Tables E.9 and E.10. The implications of the results are considered Table E.11.

Table E.9 Results

Criterion	Option	Residential properties protected	People protected (1)	Standard (%)	Costs (£m)	B/C ratio
Economic efficiency	Cells L1, R1 and R2	41	82	1.3	4.9	1.6
Equal cost per property (£10k)	All cells	14	28	10	0.4	3.0
Equal cost per property (£5k)	Flood proofing	None	None	N/A	0.3	N/A
Equality of threshold risk	All cells	14	28	10.0	0.4	3.0
		52	104	2.5	5.5	1.3
		52	104	2.0	5.6	1.3
		52	104	1.3	6.0	1.3
		52	104	1.0	6.2	1.3
		62	124	0.2	7.0	1.4

Notes: Based on two people per house.

Table E.10 Indicators

Indicator	Criterion	Economic Efficiency	Equal Cost (£10k)	Equal Cost (£5k)	Equal threshold					
	Cells	**L1/R 1/R2**	**All**	**All**	**All**	**All**	**All**	**All**	**All**	**All**
	Standard (%)	**1.3**	**10**	**N/A**	**10**	**2.5**	**2**	**1.3**	**1.0**	**0.5**
PEOPLE										
Residential properties protected		41	14	0	14	52	52	52	52	62
Residential properties not protected		11	0	All	0	0	0	0	0	0
% residential properties not protected		21	0	100	0	0	0	0	0	0
Residential properties with increased risk		11 minor	0	0	0	0	0	0	0	0
COMMUNITY										
Non-residential properties protected		12	6	0	6	13	13	13	13	18
Non-residential properties not protected		1	0	All	0	0	0	0	0	0
Infrastructure protected		1	1	0	1	1	1	1	1	1
Infrastructure not protected		0	0	1	0	0	0	0	0	0
LONG-TERM PERSPECTIVE										
Rate of flooding: larger flood		The cells are small but would flood relatively slowly during a large flood because the river is small. Thus the defences will provide some residual protection against flooding.								
COSTS AND BENEFITS										
B/C ratio		1.6	3.0	N/A	3.0	1.3	1.3	1.3	1.3	1.4
Cost/residential property (£'000)		120	30	5	30	105	108	115	119	113
Cost/property (£'000)		92	20	4	20	85	86	92	95	88
POVERTY & SOCIAL EXCLUSION: results for 10% flood										
Residential properties protected		14	14	0	14	14	14	14	14	14
Residential properties not protected		0	0	14	0	0	0	0	0	0
% residential properties not protected		0	0	100	0	0	0	0	0	0

Table E.11 Implications

Criterion	Implications
Economic efficiency	Hydraulic: There will be an increase in flood levels throughout the community at all return periods, affecting undefended areas. Downstream impact (including cells L2/R3) will be small and not measurable, but backwater effects upstream will be significant. Cells will fill slowly in floods > design standard Advantages: Best benefit/cost ratio Disadvantages: Not all areas protected (21% of properties unprotected for 1% flood) Winners: Cells L1, R1 and R2 have improved protection Losers: Cells L2 and R3 have no protection (and a minimal increase in risk)
Equal cost per property: £10k per residential property	Hydraulic: Minimal impact. Advantages: Low cost, High benefit cost ratio Disadvantages: Low defence standard (10% annual probability of flooding) Winners: Communities elsewhere in the country Losers: Everyone will flood relatively frequently
Equal cost per property: £5k per residential property	Hydraulic: No impact. Advantages: Low cost Disadvantages: Minimal protection (floodproofing only) Winners: Communities elsewhere in the country Losers: Everyone will flood relatively frequently
Equality of threshold risk	Hydraulic: There will be significant increases in flood levels upstream (backwater) and minor increases downstream. Inundation of defended areas will be relatively slow in extreme floods (greater than scheme standard), providing some residual protection. Advantages: Everyone has same minimum standard Disadvantages: More expensive than economic efficiency but more properties protected (and cost per property similar). Winners: Everyone gets protection Losers: Higher investment will mean there is less money for communities elsewhere

E.6 Conclusions

Broad conclusions are as follows:

- The flood risk area comprises a group of cells in the centre of the town, where the threshold of flooding is about 20 to 10% annual probability, and a group of cells downstream where the threshold of flooding is about 4%;
- The total number of properties at risk is about 65 spread over 1km of river on both banks. Defence costs per property are of the order of £100,000;
- The most economically efficient option is to defend the centre of the town only. This yields a benefit cost ratio of 1.6 but only protects 80% of residential properties.
- The highest benefit cost ratio is achieved by defending the centre of the town to a low standard (about 10%), and this can be achieved using the £10,000 per property criterion. However this low standard of defence would not be acceptable to the community;
- Equality of threshold risk provides benefit cost ratio of greater than one in all cases.

Case Study F

F.1 Background

Case Study F is town on a medium size river with flood risk areas on both banks. Much of the town is a conservation area and there are several listed buildings and structures (including the river bridge). About 40 properties flooded in 2000 and a scheme has been developed, as discussed below. There are only about 27 residential properties in the flood risk area and most of the benefits are derived from non-residential properties, particularly a large brewery in the floodplain.

There are existing defences in parts of the town that provide a standard of protection of between 10 and 4% annual probability of flooding. The brewery has a 10% standard. Some areas are undefended, and have a 50 to 20% annual frequency of flooding.

F.2 The proposed scheme

The flood risk area consists of four cells. Cells L1 and R1 are in the centre of the town. Cell R2 includes the brewery, and cell L2 is a small part of a housing development that encroaches onto the floodplain. The costs and benefits from cell 2 are very small and have very little impact on the analysis. Options considered include the following:

- The town centre (cells L1 and R1)
- As above, but with the addition of cell L2
- All four cells
- Cell L2
- Cell R2

The preferred option involved defending all four cells to the 1% standard, as outlined in Table F.1.

Table F.1 Proposed scheme

Scheme	Details of flood risk area				Defence standards (annual probability of flooding, %)		Scheme cost (£M)
	No residential properties	Area (ha)	Population (estimate)	Vulnerable people (based on % of population)	Pre-scheme	Proposed scheme	
Cell L1	9	3.1	18	Normal proportion	10-4	1	5.6 (all cells)
Cell R1	11	2.5	22		50-20	1	
Cell L2	3	0.3	6		2.5	1	
Cell R2	4	4.0	8		10	1	
All cells	27	9.9	54			1	

The scheme has a benefit cost ratio of about 4.4 and provides a consistent standard of protection for the community.

F.3 The flood problem

F.3.1 Properties at risk

The distribution of properties at risk is given in Table F.2.

Table F.2 Properties at risk

Cell	Number of properties at risk for different annual probabilities of flooding Res: residential; Non-res: non-residential															
	50%		20%		10%		4%		2%		1.3%		1.0%		0.5%	
	Res	Non -res	Res	Non -res	Res	Non -res	Res	Non -res	Res	Non -res	Res	Non -res	Res	Non -res	Res	Non -res
L1	-	-	-	-	1	11	7	15	9	17	9	17	9	17	9	17
R1	-	-	8	29	10	34	10	37	11	39	11	39	11	41	11	45
L2	-	-	-	-	-	-	-	-	3	-	3	-	4	-	4	-
R2	-	-	-	1	-	2	2	3	3	5	3	7	3	8	3	11
All	0	0	8	30	11	47	19	55	26	61	26	63	27	66	27	73

F.3.2 The physical environment

The river is large, with a width of about 30-40m and a 1% flood flow of about 550 cumecs. The floodplain through the centre of the town (cells L1 and R1) is about 100m wide on both banks, but is wider both upstream and downstream. Cell L2 is on the edge of the left bank floodplain downstream of the town. Cell R2 is located on the 250m wide right bank floodplain downstream of the town. The layout of the flood risk area is shown on Figure F.1.

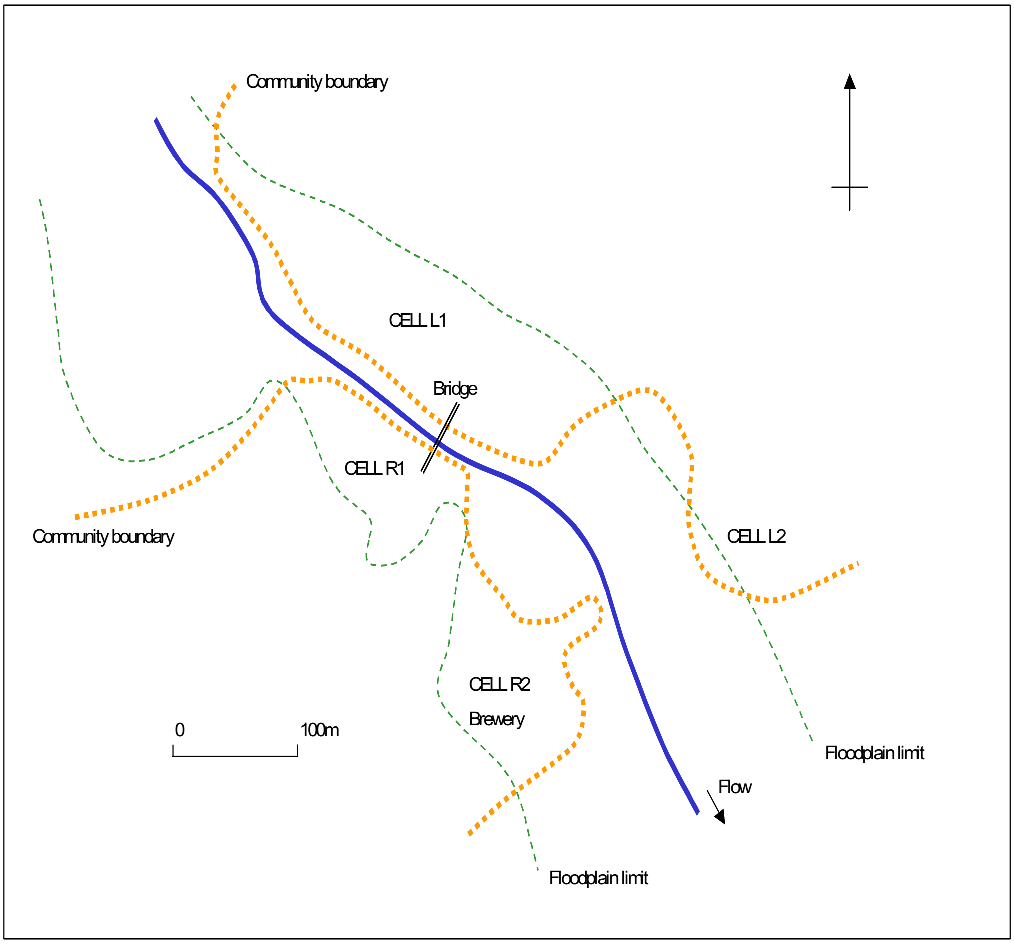
Properties protected per unit length of defence are given in Table F.3.

Table F.3 Properties protected per unit length of defence

Cell	Properties protected (1% flood)	Defence length (km)	Properties per km defence
L1	26	0.8	33
R1	52	0.4	130
R2	11	0.7	16
L2	4	0.15	26

If the cells were defended, they would fill rapidly during an event that exceeds the defence standard. This is because the floodplain cells are small compared with the flow in the river. Because of the already constricted nature of the

Figure F.1 Case Study 1: Site layout



floodplain through the town, the construction of defences will only have a relatively small impact of flood levels, typically of the order of 20mm. The backwater effect would extend some distance upstream, but the downstream impact would be minimal.

F.3.3 Appraisal results

Costs and benefits of schemes for individual and combined cells are given in Table F.4. Flood damages have been assessed using the Multi-Coloured Manual data. All damages and costs have been calculated for December 2002. Cells R1 and R2 are not completely independent, and there is a considerable cost saving if these two cells are included in the same scheme.

Table F.4 Appraisal results

a} Scheme costs

Annual probability of flooding (%)	Appraisal results - Scheme cost for cell (£ million):					
	L1	R1	R2	L2	L1 + R1	Community (all cells)
10	No data					
4	1.94	1.91	2.11	-	3.85	4.79
2	2.05	1.92	2.25	-	4.07	5.07
1.3	2.39	1.93	2.34	-	4.32	5.52
1	2.42	1.95	2.37	0.31	4.37	5.60
0.5	2.61	2.59	2.91	0.44	5.20	6.76

b} Scheme benefits

Annual probability of flooding (%)	Appraisal results - Benefits for cell (£ million):					
	L1	R1	R2	L2	L1 + R1	Community (all cells)
10	No data					
4	2.56	6.90	6.22	-	9.46	15.68
2	3.62	8.60	8.39	-	12.22	20.58
1.3	4.12	9.34	9.35	-	13.46	22.76
1	4.61	9.94	10.27	0.01	14.56	24.75
0.5	5.07	10.62	11.11	0.02	15.71	26.72

c} Benefit-cost ratios

Annual probability of flooding (%)	Appraisal results - Benefit : cost ratio for cell:					
	L1	R1	R2	L2	L1 + R1	Community (all cells)
10	No data					
4	1.32	3.61	2.94	-	2.46	3.27
2	1.77	4.48	3.73	-	3.00	4.06
1.3	1.73	4.84	3.99	-	3.12	4.12
1	1.90	5.10	4.32	0.03	3.33	4.42
0.5	1.94	4.10	3.82	0.05	3.02	3.95

F.3.4 Socio economic conditions

The flood risk area includes part of the centre of a busy market town with important local industries. There are no reported social vulnerability issues in the flood risk area.

Flooding affects one major item of infrastructure, the road between cells L1 and R1.

Flooding severely affects the functioning of the local community. Cell L1 includes the following community functions: bus station, health centre and medical centre.

F.4 Application of Methods

F.4.1 Economic efficiency

A scheme involving the protection of cells L1, R1 and R2 was considered to be the most economically efficient, and the PAG3 decision rule advised that a 1% standard should be adopted. The appraisal did not separate cells L1 and R1, which together comprise the centre of the community.

It was decided to include cell L2 in the final scheme for a number of reasons including the fact that the cost is small, and therefore the impacts on the appraisal are marginal.

F.4.2 Population efficiency

The number of residential properties is very small. Therefore an option based on maximising the protection of population was not considered.

F.4.3 Equal cost per property

The cost per residential property for schemes that provide protection for the 1% annual probability flood is given in Table F.5. The equivalent figures of cost per property (residential and non-residential) are given in Table F.6.

Table F.5 Cost per residential property

Cell	Cost per residential property (£'000)
L1	270
R1	180
R2	600
L2	80
All	210

Table F.6 Cost per property

Cell	Cost per residential property (£'000)
L1	90
R1	40
R2	210
L2	80
All	60

This criterion provides a fixed amount of funding of either £10,000 or £5,000 per residential property. Applying these values to individual cells and the whole community would provide the funding shown in Table F.7. For simplicity, the calculation is done using properties at risk for the 1% annual probability event.

Table F.7 Equal cost per property: available funds

Funding per residential property	Available funds by cell number (£'000)				
	L1	*R1*	*R2*	*L2*	*All*
£10,000	90	110	30	40	270
£5,000	45	55	15	30	135

These figures are far below the estimated costs for any of the schemes. The only options would be to provide properties with floodproofing equipment and advice or enhance non-structural measures, for example flood warning.

Flood depths are greater than one metre for the 1% annual probability flood event. Complete exclusion of water from properties should be avoided in these cases. The use of boards on openings so that water enters through floors and walls would reduce pollution inside properties.

F.4.4 Equal design standards of protection

The results of applying equal design standards to all cells are summarised in Table F.8.

Table F.8 Results

Protection standard (annual probability of flooding, %)	Residential properties	Costs (£ million)	Benefits (£ million)	B/C ratio	NPV (£ million)
4	19	4.79	15.68	3.27	10.89
2	26	5.07	20.58	4.06	15.51
1.3	26	5.52	22.76	4.12	17.24
1	27	5.60	24.75	4.42	19.15
0.5	27	6.76	26.72	3.95	19.96

It can be seen that an economically viable scheme could be developed for all standards of protection. However there are no step changes in cost and the cost of even the lowest standard scheme is significant (i.e. the cost of a 4% standard scheme is 85% of the 1% standard scheme cost).

F.4.5 Equal vulnerability

In this case there are no concentrations of vulnerable people. However, cell L1 contains some key community functions and is considered as a separate option. It could be accessed from the southern part of the town during a flood by the town bypass road, which crosses the floodplain to the south of the town.

F.5 Summary

The results are summarised in Tables F.9 and F.10. The implications of the results are considered Table F.11.

Table F.9 Results

Criterion	Option	Residential properties protected	People protected (1)	Standard (%)	Costs (£m)	B/C ratio
Economic efficiency	Cells L1, R1and R2	23	46	1.0	5.40	4.58
Equal cost per property	Flood proofing	None	None	N/A	0.27	N/A
Equality of threshold risk	All cells	19	38	4.0	4.79	3.27
		26	52	2.0	5.07	4.06
		26	52	1.3	5.52	4.12
		27	54	1.0	5.60	4.42
		27	54	0.5	6.76	3.95
Social vulnerability	Cell L1	9	18	1.0	2.42	1.90

Notes: Based on two people per house.

Table F.10 Indicators

Indicator	Criterion:	Economic Efficiency	Equal Cost	Equal threshold					Social vulnerability
	Cells:	L1 R1 R2	All	All	All	All	All	All	L1
	Standard (%)	1.0	N/A	4.0	2.0	1.3	1.0	0.5	1.0
PEOPLE									
Residential properties protected		23	0	19	26	26	27	27	9
Residential properties not protected		4	All	0	0	0	0	0	18
% residential properties not protected		15	100	0	0	0	0	0	67
Residential properties with increased risk		4 min	0	0	0	0	0	0	18 min
COMMUNITY									
Non-residential properties protected		66	0	55	61	63	66	73	17
Non-residential properties not protected		0	All	0	0	0	0	0	49
Infrastructure protected		1	0	1	1	1	1	1	0
Infrastructure not protected		0	1	0	0	0	0	0	1
Community function protected		3	0	3	3	3	3	3	3
Community function not protected		0	1	0	0	0	0	0	0
LONG-TERM PERSPECTIVE									
Rate of flooding: larger flood		Defended areas would fill quickly in a larger than design event flood as the area is small for the size of river.							
COSTS AND BENEFITS									
B/C ratio		4.58	N/A	3.27	4.06	4.12	4.42	3.95	1.90
Cost/residential property (£'000)		230	10/5	250	195	210	205	250	270
Cost/property (£'000)		61	3/2	65	58	62	60	68	90
POVERTY & SOCIAL EXCLUSION: results for 10% flood									
Residential properties protected		11	0	11	11	11	11	11	1
Residential properties not protected		0	11	0	0	0	0	0	10
% residential properties not protected		0	10	0	0	0	0	0	90

Table F.11 Implications

Criterion	Implications
Economic efficiency	Hydraulic: There will be a small increase in flood levels between cells L1 and R1 and upstream, typically of the order of 20mm. There will be a minimal increase downstream including cell L2. Rapid inundation of cells in floods > 1% annual probability Advantages: Best benefit/cost ratio Disadvantages: Cell L2 not protected (4 residential properties) Winners: Cells L1, R1 and R2 have improved protection Losers: Cell L2 has no protection (and a minimal increase in risk)
Equal cost per property	Hydraulic: No impact. Advantages: Low cost Disadvantages: Minimal protection (floodproofing only) Winners: Communities elsewhere in the country Losers: Everyone will flood relatively frequently
Equality of threshold risk	Hydraulic: There will be a minimal increase in flood levels upstream (backwater) and downstream. Rapid inundation of defended areas in extreme floods (greater than scheme standard) Advantages: Everyone has same minimum standard Disadvantages: Marginally more expensive than economic efficiency but more properties protected (and cost per property similar) . Winners: Everyone gets protection Losers:

Social vulnerability	Hydraulic: There will be a small increase in flood levels adjacent to cell L1, typically of the order of 10mm. This will affect cell R1 and any undefended properties upstream. Rapid inundation of cell L1 will occur in extreme floods (greater than scheme standard) Advantages: Community functions protected at least cost Disadvantages: Most of community not protected. Low benefit cost ratio and high cost/property Winners: Cell L1 The wide community: people who live outside the floodplain Losers: Cells L2, R1 and R2.

F.6 Conclusions

Broad conclusions are as follows:

- This flood risk area is dominated by commercial properties, particularly a large brewery;
- The benefits are high but there are very few residential properties (c£200,000 scheme cost per residential property);
- Any criterion aimed at maximum population protected would not select this area for protection;
- Key community buildings lie in the floodplain. These could be protected by defending one cell, thus reducing impact on the wider community;
- Defending cells L1 and R1 would minimise the flood impact for the wide community (as it would protect the river crossing and shops, etc) but would not prevent flooding of the brewery, which is a major employer in the town;
- The equal cost per property would not provide any flood defence other than possible floodproofing.

Case Study G

G.1 Background

Case Study G consists of two main flood risk areas within a large urban conurbation. The flood risk areas are very intensively developed with both residential and non-residential properties. Over 3,200 properties are at risk in the 1% annual probability flood. There are some much smaller flood risk areas, but this discussion concentrates on the two main flood risk ‘cells’.

Cell 1, which contains about 740 properties, has a threshold annual probability of flooding of 20%. Over 90% of properties flood in the 10% annual probability event. Cell 2, which contains about 2,500 properties, has a flood defence scheme that provides protection to the 2.5% annual probability of flooding standard. The scheme comprises channel widening and bank raising, and provides a channel capacity of 460 cumecs.

Issues of particular relevance to Consistent Standards are:

How is a ‘community’ defined in an urban conurbation? In this case, cells 1 and 2 are separate communities, with separate community centres and facilities
The number of properties at risk is very high but, being a poor area, the benefits are relatively low for the number of properties (but still high compared to other case studies).
What is an appropriate design standard for a large community?

G.2 The proposed scheme

An important constraint on the scheme is that river levels should not be increased for cell 2 because:

There are considerable urban drainage problems, that would be exacerbated if water levels were increased:

- There would be an increase in flood risk to the many cellars adjacent to the river;
- There would be an increased hazard if the defences overtopped;
- Several bridges would require major works and possible reconstruction.

Schemes involving wall/bank raising would raise river levels. The cost of a walls/embankments only scheme would be of the order of £50 million, because of the high cost of concrete walls in a dense urban area and the need for urban drainage works, bridge improvements, etc.

Other options were investigated including redevelopment, channel enlargement, flood bypass channels, storage and works in the upper catchment. The only viable options involved increasing channel capacity in some areas by channel widening and wall raising, and flood storage. The final strategy for protecting the area was as follows:

Option 1: Construct channel works so that cell 1 has the same standard as cell 2 (ie 2.5% annual probability of flooding);

Option 2: As option 1, but construct a new flood storage area upstream of cells 1 and 2 to provide a 1.3% standard to both cells;

Option 3: As option 2, but construct a second flood storage area to provide a 1% standard for both cells.

The scheme originally promoted in 1991 was Option 3, but Option 2 was approved. One consequence of adopting the 1.3% standard is in the interpretation of PPG25, where the floodplain is zoned using the 1% and 0.1% annual risk of flooding. Both cells 1 and 2 are in the <1% zone for development control purposes.
The relevant economic data for the option are given in Table G.1. The costs and benefits were calculated for 1993 and have been inflated by 33% so that they can be compared with the other case studies.

Table G.1 Scheme options

Item	Option 1	Option 2	Option 3
Standard (%)	2.5	1.3	1.0
Costs (£ million)	3.85	9.42	15.09
Benefits (£ million)	65.26	71.23	77.36
NPV (£ million)	61.41	61.81	62.27
Average benefit cost ratio	16.9	7.6	5.1
Incremental benefit cost ratio		1.07	1.08

Details of the selected scheme (option 2) are given in Table G.2.

Table G.2 Proposed scheme

Scheme	Details of flood risk area				Defence standards (annual probability of flooding, %)		Scheme cost (£M)
	No residential properties	Area (ha)	Population (1)	Vulnerable people (based on % of population)	Pre-scheme	Proposed scheme	
Cell 1 Cell 2 All cells	710 2000 2710	50 170 220	1400 4200 5600	Higher than average, but no particular concentrations	20 2.5	1.3 1.3 1.3	9.4 (all cells)

(1) Estimate, based on two people per house

G.3 The flood problem

G.3.1 Properties at risk

The distribution of properties at risk is given in Table G.3.

Table G.3 Properties at risk

Cell	Number of properties at risk for different annual probabilities of flooding Res: residential; Non-res: non-residential									
	10%		4%		2%		1.3%		1.0%	
	Res	Non-res	Res	Non-res	Res	Non-res	Res	Non-res	Res	Non-res
1	707	10	710	30	710	30	710	30	710	30
2	-	-	-	-	190	27	2000	350	2120	410
All	707	10	710	30	900	57	2710	380	2830	440

G.3.2 The physical environment

The river is large (with an estimated 1% annual probability flow of 550 cumecs and a width of about 50m). The river meanders and the floodplain is generally contained in bends in the river, with a width of up to 1000m. The layout of the flood risk area is shown on Figure G.1.

Cell 1 has very intensive urban development but with open areas to the west and east (designated as flood storage areas on Figure G.1). Cell 1 is bounded by a steep rise in ground level to the north. Cell 2 is a very intensively developed area with about 2500 properties of which over 400 are non-residential, including a large school.

Option 1 would contain flood flows throughout the reach for the estimated 2.5% annual probability event. This would raise flood levels in the river, particularly in the vicinity of cell 1. This option involves about 3,500m of bank raising and improvement works over an 8km length of river. These works are primarily for defending cell 1, and represent about 210 properties per km of defence.

The flood storage options involve off-line basins that are designed to remove the peak from the flood hydrograph, thus reducing the peak discharge but not the hydrograph duration. The resulting hydrographs will have a flat peak, and will provide an reduction in flood risk for all downstream reaches.

The scope for flood storage options is very limited because of a lack of suitable sites and the very high development in the catchment. Maximum use has been made of available land, but the scheme is vulnerable to increase in flood flows and volumes that could arise as a result of climate change.

The project appraisal included an assessment of the flooding that would occur during larger events than the design standard. In the event of a 0.04% annual probability flood, the impacts on flooding would be as follows for the 1% standard scheme:

- Cell 1: About 90% would flood
- Cell 2: About 60% would flood

Thus the scheme provides residual some protection against larger floods.

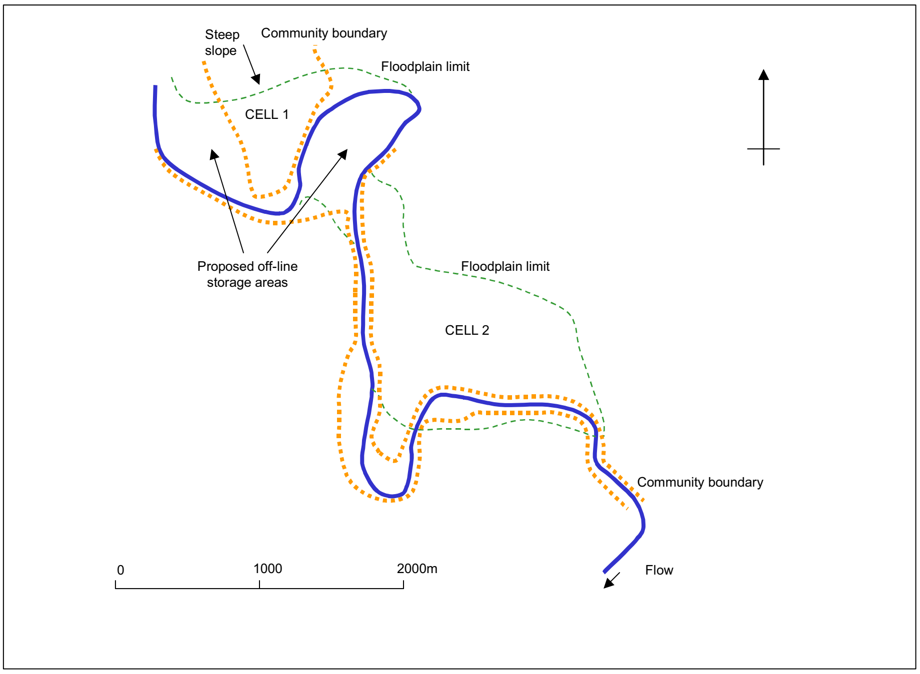


Figure G.1 Case Study 1: Site layout

G.3.3 Appraisal results

Costs and benefits of the options investigated in detail are given above in Table G.1. A full breakdown of options for a range of flood frequencies has not been carried out because:

- The requirements of the appraisal method were different in 1991, when the scheme was developed;
- There was no interest in schemes with a low standard of protection, and the 2.5% standard was considered to be the minimum (pre-scheme standard for cell 2);
- The options were very constrained by available land for storage and the requirement not to increase flood levels in the river adjacent to cell 2.

G.3.4 Socio economic conditions

The flood risk areas are occupied by large but relatively poor communities. Considerable redevelopment is proposed and old properties are being demolished to permit the development to take place. The area is very close to a major city centre and, whilst it is poor at present, there may be a significant increase in wealth as new developments are implemented.

There are no specific social vulnerability issues although such large areas inevitably contain many facilities required for a community to function, including schools, work places, a wide variety of other non-residential buildings, and important local transport links.

G.4 Application of Methods

The three options listed in Table G.1 are compared. Comment on their implications for the consistent standards criteria are given below.

G.4.1 Economic efficiency

All three options are economically viable and could be justified by economic appraisal, but option 2 was approved for construction.

G.4.2 Population efficiency

If protecting the maximum population was regarded as the main criterion for flood defence planning, this scheme would be a ‘must’. It provides protection to over 3,000 properties and of the order of 6,000 people.

G.4.3 Equal cost per property

The cost per residential property for options 1, 2 and 3 are given in Table G.4. The equivalent figures of cost per property (residential and non-residential) are given in Table G.5.

Table G.4 Cost per residential property

Option	Residential properties	Standard of defence (%)	Cost per residential property (£’000)
1	710	2.5 (from 20)	5.4
2	2710	1.3 (from 20/2.5)	3.5
3	2830	1.0 (from 20/2.5)	5.3

Table G.5 Cost per property

Option	Properties	Standard of defence (%)	Cost per property (£'000)
1	740	2.5 (from 20)	5.2
2	3090	1.3 (from 20/2.5)	3.0
3	3270	1.0 (from 20/2.5)	4.6

This criterion provides a fixed amount of funding of either £10,000 or £5,000 per residential property. Applying these values to individual cells would provide the flood mitigation measures outlined in Table G.6. The defence standards indicated in the table are approximate. For simplicity, the funds have been calculated for the number of properties at risk in the 1% annual probability event.

Table G.6 Application of fixed funding per residential property

			Flood mitigation measures	
	£10,000 /property	£5,000 /property	£10,000 /property	£5,000 /property
1	7,100	3,550	Better than 1% scheme	3% scheme
2	21,200	10,600	Better than 1% scheme	Better than 1.3% scheme
All	28300	14,150	Better than 1% scheme	1.1% scheme

The equal cost per property criterion would therefore result in:

- A very high standard of defence for all cells, based on £10,000 per residential property;
- A scheme which has a better standard than the currently approved scheme, based on £5,000 per residential property.

It is not practical to consider this case study by cell, because the flood storage works protect all cells.

G.4.4 Equal design standards of protection

Options 1, 2 and 3 provide an equal design standard to all cells.

G.4.5 Equal vulnerability

There are no particular social vulnerability issues that would change the selection of options.

G.5 Summary

Results for the three options and the equal cost per property criterion are summarised in Table G.7. The implications of the results are considered in Table G.8.

Table G.7 Indicators

Indicator	Criterion	Equal Cost (£10k)	Equal Cost (£5k)	Equal threshold (ie options 1, 2 and 3)		
	Cells	All	All	All	All	All
	Standard (%)	Better than 1.0	1.1	2.5	1.3	1.0
PEOPLE						
Residential properties protected		>2830	2800	710	2710	2830
Residential properties not protected		0	0	0	0	0
% residential properties not protected		0	0	0	0	0
Residential properties with increased risk		0	0	0	0	0
COMMUNITY						
Non-residential properties protected		>440	430	30	380	440
Non-residential properties not protected		2	0	0	0	0
LONG-TERM PERSPECTIVE						
Rate of flooding: larger flood		Rate of rise in river level could be high once storage areas are filled, leading to rapid inundation of areas near river. Total area flooded will be limited by hydrograph volume.				
COSTS AND BENEFITS						
B/C ratio		Not known	5.5	16.9	7.6	5.1
Cost/residential property (£'000)		10	5	5.3	3.5	5.3
Cost/property (£'000)		8.6	4.3	5.2	3.0	4.6
POVERTY & SOCIAL EXCLUSION: results for 10% flood						
Residential properties protected		All properties protected to better than 10% standard				
Residential properties not protected						
% residential properties not protected						

Table G.8 Implications

Criterion	Implications
Equal cost per property By cell	Hydraulic: Small impact on flood levels in the vicinity of cell 1 for flood frequencies of up to 2.5%. Advantages: Viable scheme at equitable cost High protection standard Disadvantages: Use of resources not optimised. Cost of 'best scheme' is £5,300 per property. £5,000 per property is sub-optimal (just) and £10,000 per property is more than required. Winners: Cells 1 and 2 Losers: Communities elsewhere in the country if money spent inefficiently
Equality of threshold risk	Hydraulic: Small impact on flood levels in the vicinity of cell 1 for flood frequencies of up to 2.5%. Parts of cells 1 and 2 will flood rapidly in floods > threshold. Advantages: Everyone has same minimum standard. Options are economically efficient (Note that storage schemes provide the same standard in terms of river flow) Disadvantages: Winners: Everyone gets protection Losers: Areas within the backwater influence, where there is a small increase in flood risk.

G.6 Conclusions

Broad conclusions are as follows:

- Two separate communities within a large conurbation are protected by the same scheme;
- The communities have the same standard because:
  - The channel capacity is the same for both communities
  - Storage schemes have been provided, that provide the same river flow to the same communities;

- A high standard of protection can be achieved for a low cost per residential property (of the order of £5,000)
- The scheme is vulnerable to larger than design floods (including the impacts of climate change) because there is little scope to increase the protection standard without massive cost.

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Nobel House
17 Smith Square
London SW1P 3JR

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