A Review of Current Knowledge

FLOOD MITIGATION

FR/R0028
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This review is one of a series of Reviews of Current Knowledge (ROCKs) produced by FWR. They focus on topics related to water supply, wastewater disposal and water environments, which may be the subject of debate and inquiry. The objective of each review is to produce concise, independent scientific and technical information on the subject to facilitate a wider understanding of the issues involved and to promote informed opinion about them.

Front cover image:
Flooding of York from the River Ouse in 2000
Source: www.yorkshiretimes.com

FLOOD MITIGATION

Flooding in Rhyl, North Wales, 2017
Source: Reuters

Author: Dr W R White

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Review of Current Knowledge

1 Introduction

Flooding is the most widespread natural hazard, often arising from adverse meteorological conditions such as:

- intense or prolonged rainfall in river catchments
- storm surges at the coast and in estuaries
- storm-generated waves at the coast.

Flooding may be triggered by a series of other natural hazards. For example, earthquakes may cause tsunamis. They also cause landslides which may block river valleys and impound water. These landslide deposits later breach, resulting in flooding downstream. Another source of flooding is the failure of water management infrastructure such as dams and raised flood protection embankments.

In many countries, little of the coastline or land area has escaped human influence, with increasing pressures over generations from settlement, agriculture, industry and commerce. The human influences include water and flood management activities which control the extent and frequency of floods and the drainage of water from the land. Our perception of floods and how to react to them has changed over time. Originally, floods were regarded as acts of God and society accepted the vagaries of nature. With technological development in the 18th, 19th and 20th centuries the concept developed of man attempting to overcome or control nature, an approach or attitude which continued until very recently. During this period the prevailing philosophy was one of taming floods, flood defence and flood prevention. Today, with the emergence of sustainability as a dominant driver of international policy and human activity, there is a move towards social responsibility and the development of general policies for flood risk management.

Flood risk management can be viewed as a continuing cycle of activities with alleviation and protection at the fore in normal times. When a flood is imminent or in progress, the attention moves to flood warning and emergency management responses. After the flood there is a period of recovery and review to learn lessons before the next flood occurs. Flood risk management recognises that the reduction of flood damage needs active engagement with the public at large so that when a flood comes, individuals and businesses are prepared and can act appropriately. This approach aims to create greater resilience within communities.

Flood risk can be analysed through a systematic consideration of:

- the sources of the floodwater

- the pathways by which the water moves over the land surface
- the exposure of people, property, businesses and the environment to the floodwaters
- the consequences of inundation on everything exposed to the floodwater.

Flood risk management is achieved through a portfolio of measures including the construction of traditional flood protection schemes, the use of policies to restrict inappropriate development on floodplains, the installation of flood warning systems and the testing of action plans to protect the population.

Internationally, policies and practice in flood risk management are evolving in response to many drivers including:

- consideration of potential climatic changes in terms of precipitation and sea levels,
- increasing potential for damage to the growing world infrastructure,
- decreasing acceptance of flooding by communities,
- competing demands on public expenditure,
- ageing of existing flood defence infrastructure.

In 2011 FWR produced a review (ROCK, FR/R0015) entitled Floods: alleviation, protection, response and risk management. This ROCK was wide ranging and covered the issues described above. The purpose of the current ROCK is to focus more closely on flood mitigation, including resistance and resilience, accepting that absolute protection against all future flood events cannot be guaranteed.

Chapter 2 of this ROCK is concerned with the fundamental issue of flood estimation, both flows and levels, and how these might change in future years.

Chapter 3 is a brief description of the ever increasing amount of infrastructure which is at risk.

Chapter 4 is an introduction to the measures which can be taken to mitigate the effects of flooding.

Chapter 5 is concerned with flood resistance measures, which can be temporary or permanent, and which seek to defend infrastructure against impending flood events.

Chapter 6 describes flood resilience methods which have been shown to help recovery following a flood event affecting our infrastructure, be it an individual property, a group of properties or a section of the transport network.

Chapter 7 summarizes recent official guidance for property owners on the subject matter which is covered in Chapters 4 to 6 inclusive.

2 Flood estimation

Historically ad-hoc solutions were developed, after flood events, to protect particular communities against similar occurrences in the future. Today the approach is more sophisticated and can be described as flood risk management. This approach looks more strategically at flood risks and the value of any proposed flood alleviation measures in terms of the costs and the benefits. Environmental and societal costs and benefits are beginning to be taken into account although it is often difficult to assign monetary values to these.

In order to predict the probability of a flood of a particular magnitude occurring at a particular location in any one year it is necessary to collect as much local data as possible over an extended period of time. These data are then subjected to rigorous statistical analyses and modelling. The most useful measurements taken during flood events are:

- peak water levels
- date and time at which the peak level occurred
- peak discharge
- duration of the flood and the shape of the flood hydrograph
- the flooded area.

In addition to these specific local measurements, correlations have to be made with precipitation data and the nature and state of the catchment in order to understand the way in which floods propagate downstream.

A further factor is the question as to whether past events are a good measure of what is likely to happen in the future. In particular scientists are looking at climate change and the ways in which this will affect different areas around the globe. A brief summary of these trends is given by ***White W R, 2017***. In the UK it is thought that flood magnitudes may gradually rise as global temperatures rise.

Arbitrary increases in rainfall were originally assumed with the corresponding increases in flood levels and flooded areas. However in recent years the Met Office has developed higher resolution simulations which can generate realistic weather predictions for the future. See ***HM Government, 2016***. Current thinking for the UK is that winter monthly rainfall totals could be 20 per cent higher than past extremes in some parts of the country and up to 30 per cent in other parts.

Winter rainfall in the UK is heaviest in the west which receives typically 10 times more rain than in the east. This is because the prevailing UK weather pattern is of wet air moving in from the Atlantic. This means that plausible extreme rainfall amounts will be different across the country and the Met Office has estimated increased values for each of six geographical areas. The percentage increase for each region is then applied to detailed kilometer-scale simulations of recent extreme rainfall scenarios to generate detailed future predictions for input to the Environment Agency’s catchment models.

There are three main tools for predicting the propagation of floods:

Analytical solutions

Analytical solutions incorporate simplified assumptions about the detailed topography and the hydraulic laws governing the movement of water. Analytical solutions are easy and quick to use and have a role in early assessments of flooding problems.

Physical models

Physical models cover the area of interest at a reduced linear scale. Physical models represent the detailed topography and infrastructure in a realistic manner but can suffer from scale effects which relate to the viscous and surface tension properties of water. Physical models are used less and less for flood propagation issues but are still useful for looking at detailed flow conditions in complex situations eg urban areas. They can be used retrospectively to assess flows from observed levels during major flood events or in the development of physical solutions to flooding problems.

Computational models

Computational models cover a range of complexity from steady flow in a channel, through 1D network models to comprehensive 3D models of local areas which demand high powered computing facilities and extensive data. Computational models are extensively used for a range of applications from single river reaches to whole river basins. Current UK and European practice is for the widespread use of 2D computational models for risk mapping of flood extents using digital terrain models based upon remotely sensed data at a spatial resolution of 10m or finer. Computational models are also coupled to real time meteorological and hydrological data for short term flood forecasting.

All three tools have their place in solving flooding problems but the emphasis moves inevitably towards the use of computational models, facilitated as they are by ever increasing computer processing speed and storage, coupled with improvements in the background science and the availability of more comprehensive data.

These aspects of flood estimation and propagation are covered more comprehensively by ***White W R and Samuels P G, 2011***.

3 Infrastructure at risk

Both inland and coastal flooding can cause damage to the infrastructure with the consequent inconvenience and economic costs in restoring its functionality.

Railways

There are many historic examples of flood damage to railway lines. Restoration can be a lengthy process due to the scale of the works and the safety issues which have to be addressed. Examples are given in Plates 1 and 2.

In the UK Network Rail plans to spend £900 million pounds between 2014 and 2019 improving the rail network's flood resilience. See ***HM Government, 2016***.

Plate 1 Rail flooding between Taunton and Bridgwater, Somerset, 2014
Source: www.bbc.co.uk

Plate 2 Rail flooding at Bishopton, Scotland, 2011
Source: www.bbc.co.uk

Roads

Flooding of roads is commonplace. It occurs in a multitude of situations including:

- roads adjacent to rivers
- roads behind coastal defences
- roads affected by local streams and poor drainage.

Examples are given in Plates 3 and 4.

In the UK Highways England plans to invest £78 million between 2016 and 2021 as part of its Flood Risk Management Plan plus a further £300 million as part of its Road Investment Strategy. See ***HM Government, 2016***.

Plate 3 Road flooding in Porthleven, Cornwall, 2014
Source: www.dailymail.co.uk

Plate 4 Road flooding in Loughborough, Leicestershire, 2012
Source: www.itv.com

Domestic Properties

Flooding of domestic properties is widespread throughout the world. In historic times there was little control over developments in areas subject to flooding. Living by a river was considered a benefit not a liability! More recently planning permission can be refused in order to maintain flood plains and to minimize future problems to property owners.

Examples are given in Plates 5 and 6.

Plate 5 Domestic flooding in Louisiana, USA, 2017
Source: www.latimes.com

Plate 6 Domestic flooding in Moorland, Somerset, 2014
Source: www.dailymail.co.uk

Other Key Infrastructure

There are some key elements of infrastructure which deliver critical local services and which are at risk of flooding. These facilities include:

- water supply and waste water
- fixed and mobile telecommunication
- electrical transmission and distribution
- gas transmission and distribution
- oil transmission and distribution
- medical establishments.

4 Flood mitigation

The purpose of flood mitigation is to minimise the damage, cost and inconvenience of flooding. However, rigorous means of establishing cost and inconvenience remain somewhat illusive.

Taking a global perspective, a high proportion of the world population exposed to flood risk, particularly from rivers, is in developing countries. Data is available from the World Resources Institute (WRI) which is a global, non-profit research organization established in 1982. It focuses on six areas: food, forests, water, energy, cities and climate. Offices of WRI are to be found in the United States, China, India, Brazil and Indonesia.

WRI has established that fifteen countries account for 80 percent of the population exposed to river flood risk. Figure 1 shows these fifteen countries which are most vulnerable to flooding together with the population which is exposed to river flood risk.

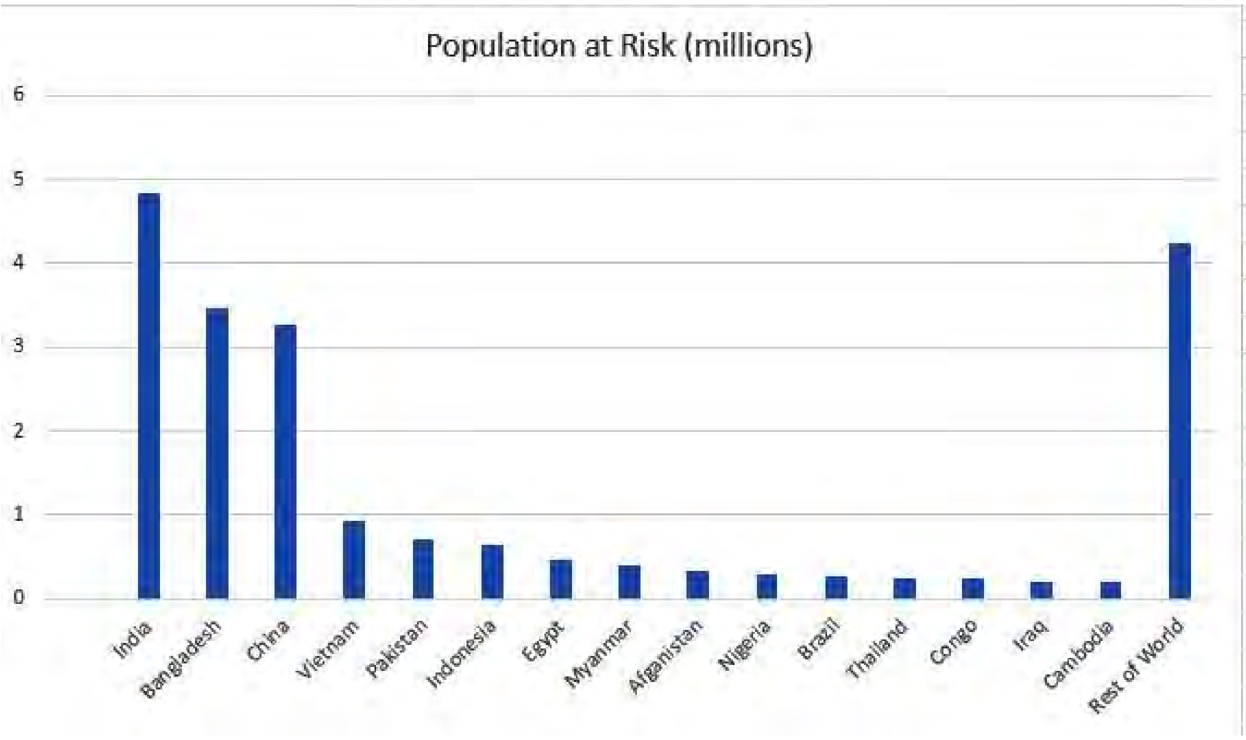


Figure 1 Population exposed to river flooding
Source: www.wri.org

There are many large cities and/or conurbations around the world which are either on the coastline or alongside major estuaries. These will be increasingly susceptible to flooding if sea levels rise significantly as a result of climate change.

The economic losses associated with flooding can be obtained from several sources. Figure 2 shows one example of these losses for the period 1960 to 2014. It is clear that the economic losses have escalated in the last 30 years, partly due to the increased world population and partly due to the location of urban developments.

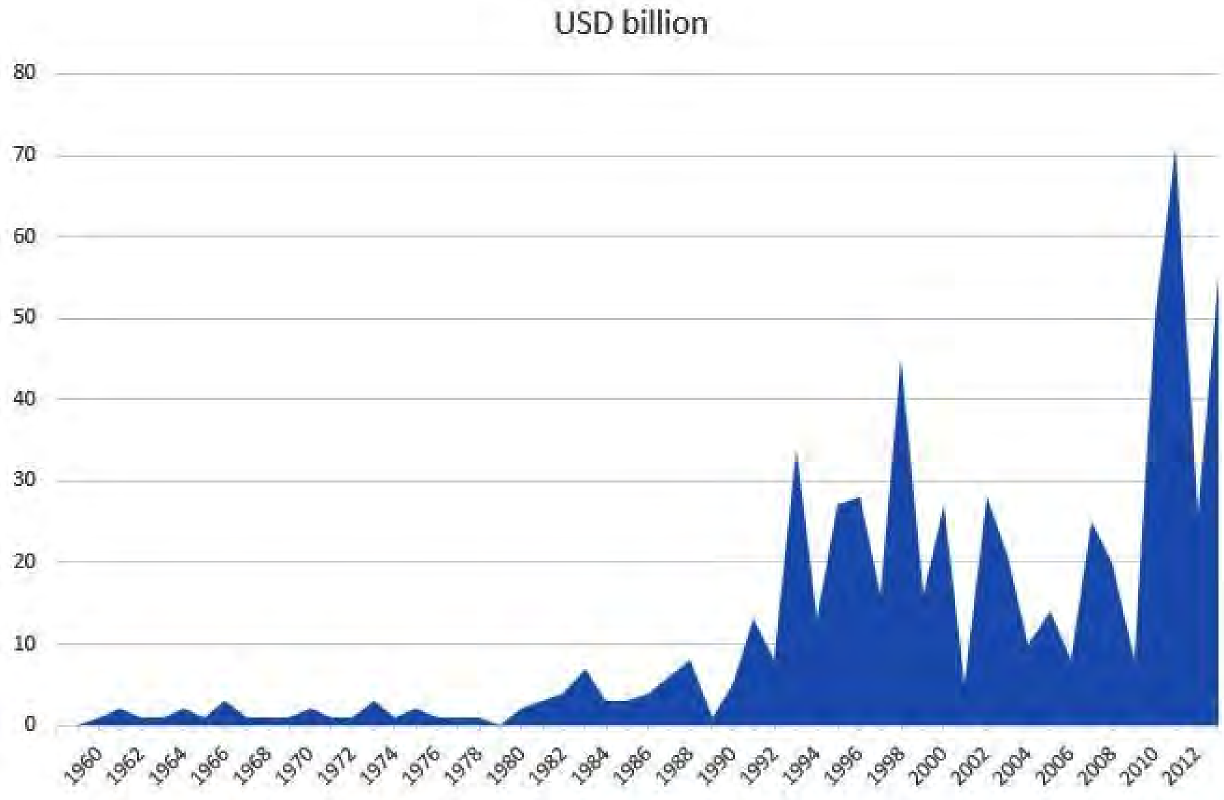


Figure 2 Worldwide economic losses due to flooding
Source: www.nature.com

In the UK the Government statistics published in 2016 suggest that 1 in 6 homes are at risk of flooding. This amounts to around five million properties. The types of flooding include:

- tidal flooding caused by the sea and tidal rivers
- pluvial flooding when the ground is saturated with water from rainfall which cannot run off
- fluvial flooding which occurs when rivers overflow or burst their banks

- groundwater flooding which results when water re-emerges from the underlying strata or from overloaded drainage systems.

One measure to evaluate the cost of flooding is to look at insurance claims following flood events. However, this represents only part of the overall cost. It excludes:

- uninsured properties and other valuables
- loss of earnings during and after flood events
- permanent loss of businesses
- the costs of reinstating national assets such as railways and roads
- the costs of delays caused by damage to the general infrastructure.

An example of insurance claims for the UK floods which occurred during December 2015 and into January 2016 was given by the Association of British Insurers as follows:

- flood damage claims - £1.3 billion,
- average value of a single claim - £50 000,
- temporary accommodation for 3 000 households - £24 million.

Around 40 per cent of businesses never re-opened after this event and the flood damage claims exceeded the annual claims for fire and theft combined.

The nomenclature surrounding different aspects of flooding have changed over the years. In the 1960s many major works were labelled “flood prevention” schemes. Today the more accurate “flood alleviation” scheme is normally employed. Additionally flood “resistance” and flood “resilience” are often used with different meanings.

For the purposes of this ROCK, the subject of flood mitigation is conveniently divided into two categories.

Flood resistance

Flood resistance measures may be permanent or temporary. The works are designed to deter flood water reaching and/or inundating the infrastructure which is at risk. In the case of properties at risk these may take the form of flood barriers or adaptations to the properties such as the sealing of air vents.

Flood resilience

Flood resilience measures tend to be permanent. They take the form of adaptations to the infrastructure which aid recovery following major flood events. In the case of properties at risk, an example of such adaptations would be to lift electrical sockets above the anticipated flood level.

5 Flood resistance

5.1 Temporary flood resistance measures

Free standing barriers

Free standing barriers may protect a wide area from flooding and are best deployed for:

- river overbank flooding where the depths are modest, say up to 1m
- road flooding due to inadequate drainage facilities.

It is important that temporary barriers are not placed on permeable ground to avoid seepage beneath them. These barriers take some time to construct and therefore require adequate warning of the impending flood event.

Plate 7 Temporary flood barrier, Fowey, Cornwall
Source: www.bbc.co.uk

Adaptations to properties

There are many ways in which individual properties may be adapted to provide flood resistance. They are effective where flood depths are not excessive and where the flooding is of relatively short duration. These adaptations may take the form, for example, of door guards and air brick covers. Occasionally flood skirts have been deployed to surround properties with an impermeable membrane.

Plate 8 Removable swing hinged door guard
Source: www.floodcontrolinternational.com

5.2 Permanent flood resistance measures

Permanent flood resistance measures come in all shapes and sizes. At the largest scale they may provide some protection to whole towns and cities and at the smallest scale they may protect individual structures such as houses, electrical sub-stations, etc.

Large scale measures

There are many examples of flood alleviation schemes which have been built to provide a degree of flood protection for towns and cities. Common types are as follows:

- schemes which involve the raising of river banks, thus providing a greater flow capacity before overtopping and inundation occurs
- schemes which provide an additional channel running parallel with the main river channel. The additional channel is usually designed to operate only during flood events
- schemes which provide storage for flood waters upstream of the area at risk. These flood waters are released later at a modest rate which avoids flooding downstream
- schemes in coastal areas which help to prevent overtopping by waves and tides.

Plates 9 and 10 show flooding in Exeter in 1960 and the subsequent flood alleviation scheme which involved a bypass channel through the critical area of the city.

Plate 9 Flooding in Exeter, Devon, 1960
Source: www.flickr.com

Plate 10 Exeter flood relief channel
Source: www.gov.uk

Most flood alleviation schemes require maintenance and/or upgrading after a number of years due to siltation in the enlarged waterways and additional infrastructure developments. The Exeter scheme is no exception and plans are currently in hand to upgrade the works.

The alternative approach of storing flood waters upstream of the area at risk was adopted for the recently completed Banbury flood alleviation in Oxfordshire.

Plate 11 shows flooding in Banbury in 2007.

Plate 11 Flooding in Banbury, Oxfordshire, 2007
Source: www.bbc.co.uk

The scheme for Banbury involves an area of mainly agricultural land contained within an embankment which stores water during flood events. The flood waters are released gradually through a controllable structure when it is safe to do so, see Plate 12.

Plate 12 Banbury flood water release structure
Source: www.bv.com

Schemes in estuaries which help to prevent the incursion of high tidal levels include the use of tidal barriers, either fixed or moveable. The Thames Barrier is a good example of the latter.

Small scale measures

There are many ways of providing a degree of permanent flood protection to individual properties or structures. There are listed by ***Bowker P, 2007*** as follows:

- garden or site landscaping to divert flood waters away from the property
- revised local drainage layouts
- low bunds around the site or property
- periphery walls/fencing
- flood resistant gates
- periscope air vents
- outside wall renders and facings, including veneer walling
- non-return valves on waste pipes and outlets
- resistant external doors.

For structures built in flood prone areas there are additional options such as raising threshold levels. Looking around the world this is an age-old method of avoiding flood inundation.

Plate 13 shows a structure at Angkor Wat, Cambodia. The floor level is raised well above anticipated flood levels.

Plate 13 Structure at Angkor Wat, Cambodia
Source: www.escape.com.au

Plate 14 shows the ex Thames Conservancy building in Wallingford, Oxfordshire. It was built in 1917 and the floor levels are above the highest Thames flood level on record which occurred in 1894.

Plate 14 Ex Thames Conservancy building, Wallingford, Oxfordshire, UK
Source: W R White

An unusual form of resistance is the "floating home". Plate 15 shows an example of this in the Netherlands.

Plate 15 Floating properties in Amsterdam, Netherlands
Source: www.dutchwatersector.com

6 Flood resilience

6.1 Resistance versus resilience

Flood resilience measures apply mainly to individual structures such as houses, factories, electrical sub-stations, etc. A balance is needed between incorporating measures needed to help prevent flood water entering the structure (resistance) and measures to facilitate rapid recovery following flood events (resilience).

Guidance given by the UK Government in 2003 suggested the use of flood resistance measures where flood depths did not exceed 900mm. See ***Department of Communications and Local Government, 2003***. However, in 2007 the Environment Agency suggested a more detailed approach based on the anticipated flood depths. See ***Environment Agency, 2007***.

The 2007 report recommended that resistance measures should only be used, at property level, to protect against flood depths of up to 600mm because research had shown that the structural integrity of a building may be compromised above this depth. Structural surveys of buildings should be carried out before resistance measures are used on the building fabric above this depth.

For flood depths above 600mm the report recommends allowing water to pass through the building to minimize structural damage. For flood depths between 300mm and 600mm the report recommends that attempts should be made to keep the water out, assuming the structural survey suggests it is safe to do so. For flood depths less than 300mm the report recommends making positive efforts to keep the water out of the building.

6.2 Flood resilience measures

Resilience measures are generally carried out with the aim of minimizing the damage caused by the flood waters entering the property. They can be applied to existing properties and to new builds. See ***Environment Agency, 2007***.

Internal doors

Wooden doors are prone to damage by flood waters. These may be fitted with hinges which allow the door to be removed prior to the flood event. Water resistant or acrylic doors may be fitted as an alternative. The cost / benefit ratio for these are relatively high.

Basements and internal walls

Basements and internal walls suffer damage, particularly where flood waters remain in the property for long periods. Water resistant membranes are available to protect walls but the work is of a specialist nature and tends to be expensive.

Floors

Concrete floors are reasonably resilient, particularly if they are covered with a waterproof membrane and finished with ceramic tiling. Suspended wooden floors can suffer serious damage and should be replaced with concrete where practicable.

Internal fixtures and fittings

There are usually many expensive items within properties which are best protected from flood waters, either by raising them above anticipated flood level or physically protecting them from the flood waters.

Electrical sockets and consumer units
Electrical sockets, TV points and telephone points are often at a low level in existing properties. Occasionally the consumer unit and/or fuse box is also at a low level. All these items should be raised above anticipated flood level.

Kitchens and domestic appliances
Damage to the kitchen and domestic appliances is probably the most costly aspect of flood waters within existing homes. Various proposals have been made to minimize this damage:

- ensure that other measures such as concrete floor, water resistance doors, etc are in place
- raise appliances on plinths (but there is clearly a limit in the height to which the appliances remain useable)
- install water resistance fixtures and fittings which can be readily cleaned once the flood waters recede.

Plate 16 shows an example of a flood resilient home. This is only an example and there are, and will be, many variations as new ideas are developed.

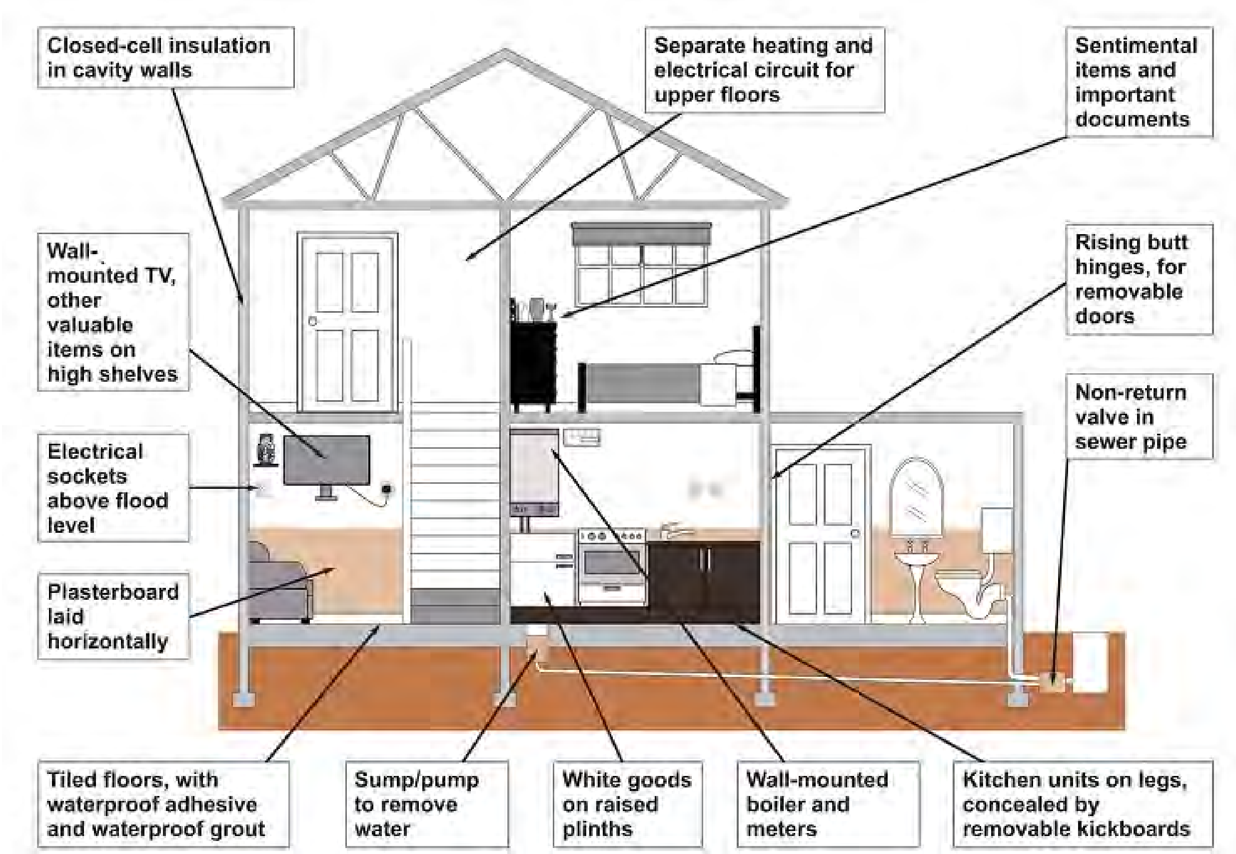


Plate 16 Typical flood resilience measures
Source: www.easysite.southlakeland.gov.uk

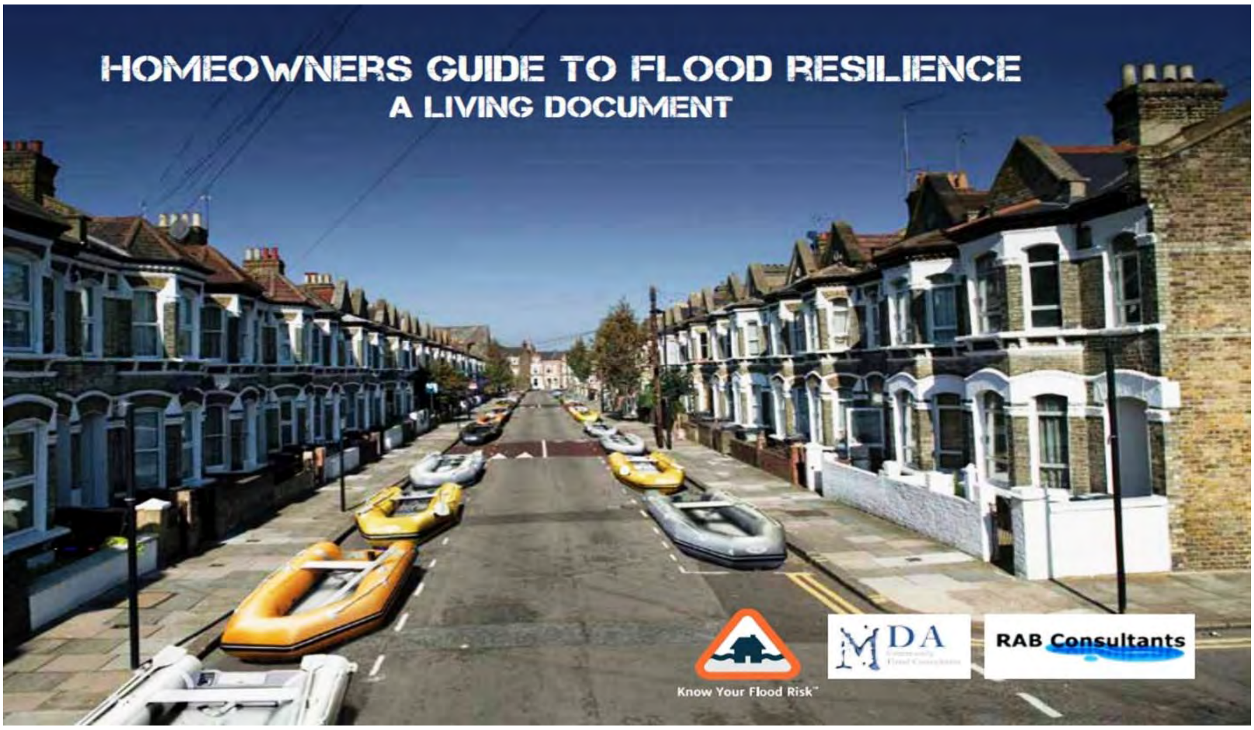
7 Guidance for property owners

There are numerous useful guide documents for homeowners who feel that their property may be subject to flooding and who wish to take steps to minimize the damage to their property during flood events.

In the UK it is possible to be notified of impending flood events by the Environment Agency. The service is free of charge. To obtain flood warnings property owners need to register at www.gov.uk/sign-up-for-flood-warnings.

A useful paper on European practice can be found in ***White I, Connelly A, Garvin S, Lawson N and O'Hare P, 2016***.

A comprehensive guide, which is regularly updated, has been produced by ***Dhonau M, Wilson D, McHugh A, Burton R and Rose C, 2014/15/16***. The guide was co-ordinated by the Know Your Flood Risk Campaign in association with RAB Consultants.



The guidance is endorsed by:

- the Association of British Insurers,
- the Department for Environment, Food and Rural Affairs (DEFRA),
- the Environment Agency,
- the Flood Protection Association,
- the Local Government Association,
- the National Flood Forum.

Particularly valuable are the following:

Advice on flooding
http://www.environment-agency.gov.uk/homeandleisure/floods/default.aspx

Guidance on flood resilience
http://www.knowyourfloodrisk.co.uk/pdf/protection-guide.pdf

Preparations before flooding occurs
http://nationalfloodforum.org.uk/wp-content/uploads/Ready-for-flooding.pdf

Insurance in high risk areas
http://www.biba.org.uk/UploadedFiles/600floodguide.pdf

Guidance on repair following floods
http://www.abi.org.uk/Publications/ABI_Publications_A_Guide_to_resistant_and_resilient_repair_after_a_flood_670.aspx

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