Assessment of the vulnerability of critical infrastructure buildings to floods

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Summary

Flooding in urban areas causes damage to peoples' homes and businesses and disrupts their lives. However, the effects of flooding can extend way beyond those directly affected by the water. This is the reason why Work Package examines the effects of flooding on critical infrastructures in urban areas and to explore ways to predict the consequences of flood events. Critical infrastructures include not only the physical networks of cables, pipes and roads, but also the organisational networks of health, security and emergency services. Buildings play an important role in protecting the equipment and personnel related to these networks (e.g. hospitals, fire stations, communications centres, power stations etc.). However, the variety of designs and constructions of these buildings make it unrealistic to categorise them into meaningful types when considering their vulnerability to flooding. In order to be able to predict the effects of flooding and costs of reinstatement of these buildings, an individual approach needs to be taken, taking into account the specific characteristics of each building.

The key risks used in flood damage estimation are first identified and those that are particularly relevant to the calculations required for devising a method of estimating flood damage to individual buildings are selected. These relate directly to the characteristics of the flood, namely flood depth, levels of pollution, velocity and debris and duration of flood; as well as the nature of the structure, construction and building materials used for the building. A collation of the effects of floods on buildings is carried out and a review of the effects on different parts of the building structure, construction and materials is summarised.

The state of the art of existing methods and tools for damage estimation was reviewed and summary is provided, with the conclusion that none of the existing methods is suitable for precise prediction of the damage of floods to individual buildings, taking into account all their individual characteristics. The necessary calculation factors that relate to the design of a new estimation tool aimed at individual buildings are described.

A review of standardized damage parameters/relationships used in flood repair practices in the UK is made. Although there are standard approaches for calculating the flood damage for residential and non-residential properties, based on a large dataset of building stock and experience from major flood events. However the available depth/damage curves are not applicable to critical infrastructure buildings.

The development of a prototype flood damage assessment tool related to individual buildings is described, taking into account the wide range of possible constructions and building materials, and estimations of the direct costs of flood damage to each, depending on the characteristics of the flood event. The calculations are based on percentage of new-build costs related to the extent of the damage to each construction, aggregated from the different effects of water ingress. Only the direct costs to the building fabric are considered. The workings of the tool are explained and the user interface illustrated.

The testing/verification of the prototype tool is described. Three case studies of different buildings subjected to flooding in 2007 are examined and the cost predictions of the tool are checked against the actual costs of repair and reinstatement. The predicted costs involved in two of the cases are closely aligned with the actual costs, though in the third case, the predictions were not

sufficiently accurate. Reasons for this were difficult to ascertain due to the sketchy nature of the case documentation.

The conclusions are that this prototype tool demonstrates a viable methodology for predicting the direct costs of damage to individual buildings according to their construction, but that more work needs to be done to extend the range of constructions covered, and more detailed real-case information is needed both to inform the calculations and test the outcomes of the tool.

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1. Introduction

This report summarises the actions and results of the work done in Work Package 2 Task 2.2 - *Assessment of the vulnerability of critical infrastructure buildings to floods.*

Flooding in urban areas causes damage to peoples' homes and businesses and disrupts their lives. However, the effects of flooding can extend way beyond those directly affected by the water. For example, as a result of the July 2007 rising level of the River Severn around Tewkesbury and Gloucester in the UK, 5,000 homes and businesses were flooded, but due to the inundation of the Mythe Waterworks at Tewkesbury, 135,000 homes (over half the homes in Gloucestershire) were without drinking water for up to 17 days, and the flooding of an electricity substation rendered 48,000 homes without electricity for two days. Had the water risen by another 10cm, it would have overwhelmed the hastily erected flood barriers around the Walham substation with the result that 500,000 people would have been deprived of electricity for much longer (Bali, 2010).

The aim of Work Package 2 was to develop risk and vulnerability methodologies directly related to urban critical infrastructures subjected to flooding, using an interdisciplinary, holistic approach at different levels of detail. One of the most important issues which needed to be addressed in Work Package 2 was the definition of "critical infrastructure". International existing definitions and standards were used to develop a common language within the entire project. Critical infrastructures include not only the physical networks of cables, pipes and roads, but also the organisational networks of health, security and emergency services. These methodologies will be useful for strategy development and implementation in the sectors of urban power, drainage, communications, healthcare, security, emergency services. The study included both the networks and nodes of these infrastructures and the interactions between them. Buildings play an important role in protecting the equipment and personnel related to the nodes of these networks (e.g. hospitals, fire stations, communications centres, power stations etc.).

In Task 2.1, the assessment included both direct damages and indirect consequences. Different infrastructures and components of the built environment can be assessed using comparatively coarse analysis methodologies so that the responsible authorities receive necessary support for decision making processes like land use planning, mapping of hazardous areas, flood prevention, flood forecasting, emergency preparedness and management.

Task 2.2 concentrated on critical infrastructure buildings (the nodes of the infrastructures). Critical infrastructure buildings are those whose continuing use is essential to the maintenance of services to the population for their security and safety and that need to remain operational during flood events. For example, a simple notional emergency infrastructure network diagram is shown in Figure 1 with the nodes representing built installations such as the central emergency centre, the various emergency services centres and the local stations. Diagrams showing networks of different kinds, often less tangible, such as food supply, healthcare, emergency refuges, etc. can be developed for each critical infrastructure type.

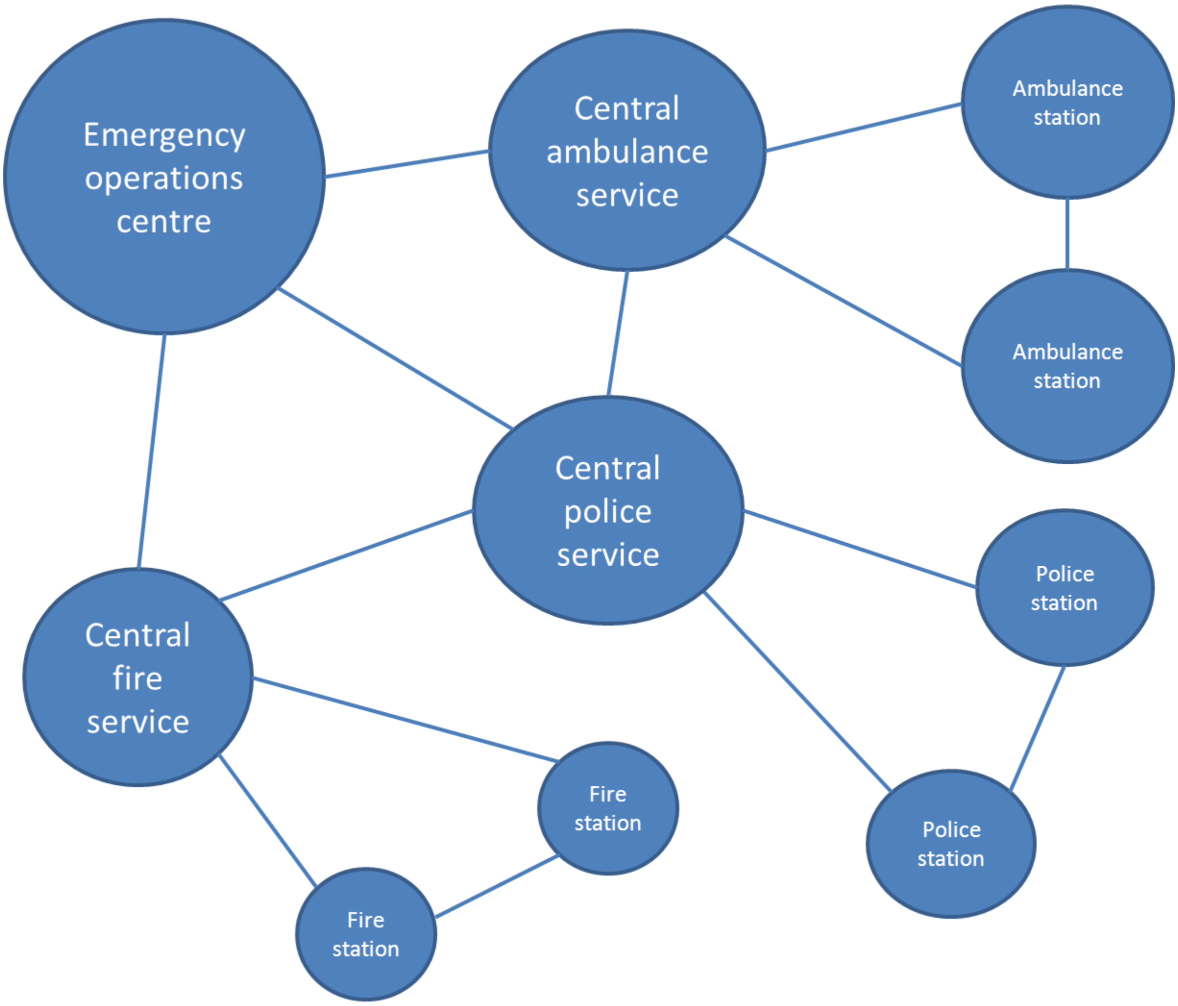


Figure 1 Simple notional emergency infrastructure network with nodes representing critical infrastructure buildings

There is no internationally recognised list of critical infrastructure building types, so the first step in this task was to identify these buildings by function and type of construction. Likely examples were hospitals, fire stations, water supply and treatment works, energy generating stations and communication network buildings. Deliverable 4.4 provides a list of those considered for inclusion in this research project. In Work Package 4, Task 4.2.1, the use of the term ‘hotspot buildings’ is used to describe these critical infrastructure buildings, this task being concentrated on methods of flood proofing.

With present construction and planning practices, which in the main do not include specific provision for flood resilience, most buildings will sustain some damage in the event of flooding but the degree of damage will depend on many factors, including:

- Source of flooding (e.g. pluvial, fluvial, groundwater)
- Severity (i.e. duration) and depth/velocity of flooding linked to debris content of floodwater
- The level and type of contaminants in floodwater
- Loads imposed by hydrostatic pressures resulting from building elements resisting the passage of water
- Dry out conditions
- Materials
- Construction techniques.

The predicted frequency of flooding is another parameter that is necessary to consider when defining vulnerability of buildings, at an individual level or at a community/neighbourhood level. It is important to understand that building vulnerability is associated not only with the external physical factors present during flood events (water depth, flood water quality, frequency of inundation) but also with the response of buildings to such loads (e.g. susceptibility to flood water entry, effect on construction material performance, time required for drying after a flood event and impact of different drying techniques on building fabric, time for re-occupation of properties).

At present there is no reliable way of anticipating and estimating post flood remedial works to buildings at an individual scale. This is problematic in that plans need to be developed in advance of flooding to ensure expeditious rehabilitation of buildings. The need for such plans is particularly relevant for critical infrastructure buildings. In the majority of cases, the production of a site-specific remediation plan only occurs following a major flood event.

Therefore, an assessment methodology that will identify the likely level of damage to buildings in the case of flooding was developed, the results being expressed as the predicted costs of remedial works. The assessment methodology distinguishes between buildings built using different constructions and materials and is relevant to critical and non-critical buildings. This damage prediction tool will facilitate:

- Forward planning of rehabilitation responses
- Identification of key risks in order that buildings can be retrofitted to improve their robustness against flooding
- Target investment for reducing future vulnerability
- Better land-use planning for new build and re-development of brownfield sites.

1.1. The sections of this report

The sections of this report are based on the various actions as outlined in the Research Implementation plan for Task 2.2 of Work Package 2.

Section 2 relates to Action 2, the identification of key risks used in flood damage estimation.

In order to estimate the damage to buildings caused by floods, it is necessary to examine the possible types of flood damage, that can have far reaching consequences, not only economic but also social and health related. As the range of damages is so large and many aspects are very difficult to estimate, it will be necessary to be selective in any method devised to estimate flood damage to buildings and limit the factors to those that can be realistically calculated.

Section 3 relates to Action 3, the collation of effects of floods on buildings. A review of the effects on different parts of the building structure and construction is summarised.

Section 4 relates to Action 1 – State of the art of existing methods and tools for damage estimation. A summary of a more comprehensive review (Appendix 1) is provided, with conclusions that relate to the design of a new estimation tool aimed at individual buildings.

Section 5 relates to Action 4 - Development of standardized damage parameters/ relationships. Flood repair practices in the UK are used as a basis for developing standardised approaches for use by the flood repair industry. A template for data collection has been developed to help improve the quality and quantity of the data collected by the industry on parameters such as humidity, its “hot-spots” in a flooded building and its evolution with time. This will assist in reducing the drying process and hence expedite re-occupation thereby minimising the social impact of floods.

Section 6 relates to Action 5 - Development of a prototype flood damage assessment tool related to individual buildings. The workings of the tool are explained and the user interface illustrated.

Section 7 relates to Action 6 – Testing/verification of the prototype tool. Three case studies of different buildings subjected to flooding in 2007 are examined and the cost predictions of the tool are checked against the actual costs of repair and reinstatement.

Section 8 provides conclusions to the study and Section 9 makes recommendations and analyses gaps in knowledge with suggestions for further research.

After the list of references, these sections are followed by several appendices that supplement the information given in the report.

1.2. Links to other Tasks and Themes

Task 2.2 of Work Package 2 is seen as a direct precursor to Task 4.3 of Work Package 4 - *State of the art, guidelines and a roadmap for wider implementation of flood resilience technologies in Europe.* The work that has gone into defining the type and amount of damage caused by floods to different building constructions and the development of the flood damage prediction tool will provide a better understanding of the possible and most effective ways to reduce the damage using flood resilient technologies. The results of application of various technologies to specific buildings can be tested by application of the damage prediction tool on a before/after basis. A cost/benefit assessment can then be made of the different technologies.

Task 2.2 is also integral to Task 2.1 - *Identification and analyses of most vulnerable infrastructure and indicator sets for R&V analysis in respect to floods*, which is concerned with the performance of infrastructure networks when subjected to flooding. The buildings considered in Task 2.2 are generally those at the nodes of the infrastructure networks.

Useful links can also be made with both Task 4.2.1 - Technologies for flood-proofing “hotspot” buildings (public, commercial or residential use) - and Task 4.2.2 - Technologies to integrate sheltering function to buildings - which are both part of Work Package 4 Task 4.2 Concepts and technologies for damage mitigation in the urban built environment. These are both concerned with flood proofing and resilience of buildings.

Collaboration with Work Package 5 is necessary for integrating newly developed knowledge as well as integrated pilot studies, for integration in flood risk management decision support models and systems and for future design guidance.

2. Identification of key risks in flood damage estimation

Key risks when related to buildings include:

- Floodwater ingress through underground services
- Floodwater ingress through the fabric of the building or through apertures such as doors
- Exceptional risks to buildings without foundations or with modern ‘light’ foundations based on short bore piles and similar where friction forces may be lost
- Deterioration of organic construction materials used at low level e.g. suspended timber ground floors and timber framed ground storey walls
- Disruption to buildings that are intolerant of movement (such as those with high levels of glazing)
- Loss of low level ground storey services in buildings subject to shallow flooding
- Corrosion of fixings and structural connections designed to function principally in dry internal environments
- Collateral damage to elements that would normally be flood resistant that might arise from the failure of ‘key risk’ items e.g. masonry elements stabilized by timber structures.

2.1. Types of flood damage

Figure 2 provides an overview of the different types of damage that can be incurred in the case of floods. As can be seen, flooding can have far reaching consequences, not only economic but also social and health related. As the range of damages is so large and many aspects will be very difficult to estimate, it will be necessary in this Task to be selective in any method devised to estimate flood damage to buildings and limit the factors to those that can be realistically calculated.

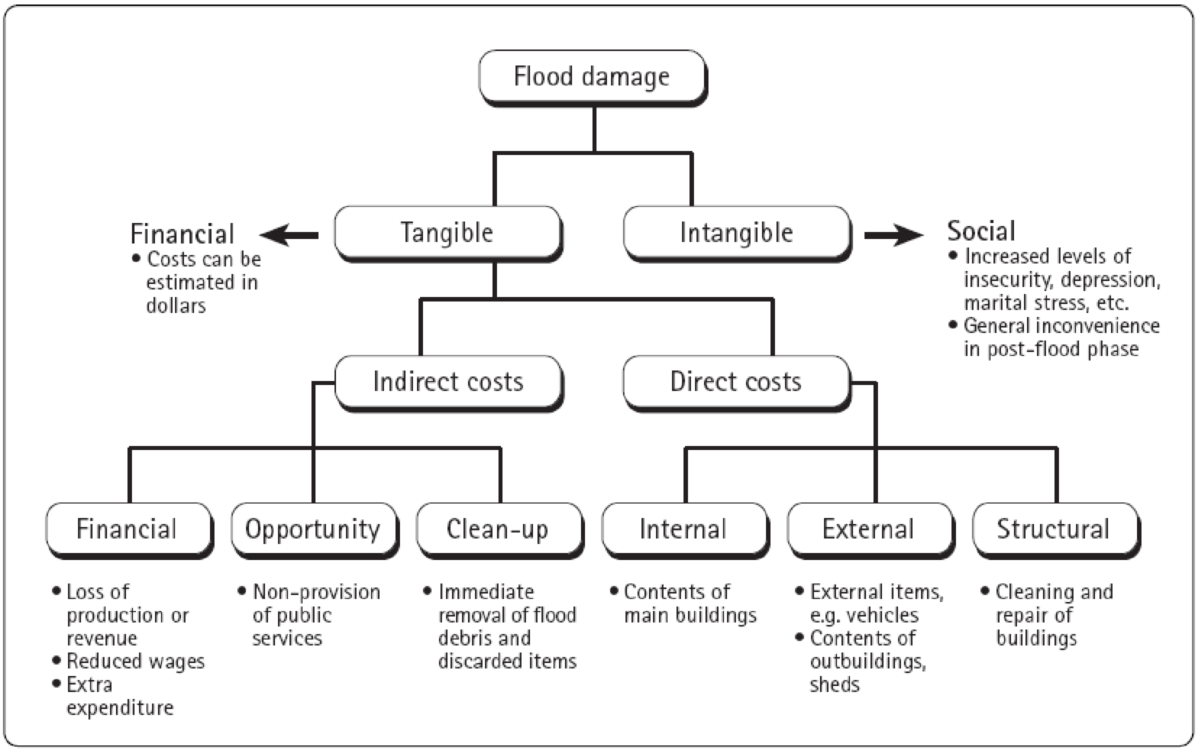


Figure 2 Types of flood damage – tangible/intangible damages.

(Source: Government of Queensland, 2002, p1)

For the sake of this study, the calculations have been limited to tangible direct costs; structural aspects concerned with the cleaning and repair of buildings expressed in financial terms. These direct costs are directly related to the physical fabric of the buildings and to the structure, construction and materials they employ. These are relatively easy to survey and record accurately at various levels of detail by building specialists such as architects and surveyors. The contents of the building and their value, vulnerability to flood damage is more likely to be known by the building occupant, and is not featured in the calculations. This is likely to be the case also for external items and contents of outbuildings. As indirect costs, the clean-up costs are also likely to be possible to estimate with reference to the likely effects on the building and its contents, though the amount of flood debris will depend very much on the type of flood and surrounding buildings, objects and vegetation. The other indirect costs can only be estimated by the building users according to the severity of the flood effects on the building and with reference to the services they provide and nature of business and employment. This should not form part of the damage estimation with regard to the buildings, but can use this estimate to help to calculate these indirect costs.

2.2. Flood event variables

Flood damage to buildings and contents are dependent on several variables in relation to the flood events. The variables, their descriptions and literature that refers to them were reviewed by Gissing and Blong, (2004, p215), and a summary of their findings is given below.

Over-floor depth, the higher the over-floor depth, the greater the depth damage to structure and contents - Nicholas *et al*. (2001); USACE (1996); Smith and Tobin (1979); Handmer (1986)

Velocity, the greater the velocity of floodwaters, the greater the probability of damage to structure and contents - Nicholas *et al*. (2001); USACE (1996); Smith and Tobin (1979); Handmer (1986)

Rate of rise, as the rate of rise increases, it becomes increasingly difficult to reduce flood damage - Smith and Tobin (1979); Handmer (1986)

Debris, the presence of debris in floodwater increases the potential for structural damage - Handmer (1986)

Contaminants, contaminant content includes the amount of sediment, sewage or pollutants present within floodwaters. The greater the amount of contaminants the greater the clean-up costs - (Nicholas *et al*. 2001). Sediment can damage mechanical equipment - Nicholas *et al*. (2001); USACE (1996); Smith and Tobin (1979); Handmer (1986)

Frequency of inundation, repeated flooding may have cumulative effects, increasing the probability of damage - USACE (1996)

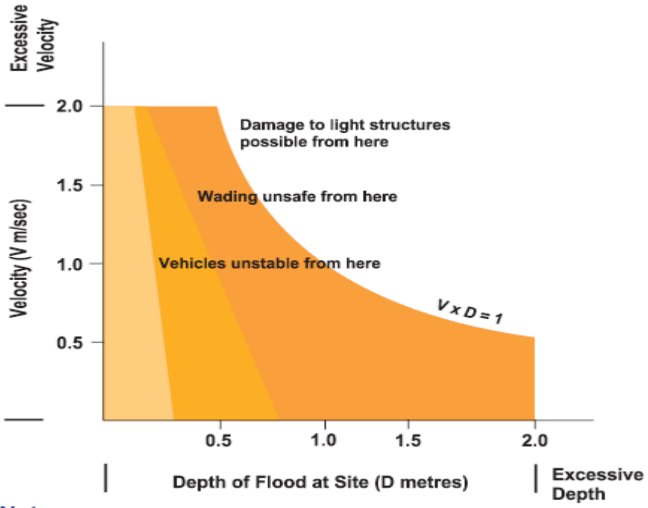
Duration of inundation, the longer the duration of inundation the greater the saturation of structure and contents, increasing the probability of damage - Nicholas *et al*. (2001); USACE (1996); Smith and Tobin (1979); Handmer (1986)

Timing, floods occurring at night may be associated with greater damage owing to ineffective warning dissemination. Floods occurring during holidays and when property owners are absent and unable to take damage-reduction measures - Smith and Greenaway (1984). Seasons are also important, with businesses vulnerable to higher or lower damage depending on seasonal trends - Yeo (1998); Smith & Greenaway 1984); Smith & Tobin (1979); Smith (1992).

Although depth is the most common variable used in the calculation of flood damage, the perceived relative importance of flood variables places this variable at equal 2nd, according to an assessment of flood damage over 10 years for domestic properties in a survey of 289 UK building surveyors (Soetanto and Proverbs, 2004, p100):

1. Sewage and faeces content
2. Contaminant content
3. Floodwater depth - equal 2nd
4. Duration
5. Source of floodwater
6. Velocity

The first three characteristics were regarded as being very important and the remaining three rated as important. However, the importance of velocity is likely to have been undervalued due to the experience of flood conditions in the UK, where high water velocity is relatively rare. A graph produced by the New South Wales government provides some indication of the effects of velocity in relation to depth, showing that a small increase in velocity can have a significant impact, particularly at greater depths (see Figure 3).



Notes

1. At velocities in excess of 2.0 m/s, the stability of foundations and poles can be affected by scour. Also, grass and earth surfaces begin to scour and can become rough and unstable
2. The velocity of floodwaters passing between buildings can produce a hazard, which may not be apparent if only the average velocity is considered. For instance, the velocity of floodwaters in a model test has risen from an average of 1 m/sec to 3 m/sec between houses.
3. Vehicle instability is initially by buoyancy.
4. At floodwater depths in excess of 2.0 meters and even at low velocities, there can be damage to light-framed buildings from water pressure, flotation and debris impact.

Derived from laboratory testing and flood conditions which caused damage.

Figure 3 Critical depth–velocity relationship

(source New South Wales, 2005, Floodplain management manual L3)

2.3. Variables related to the buildings

Variables relating to the building characteristics are also mentioned by Soetanto and Proverbs, such as the materials that the building is constructed from, the drying characteristics of the materials and the condition of the building prior to being flooded (Soetanto and Proverbs, 2004, p95). To this can be added the structural system used, the types of building construction (the way that different materials are combined together), the planning of the spaces within the building (basements, level of ground floor above ground etc.), the services and their positions within the building (electrical supply, air conditioning equipment, circuit boards, boilers etc.) as well as the contents and their locations.

A flood damage estimation tool that can deal with all these variables is likely to be very complex and difficult to manage, though oversimplification of the variables is likely to lead to inaccurate estimations. A balance must therefore be drawn between excessive complexity and accuracy, and ultimately usefulness.

3. Effects of floods on buildings

When looking at individual buildings in detail, there are numerous effects that flooding can have on the structure, primary and secondary elements, services and finishes. These are briefly summarised below based on information available in the literature (BRE, 1997; CIRIA, 2006; CLG, 2007).

3.1. Structural damage

Structural damage can occur when the building is subjected to fast flowing water, large waves, or heavy flotsam due to steep slopes and watercourses and proximity to large bodies of water. Tsunamis can create these effects far inland in flat areas. The result can undermine or expose the foundations, rip away or collapse walls and break windows and doors, leading to instability or even collapse of buildings. The shallow foundations of older buildings are particularly vulnerable.

Differential settlement of the ground due to the effect of flooding on granular fill, and ground heave due to expanding wet clay soils and subsequent drying shrinkage, can cause cracks in foundations, floors and walls.

The added depth of water in basements can result in fast inflows that cause doors and windows to fail and other structural damage, such as failure of the tanking or damp-proofing systems. Additional silt and other pollutants increase the cleaning tasks, and the small openable window areas can lead to poor ventilation for drying out.

3.2. Primary elements

3.2.1. Floors

Although concrete floors do not take up much water, they take a long time to dry if soaked. Therefore, if in a ground bearing concrete floor, the damp-proof membrane is below the screed as opposed to under the slab, drying times will be less. Any insulation or battens under timber floor finishes will be difficult to dry out at all. Poorly compacted hardcore or that containing gypsum or un-burnt colliery shale may expand and crack perimeter walls and displace the damp proof course.

Lightweight concrete and hollow clay infill blocks in concrete block-and-beam constructions may take up a lot of water when submerged and may not drain away easily, prolonging drying times and damage replacement coverings. Water beneath the floor can get trapped and lack of ventilation inhibits drying. High chloride content in floodwater can lead to corrosion of concrete reinforcement.

Timber floor joists can be dried out effectively if well ventilated, but mould can quickly grow in wet areas. Old softwood timber can be more susceptible to wetting due to previous history of rot or woodworm attack. When wetted, suspended timber floor insulation such as mineral wool will lose its insulating properties and must be replaced. Plastic foam insulation boards are generally water resistant, but semi rigid fibre batts may take several weeks to dry. Aluminium foil insulation may sag and hold water.

Chipboard flooring, particularly older varieties, will be weakened by water and may need replacement if no longer fit-for-purpose. It may sag where it supports partition walls, particularly if they are load-bearing walls, with significant structural consequences.

3.2.2. Walls

Although solid brick, concrete block and stone walls have no cavity, they often contain voids that will fill with water and delay drying. Depending on the porosity of the walling material and the thickness, solid walls take many months to dry out. While wet, rendering and other surface areas, particularly of the less dense materials, are susceptible to frost damage and sulphate expansion. Efflorescence may appear as drying takes place. Reinforced concrete walls are generally resistant to water, though sea water might increase the risk of corrosion of the reinforcement.

As with solid walls, the outer leaf of cavity walls will be susceptible to more damage if drying is slow or during the winter months. Drying shrinkage may cause cracking. The cavities of cavity walls may retain debris and silt which will lead to internal damp if the damp proof course or cavity is bridged. Wall ties may corrode if the galvanizing is faulty. The effect of water on cavity insulation depends on its absorbency and buoyancy. Slumping, displacement, compaction will all result in permanent loss of insulation values and extended drying times – some materials such as blown-in cavity fill may never dry, while others such as closed cell plastic foams will not take up water at all. Full cavity built-in semi-rigid batts should eventually drain out and dry within a few months.

The inner leaf of cavity walls may shrink as they dry out. Plaster finishes usually need replacing, but have been known to dry out successfully. However, all affected plasterboard will be irrevocably damaged and will need to be replaced. Corrosion of metal beads and conduit may occur.

Timber framed walls dry quickly if well ventilated, but the risk of decay is increased if the timber remains wet. No vapour control barriers should be fitted before the timber moisture content is below 20%. Plywood sheathing is normally unaffected if dried out soon, though soaking of insulating fibreboard sheathing results in permanent loss of structural strength and racking resistance. Foil backed plasterboard will generally suffer damage to the foil even if the plaster can be dried out.

Wall claddings, such as tiles, cement-bound boards, timber or plastics siding and metal sheeting, usually need little or no repair as a result of flooding.

3.2.3. Stairs

Concrete and steel stairs are not damaged by water, though the steelwork may begin to rust if not well protected. Stairs constructed of timber and timber based boards will shrink after swelling due to soaking. This will loosen the joints and make them unstable. Supporting chipboard flooring will no longer provide structural support if damaged by water.

3.3. Secondary elements

3.3.1. Partitions

Masonry partitions take several months to dry but will not be damaged by water. Plaster may dry out successfully and harden after being softened by water. Older plaster might suffer damage beyond repair, depending on its condition.

The timber or galvanised steel studs of lightweight partitions should not be damaged if dried out effectively, but plasterboard will need to be removed to drain the voids and enable drying out. If the flood is shallow and brief, plasterboard might also dry out successfully without serious damage. Cellular plasterboard partitions are very vulnerable to water, which weakens the paper honeycomb core and the panels lose integrity.

3.3.2. Doors

Timber swells when wet and shrinks as it dries. This can lead to distortion of solid timber frame and panel doors and doors when wet, but they can recover their form when dry. Hollow core doors are far more vulnerable, and tend to delaminate and distort. The cores of fire doors may absorb water and therefore dry out very slowly. Frames and doors made with timber-based materials will shrink when drying and may distort to make fitting difficult.

3.3.3. Windows and patio doors

The seals of double glazed units can be damaged by pressure of flooding and distortion of wooden frames. Silt and water retained in hollow aluminium and PVC frames can also lead to the breakdown of the edge seals of the units, making reglazing necessary. Timber frames can distort as they dry and paint may flake due to the swelling and shrinking of the wood.

3.3.4. Skirtings and architraves

Timber skirtings and door architraves may dry without distorting, and could be retained if they do not need to be removed to allow walls to dry. Plastic skirting that serves as electrical and communications cable ducting will have to be opened and cleaned, and the sockets checked.

3.3.5. Finishes

Wet carpet should be removed immediately from chipboard floors to reduce swelling and weakening of the chipboard, though this may need to be replaced. Low-permeability coatings, such as vinyl wallpaper, gloss paint and ceramic tiles, slow down drying of masonry partitions and may lead to rotting in timber stud partitions. Ceilings may be damaged by repair work on the walls.

3.4. Building services

3.4.1. Wiring, electrical services and appliances

Although insulated wiring is resistant to water, the connections, switches, socket outlets and equipment to which it is connected may be damaged. Retained water or conductive particles can cause short-circuiting even if damage is averted. Sockets, switches, junctions and appliances can develop dangerous faults which may be intermittent.

Gas meters are sometimes affected by flood water and water and silt may infiltrate pipework through pilot lights and burners on heaters and cookers, causing malfunction.

Boiler units and associated pumps and controls that have been immersed will need maintenance or replacing. Electric storage heaters will probably be unusable because of damage to the heating elements. Ducts for warm-air heating or ventilation will generally retain water that can cause corrosion. Fireplaces and chimneys will absorb water, which can cause staining of the wall finishes. Water in the structure can expand to steam when fireplace is brought back into use, damaging the structure.

Wiring for television and telephone installations can become faulty due to water entering the conduits. These problems may be intermittent and may not start immediately after a flood.

3.4.2. Water services

Water meters and pipework, including central heating pipework and radiators, will not normally be affected by flooding. However, there is danger of corrosion if the pipes are subjected to long periods of water containing salts, for example, if they are buried within concrete floors. Older type pipe insulation can be damaged by water, though modern plastic foam materials will not be adversely affected.

3.4.3. Drains and sewage

Mud and silt can build up in drainage systems during a flood. This may block waste and foul-water drains. After a flood, silt in the local drainage system may affect the drainage in a building until the local authority has cleared the whole network.

Drainage systems and treatment works are designed to restrict backflow of sewage; in addition, flood water tends to flow away from buildings and dilute any foul-water which may have escaped. Even so, precautions should be taken against any slight risk to health from contamination by sewage or effluent from local factories and farms.

3.5 Finishes

3.4.4. External surfaces

The amount of staining from silt and pollutants in the water will depend on the length of immersion and the porosity of the material. Permanent staining can result if the surfaces are not cleaned immediately. Metal and plastic finishes are easier to clean than masonry and timber as they are less porous. The joints and cavities must be carefully cleaned to remove silt and other materials that may cause blockage of air and water paths e.g. in rain-screen cladding. Debris deposited against the base of external walls and not removed may bridge the dpc, leading to persistent dampness.

3.4.5. Internal surfaces

Most finishes and furnishings will be permanently affected by pollutants in the water and will have to be removed and renewed. Waterproof tiling as designed for showers, floors etc. can usually be successfully cleaned and will not suffer damage. Other wall and floor finishes that are not designed to resist water will retain a lot of water and tend to loose adhesion and become distorted. Any finishes that are retained will have the effect of slowing the drying of the underlying construction, resulting in, for example, the distortion of timber floors and rotting of timber components, as well as the promotion of mould growth.

3.4.6. Cavities and voids

Water will enter any cavities and voids under the floor and within the walls, bringing with it silt and other pollutants. Investigations must be carried out to ascertain the effect of this on the adjacent materials and on the ability to drain and dry out. Persistent water and dampness will case long-term problems to the building and finishes, so measures will have to be taken to access and clear out these cavities and voids.

3.4.7. Kitchen and cloakroom fittings and equipment

Flooded chipboard kitchen storage units will distort and require replacement. Units with timber frames will suffer less damage, while stainless steel will simply require cleaning. Units will probably have to be removed to allow access for cleaning floors and walls and drying. Gas appliances are more resistant to wetting than electrical appliances, although the thermal insulation lining may deteriorate in both types. Sanitary ware is generally unaffected by flood damage when supported on rigid floors. Floors under shower trays and other confined areas should be exposed in order to clear mud and allow drying.

4. State of the art of flood damage estimation methods relevant to buildings

Much research has already been carried out on flood damage prediction methods for residential buildings, with less research on non-domestic buildings. A review of these methods was carried out in order to avoid repeating research and for building on the state of the art in this subject. The most relevant methods to this project are described briefly below, and their possible usefulness for individual non-domestic building flood damage estimation is assessed. A more detailed review can be found in Appendix 1 of this report.

4.1. ANUFLOOD methodology

This methodology is Australia's most commonly used commercial flood damage estimation model. It uses potential stage-damage curves based on actual data from flooding in Australia and UK. Stage damage curves are categorised into different building sizes, types and uses. The commercial properties in the database are classified by size and value class that reflects the vulnerability to flood damage of the business's contents. The damage is only based on over-floor flood depth. As the data is based on averages, they tend not to reflect the variability of individual buildings. In fact, damages can vary greatly in non-residential buildings, and analysts need to ascertain the size and type and content of each building. The damage to the individual properties often diverged considerably from the line of regression, hence the results tend to be inaccurate for individual buildings (Gissing and Blong, 2004).

4.2. USACE velocity-damage curves

Floodwater velocity is rarely taken into account in calculating damage curves. The USACE (U.S. Army Corps of Engineers) Portland District velocity-based building collapse curves are one of the few that do (USACE, 1985). These curves predict the collapse potential of buildings based on their types of construction, i.e. wood frame, masonry and concrete load bearing walls, steel frame, correlated with floodwater depth and floodwater velocity. The only output of the model is at what point the buildings are likely to collapse. There is no estimate of the range of partial damage to the building or costs of repair.

4.3. HAZUS-MH Flood Model – adaptation of earthquake model

HAZUS-MH (HAZards U.S. Multi-Hazard) is a United States nationally standardized methodology and risk assessment software program that comprises three models for estimating potential losses from natural disasters (i.e. earthquakes, hurricane winds and floods).The HAZUS Flood Model is used to characterise riverine and coastal flooding as a basis for damage and loss estimation in relation to buildings. This damage and loss capability includes a library of more than 900 damage curves for use in estimating damage to various types of buildings and infrastructure. The model uses estimates of flood depth along with depth/damage functions to calculate likely damage to buildings. The building occupancy type and ground floor elevation are required as inputs to make the calculation. The output is in the form of area-weighted estimates of damage as a percentage of replacement cost, at block or individual building scale (Scawthorn et al, 2006). However, the flood damage data and damage curves highest resolution is census block level so damage predictions are more reliable for large groups of buildings and unsuitable for use on individual buildings.

4.4. Stochastic methodology using Monte Carlo simulation

This stochastic methodology has been developed by Nadal et al (2010) that takes account of flooding hydrodynamics – waves, turbulent bores, debris impacts, time dependent local soil scour as well as depth of flooding. The building vulnerability is modelled using analytical representations of the failure mechanisms of individual building components. The flood actions of recent events have been assessed and compared to the resistance of each building component. Monte Carlo simulation was then used to expand available building data and perform load/resistance analysis and to account for the uncertainty of input parameters. The output estimates the average expected flood damage to individual buildings due to both floodwater depth and velocity on the basis of 10,000 hypothetical buildings. The outputs are expressed as three dimensional functions dependent on floodwater depth and floodwater velocity. The main feature of this methodology is the important distinction it makes between flood damages caused by hydrodynamic actions and floodwater depth. It shows that floodwater velocity can increase the damage to buildings by up to 100 – 190% depending on the type of event. Although the study concentrates on reinforced concrete frame domestic buildings with infill concrete-block walls (including doors and windows), it could be applied to other structures using the same methodology, but lacks the flexibility to cope with combinations of different construction types and materials in individual buildings.

4.5. Damage and loss prediction based on an engineering evaluation system of building construction types

A study by Schwarz and Maiwald (2005, 2008) at the Bauhaus University in Weimar uses an engineering evaluation system in order to predict damage and losses based on the vulnerability of building construction types. This takes into account the inundation level, flow velocity, duration and building type (Kreibich et al, 2009). The buildings are classified into six types by material used for the construction and the structural system. The study was based on data gathered after the flood in Saxony in 2002, which featured some very high water velocities. The dataset included about 1220 residential buildings, most of substantial size with multiple accommodation units. The buildings were categorised into type according to their main construction material: clay (referring to earth construction - cob, adobe or rammed earth), prefabricated (presumably referring to open timber panel construction), timber frame (meaning heavy timber frame, e.g. oak frame), and masonry (brick or stone construction) and reinforced concrete. A range of damage grades were compiled, from D1, the lowest, to D5 the greatest damage requiring complete rebuilding, based on physical, chemical, structural damage and resulting requirements for repair and replacement. The different building types were allocated to five flood vulnerability classes, with specification of the range of probable scatter into adjacent classes depending on factors such as building condition, quality of workmanship, types of building material etc. From this, damage curves were derived according to the depth of water. The developed tool is based exclusively on data from residential buildings and, owing to considerable variations in predicted possible extent of damage in individual buildings, is best suited for general damage prediction of different building construction types in urban areas. This can identify critical zones, and aid short and long term disaster management decisions. The predictions are however not sufficiently reliable for making precise damage predictions for individual buildings, particularly those featuring several different construction methods.

5. Development of standard damage and repair parameters

5.1. Considerations on flood damage models

In the previous section an overview of the state of the art of flood damage models was presented, including the conclusion that the existing models are not suited to the evaluation of critical buildings (this is further discussed in Section 6). However, there seems to be a general consensus on the parameters that influence flood damage – this has been elegantly summarised by Nicholas et al (2001), in their conceptual model for flood damage (for domestic properties). The model comprises two factors on which flood damage is dependent: the flood characteristics (floodwater depth, velocity, contaminant contents, flood duration) and the building characteristics (location, construction characteristics, nature of furnishings).

Flood damage assessment in the UK is normally based on the information contained in the 'Multi Coloured Manual' (FHRC, 2005). This provides standard approaches for calculating the flood damage for residential and non-residential properties, based on a large dataset of building stock and experience from major flood events. Although depth/damage curves are available, there are very few that can be considered to be applicable to critical infrastructure buildings, with the majority of the non-residential categories being of a commercial nature (shop or factory). A sample dataset was provided to FloodProBE by FHRC, taken from a detailed questionnaire on non-residential properties, and this is shown in Appendix 2. It had been hoped that this could be tested with the model, to compare its results against the national depth-damage data. However, the details on the building fabric and construction are not sufficient to enable this to be used directly in the model. Work is continuing to try to agree certain assumptions which would allow its use in the future. This illustrates one of the main findings of this research, namely that the availability of detailed information on building construction, which this project is trying to understand and improve, is lacking in most of the literature and difficult to obtain from building owners.

5.2. Costs of repair of flood damaged buildings

When determining the costs of repairing flood damaged buildings it is important to highlight that these costs are influenced by a multitude of factors, as discussed by Proverbs and Soetanto (2004); factors include technical considerations as well as commercial drivers such as cost or time of repair. Different repair strategies can be developed for the various individual building components (from the do-nothing case to the full replacement of a component) along with performance criteria on which to base decisions on the strategies to adopt. Proverbs and Soetanto suggest the following performance criteria: cost, quality, time and client satisfaction; and recommend that the various options for repair be assessed against these criteria. Responses on several flooding scenarios set by the authors to cover a range of construction elements affected by floods (e.g. "floodwater in contact with internal timber partition wall") were obtained from over 250 UK professionals working in the field of flood damage repair (mainly loss adjusters and surveyors but also consulting engineers, damage repair specialists, estate agents/housing associations and others). Based on these responses, benchmark repair strategies were developed for the reinstatement of flood damaged floors, walls, doors and windows, and utilities (see Table 1). This table shows that the benchmark strategies are quite variable, ranging between the clean-up and the replacement of the whole element. It is also apparent in the original tables that it is sufficient for the unit to have been in contact with floodwaters to require replacement or clean up regardless of the depth of floodwater.

It was also noted that the most popular strategies were not necessarily the best in terms of cost, quality, time and satisfaction nor did they coincide with the benchmark strategy. A high level of disparity was found in current practice in the UK (as of 2004) and costs were mentioned as a barrier to the selection of the most efficient method by some respondents. In 2012, this variability in the restoration techniques used by different UK restorers remains, in spite of the experiences and lessons learned from recent floods, such as summer 2007. One initiative, to address this variability, is the update of PAS 64 (BSI, 2005), an industry-sponsored code of practice. This provides guidance and good practice for the restoration of a water damaged building from the initial incident to the point at which re-instatement and re-decoration can commence.

Table 1 Repair strategies for flood exposed construction elements

(adapted from Proverbs and Soetanto, tables 9.1 and 9.2, 2004)

Flood damage scenario	**Benchmark repair strategy**
Floors	
Vinyl floor tiles submerged by flood water	Replacement of all floor tiles
Vinyl sheet floor covering submerged by flood water	Replacement of the floor covering
Quarry tiled floor submerged by flood water	Clean tiles in place
Solid concrete floor submerged by flood water	Clean floor and allow to dry
Suspended timber (chipboard) floor submerged by flood water	Replacement of chipboard and of warped and rotten timber components
Suspended timber (chipboard) floor with tongue and grooved floorboards submerged by flood water	Replacement of all timber components (joists, floorboards, skirting, etc.)
Flood damage scenario	**Benchmark repair strategy**

When the floorboards are removed it is discovered that the sleeper walls are constructed directly on the ground (i.e. no concrete slab has been included)	A dpc is installed onto the present sleeper walls
A concrete floor covered with solid oak blocks	Replace all floor covering (i.e. the oak blocks)
Walls	
External wall is brickwork with cement mortar joints	Clean wall
External wall has a rendered finish	Clean the render
External walls with pebbledash finish	Clean the finish
Internal wall is brickwork with paint finish applied directly to it	Clean and repaint the wall
Internal wall with plasterboard and ceramic tiles	Replace all plasterboard and tiles
Internal wall covered with a wood veneer on timber grounds	Replace the wood veneer
Internal wall decorated with wallpaper	Replace all wallpaper
External wall with evidence of a rising damp problem	Inject the wall with a dpc and replace plaster
After removal of plaster it is found that the wall was incorrectly constructed	Plaster the wall
Internal block wall with gypsum plaster finish	Replace all the wall's plaster
Internal block wall with a cement/sand mix undercoat and a 1mm plaster skim	Clean the plaster
Internal brick wall finished with lime/ox-hair mix and a lime putty finish	Replace all the wall's plaster
Internal timber partition wall	Replace all plasterboard
Internal metal framed partition wall	Replace metal components and plasterboard
Doors and windows	
Softwood front door	Replace door
Flood damage scenario	**Benchmark repair strategy**

Double glazed hardwood patio doors	Allow door to dry out and then assess damage before replacement of the glazing units if the seals have perished
Hollow cellular type infill wooden doors	Replace doors
PVC external door	Clean door
Wooden window frames	Allow windows to dry out and then assess damage before replacement the glazing units if the seals have perished
Utilities	
Steel panel radiators	Allow to dry, clean/sanitise and then repaint
Gas fired heater	Replace heater
Gas meter	Refer to gas supplier
Wall-hung gas fire	Replace the fire
Electrical circuit containing sockets and cables that have been partly submerged by floodwater	Replace the whole of the installation
Wall-hung electrical heater	Replace the heater
Timber skirting boards	Replace all skirting boards
Timber staircase	Replace only the timber components that have been in contact with floodwater
Built-in wall cupboards	Replace all cupboards
Fitted kitchen that has been partially submerged above plinths	Replace all the fitted kitchen

Another comprehensive source of guidance for flood affected properties is the CIRIA Report C623 (CIRIA, 2005). It is noted that achieving the appropriate standard of repair goes beyond simply improving the resilience or design of the building, but requires the setting up of a proper regime for decontamination and drying the building, as well as a thorough post flood survey and assessment of future flood risk (see also Garvin & Kelly, 2007). Three standards of repair level are proposed, depending on the estimation of future flood risk, as summarised in Table 2:

Table 2 Standard levels of repair

(adapted from CIRIA, 2005)

Standard repair level	Future flood risk	Examples of repair measures
Level A	Little or none (e.g. source of flood removed due to sewer repaired or flood defence constructed)	Keep to original specification with possible minor upgrades such as local repointing of mortar in masonry
Level B	Low to medium (typically if flood depth above floor level but flood duration up to 12 hours)	Repairs to increase resilience/resistance
Level C	High (typically if flood depth above floor level, flood duration over 12 hours and significant work was required to decontaminate and dry the building)	Repairs to increase resilience/resistance plus consideration of relocating services and rooms and use of temporary flood protection

For buildings supplying an essential service (critical infrastructure buildings or hotspot buildings) the guide recommends to increase its risk level to minimise potential future disruption of services. Repair measures are presented in detail for external walls, internal walls, floors and basements.

6. Principal Results: Development of a prototype damage prediction tool for individual buildings

Despite a plethora of data from various parts of the world, it is evident that there is no established damage prediction tool for individual non-domestic buildings that can account in any detail for their different types of construction. Unlike domestic buildings, non-domestic buildings often feature several different types of construction within the same premises. This makes categorisation of buildings simply according to construction types insufficient. It would therefore be a better approach to estimate damage at an elemental level – e.g. wall, floor, ceiling, services etc., rather than a whole building level. This would give a 'menu' that could be used to select the particular construction types used for the various elements of an individual building, and the particular building materials used, thus leading to far greater accuracy in the estimates of damage and consequent costs for repair or replacement.

Damage predictions rely on accurate measurements of the effects of flooding on buildings of different constructions either from past events or as estimates based on technical information and laboratory tests on the different building materials. Owing to the wide range of building types represented in non-domestic buildings, a great amount of detailed information will be required. This volume of data has the potential to make any calculations required to provide reliable estimates very complicated and user unfriendly unless a sophisticated system is devised to facilitate processing of the necessary inputs.

Most damage predictions at present only take into account flood depth (i.e. they are stage-depth predictions). This will not be sufficient in cases where high velocities and levels of pollution are anticipated. Therefore the tool should take into account these additional flood characteristics that cause different kinds of damage to buildings, such as velocity, duration, different types of pollution, e.g. oil, sewage, sediment, as well as debris. Therefore, the function of the proposed damage estimation tool is to predict the extent of damage to individual buildings depending on the severity of the flooding and the construction type of the building. The output of the tool should express the damage in cost form. This will enable calculations to be made in order to assess the cost/benefit analysis of installing flood mitigation measures to the building and/or its surroundings. A simple diagram of the principles of such a tool is presented in Figure 4.

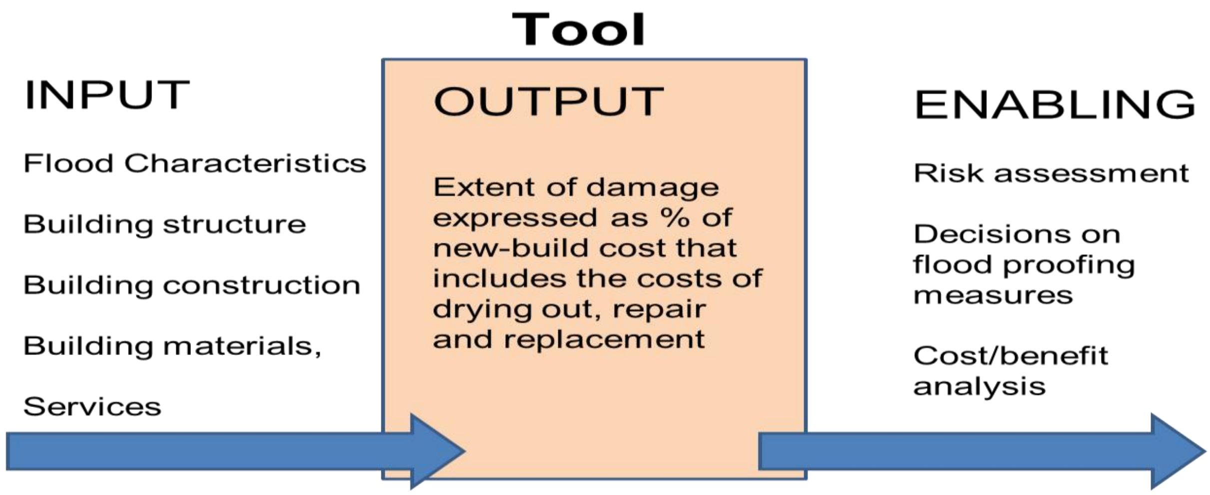


Figure 4 Building damage estimation tool principles

6.1. Status of the tool as presented in this research

It is important to stress that the aim of this research was to devise the principles and design a prototype of a flood damage prediction tool aimed at individual buildings and to test it in a limited way in order to gauge its effectiveness in principle.

It was not the intention to produce a fully developed and verified tool that could be used in general practice. Further resources will be needed in the future to extend what has been achieved in this research in order to produce a comprehensive and robust tool for general applicability. A much larger choice of construction types and materials will need to be provided, more evaluation of the behaviour of these when subjected to flooding will be required, more refined damage/repair/replacement costs developed, and a comprehensive regime of testing against more detailed information from previous flood events should be carried out before the tool can be released for general use.

The tool as presented in this research should be regarded as a demonstration of the methodology for calculation of flood damage costs based on flood characteristics, detailed constructional information and associated damage factors. It will provide a springboard for the development of a fully functional tool that can be used for buildings of all types throughout Europe.

6.2. End users

The tool will be designed for use by people with sufficient technical knowledge of the planning and construction of buildings in question, such as surveyors, architects and other building designers, quantity surveyors and property managers. The purpose of the tool will be to enable building professionals who have no specialist knowledge of the effects of flooding on buildings to predict the cost of flood damage to individual buildings depending on the nature of the flood event and the individual constructional characteristics of a particular building. This will enable them to foresee the likely consequences of flooding and to make a cost/benefit analysis of different measures that could be undertaken to protect the building from these consequences.

Various solutions using dry proofing and wet proofing techniques can be explored and run through the tool to gauge their cost effectiveness. Of course, decisions on protecting the building against floods will also be affected by the function and contents of the building – in some cases the fabric of the building and its protection might only be a relatively small economic consideration. The tool does not calculate the damage to contents and secondary costs associated with these.

The tool is designed to be used by building professionals throughout Europe. Although the cost data is based on UK prices in 2012, there are conversion factors built in to the tool to make adjustments for the different building costs in the EU countries. The prices and the conversion factors would have to be updated regularly to reflect changes in these over time.

6.3. Input data required

The basic data required to be input into the tool by the user are:

- The flood characteristics of the event that is predicted
- Floodwater depth
- Velocity and debris
- Contaminant content
- Flood duration
- Identification of the main structural system
- The building divided by elements (external walls, floors, internal partitions, windows and doors, electrics, mechanical services, communications etc.). Each element is analysed according to the materials used and the layering of them. To simplify the range of options, a list of typical constructions has been devised from which a choice can be made.
- Dimensions of walls, floors etc. and numbers of doors and windows that are affected by the selected flooding event.
- Types of services, their positions and layout and the extent of these that are affected by the selected flooding event

6.4. The basic data that are contained in the tool

The basic data that are contained in the tool are:

- A database of common elements of different constructions and materials

- A database of effects of flood damage to each construction and the % newbuild cost incurred by clearing up costs, repair/replacement of the affected area of the construction, assuming clean water
- An additional cost to add for mechanically assisted drying
- An additional percentage calculated to add for pollution of different types, i.e. hazardous and non-hazardous
- An additional percentage calculated to account for the effects of high velocity and debris
- An additional percentage calculated to account for the duration of the flood
- A database of effects of flood damage to each of the different services
- An adjustment factor calculated for regional differences (i.e. different countries).

6.5. Sources of data

An important issue when collating the above was where reliable data could be sourced. The expert knowledge of architects and quantity surveyors was used, together with information from the literature reviewed in Section 5 of this report.

The information about current materials and constructions used in buildings is easily available from technical publications and professional practical experience. The range of choice of different constructions and materials provided in this prototype tool was necessarily restricted but sufficient to cover some of the most common forms of building. The current new-build costs associated with these is readily available from databases used by quantity surveyors and building price books. This is also the case for demolition, removal and disposal of debris. For this research, a quantity surveyor (Member of the Royal Institution of Chartered Surveyors _ RICS) was employed to tabulate the new-build costs of each selected construction type and all its variations, and also to list the demolition and disposal costs. He also provided cost data obtained from industry sources relating to the cleaning and disposal of hazardous and non-hazardous pollution, as well as the costs of for mechanically assisted drying (see Appendix 3, 4 and 5).

Assessment of the percentage of the new-cost allocated to the repair/replacement of the constructions is made by a registered architect (ARB) considering the extent of the damage according to the data from sources described in 5.2, and the extent of demolition and removal/disposal of waste incurred. The estimation percentage allocated to pollution cleanup costs and disposal was made considering the ease of cleaning of the different types of material, and the complexity of the surfaces. The robustness of the constructions was the main factor is determining the effects of velocity and debris, and the absorption characteristics and permeability of the constructions were taken into account when estimating damage from duration of flood. These assessments were made using expert architectural knowledge of building constructions and materials, and the existing detailed data on materials performance relevant to flooding as described in 5.2.

The correction factors for relative costs in different countries in the EU were derived from regularly produced comparison lists used by quantity surveyors and building estimators when preparing international estimates of building costs (e.g. Gardiner & Theobald, 2011).

6.6. Structural collapse

Before calculating the damage to the building, it is worth checking that the building is not prone to collapse due to the flooding, as this will make the damage calculations superfluous. The likelihood of collapse can be determined either:

by calculation, (Nadal et al, 2010). Formulae available for different flood types (riverine, coastal – storm surges, tsunami) and debris impacts. Only applicable to concrete frames, concrete block walls, doors and windows, utilities and finishes. 3d damage curves, also indicating total damage

by depth/collapse curves (Davis 1985). This provides curves for wood, metal, masonry constructions for single and multi-storey buildings.

6.7. Tool calculations and output

The tool calculates the actual cost of flood damage to individual building elements according to their construction and materials, the types of services and the nature of the flooding. The example below shows a summary of the process for calculating the cost of flood damage to typical non-domestic building consisting of an office area constructed in load bearing brick/block construction and a steel framed production area clad in composite steel insulated cladding panels. Table 3 summarises the characteristics of the flood event, and Table 4 illustrates a typical spreadsheet calculation as produced by the flood damage prediction tool.

It should be noted that the way in which the flood depth is taken into account with regard to repairs of building elements depends to a large extent on the different approaches in each country and on different individual practices within a country. For this project the UK National Flood School provided helpful advice based on practices by most chartered surveyors in the UK (for domestic properties): it is common practice to remove all plaster/plasterboard up to about 1m regardless of the depth of flood if it is from 0.05m to 0.5m. The reason given by practitioners is to cope with capillary action; above this, they generally specify approx. 0.3m-0.5m above the flood depth. In practice this corresponds to the general guidelines:

if flood depth below 0.5m – strip to 1m and repair,

if above this depth, strip to full room height.

The above guidelines apply to domestic properties but, in the absence of specific guidance for infrastructure buildings, they were adopted in the tool, as can be seen in Table 3.

Table 3 Characteristics of flood event

Characteristic	Type of measurement	Units of measurement	Predicted flood event
Flood depth	In 0.3 metre increments Related to practical norms, repairs to walls are made up to 1.0m whenever the flood depth is less than that; for flood depths above 1.0m, the whole height of the wall is repaired. Repairs to windows for flood depth above 0.6m Repairs to lighting for flood depth above 2.2m	0.3m – 4.5m.	0.9m (1.0m)
Flood duration	2 levels of measurement	Up to 24 hours, more than 24hours	Up to 24 hours
Velocity and Debris content	Two levels of measurement	None, significant amount	None
Types of pollution	Two levels of measurement	Non-hazardous, hazardous	Hazardous

The initial output, based on the database contained within the tool, predicts the cost of cleaning, repair or replacement and is expressed as a percentage of the new-build cost of each element. The percentage can be greater than 100%, reflecting the costs of demolition and disposal of materials, as well as cleaning costs prior to rebuilding. Additional percentages are added for pollution clean-up and sterilization and mechanically assisted drying. An adjustment for regional factors (country etc.) can then be made. An approximate indication of the actual cost of returning the building to use, depending on where it is and when the flooding occurs, can then be produced by the tool when it is combined with calculations using the areas, lengths or numbers of affected elements, the current or predicted rates of construction prices.

This tool can be used to compare the implications of flooding for different types of building construction, and to assess the value/cost of installing flood protection installations to the building to reduce the damage from future flooding.

Table 4 Typical flood damage prediction tool calculations

1	2	3	4	5	6	7	8	9	10
Element construction	Damage repair/Re-placement and drying as % of new-build cost	Flood duration (up to 24 hrs)	Flood Velocity (none)	Addition for hazardous pollution clean-up	Total % new-build cost – sum columns2-5	Square metre, length or number affected	Current new-build cost in € (per m2 or m or number)	Regional adjustment - Spain 95% (minus 5%)	Actual total cost of re-instatement in € (column 6x7x9)
External brick/block cavity wall with rigid foam insulation	35	0	0	5	41	70	90	85.5	2457
Internal stud and plasterboard partitions	140	0	0	0	140	40	90	133	5040
Aluminium windows	50	0	0	0	55	10	385	52.5	1890
Timber /glass external doors	130	0	0	0	130	4	660	123.5	3260
Timber internal doors	130	0	0	0	130	8	174	123.5	1725
Raised steel/plywood flooring (office)	150	0	0	0	150	375	78	142.5	4168
Concrete floor, vinyl finish (office)	10	0	0	5	16	375	45	15	2531
Concrete stair	10	0	0	5	16	12	600	15	756
Steel structure	0	0	0	2	2	16	390	2	125
Composite steel cladding	2	0	0	3	6	198	190	6	2257
Steel cargo doors	5	0	0	5	11	2	540	10.5	114

Steel personnel doors	5	0	0	5	11	1	150	10.5	16
Concrete floor, resilient finish (production)	1	0	0	2	4	2275	18	4	846
Water supply	12	0	0	3	15	45	9	14	56
Electric supply office	120	0	0	0	120	375	30	114	12825
Electrical supply prod.	120	0	0	0	120	2275	7	114	18154
Telecommunications	120	0	0	0	120	375	10	114	900
Sanitary fittings	20	0	0	5	25	6	318	24	458
Heating installation	50	0	0	5	55	1	4380	52.5	2299
Air conditioning	70	0	0	5	76	0	222	72	0
Built-in furnishings	150	0	0	0	150	6	144	142.5	1296
								Total	**61,163**

6.8. Relevance to Practice

The aim was to produce a simple-to-use system that would encompass the elements of individual buildings likely to be affected by flood water, namely the basement and foundations, the external walls, the ground floor, the internal partitions including the internal doors and joinery, the external doors and windows, as well as the associated services such as electrics, plumbing and ventilation. The tool is aimed at building professionals with sufficient technical knowledge of the planning, construction and costing of buildings in question, such as architects, surveyors, facilities managers, quantity surveyors, and are comfortable with interpreting drawings and calculating areas of walls, floors etc. The output of the tool expresses the damage in cost form. This will enable calculations to be made in order to assess the cost/benefit analysis of installing flood mitigation measures to the building and/or its surroundings. The issue of suitable building based flood mitigation methods is dealt with in WP 4 task 4.3.

6.9. User interface

The tool has one page for inputting the required information, which is repeated for each building element and each type of construction. The selections are made from drop-down menus for all of the variables that are needed in order to complete the calculations of cost. A list is compiled that displays all the calculations and the final total cost, taking into account all the information that has been entered in the boxes, similar to the Tables 1-4 above. A screenshot of the inputting page is displayed below, with the information for one construction element (in this case internal partitions) added in. It is the intention to make the prototype tool available on the project web site at the end of the project.

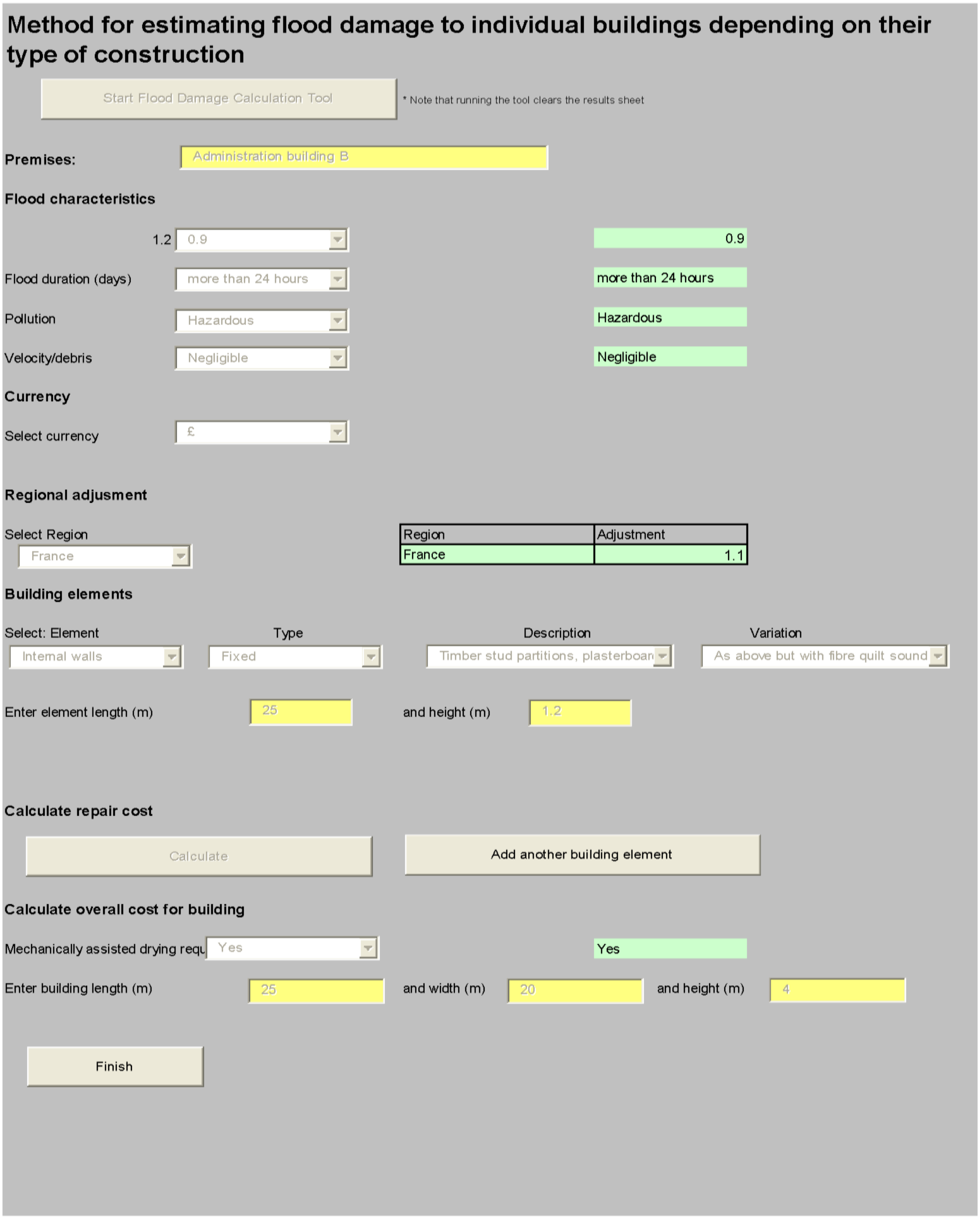


Figure 5 Input page of the tool

7. Verification of the prototype tool: checking the tool outputs with existing flood damage data

It is evident that much detailed data on the effects of flooding on different building materials depending on their use in different constructions will be required to make this model accurate in its predictions. The aim of this research project is to devise the calculations required by the tool to make predictions from input and stored data, using available technical data, and then to test the outcomes against real building flood damage records from past flood events. The testing will be carried out throughout the rest of the FloodProBE duration, as new data become available.

The data contained in detailed records of these damages are being compiled from several sources. Permission has been gained to explore the flood records of the leading international insurance company AXA Insurance, from which six case studies have been selected. Links have also been established with relevant organisations and building owners who coped with the flooding in the Humber Estuary in the UK, including Yorkshire Water. However, it is worth recording that significant effort was used in trying to collect a wider body of data for different infrastructure buildings. This proved to be difficult, partly reflecting the sensitivity of infrastructure owners to release such data. Also, because the tool requires detailed information on the building construction, as well as on the flood characteristics, this was not often available (as in the data from FHRC, see section 5). The verification of the tool has therefore been more limited than planned.

The HOWAS 21 database (Bavarian Water Management Agency) is also being used to provide an overview of extent of damage to buildings (Online data base for flood damage – HOWAS 21). This contains flood damage information of almost 6,000 buildings in numerous floods since 1978 in Germany. The database was compiled according to damage values estimated by damage surveyors of insurance companies who completed a standard questionnaire form on the importance of a great number of criteria. As a result, a list of 20-30 core criteria was identified for each sector, including buildings, businesses, infrastructure, agriculture and others. The data is divided into sub-sets by building functions, and is used to develop depth-damage curves. The database concept contains object-specific flood damage and damage determining factors using four core criteria: event information (type of flood, date, water level etc.); object information (building type, building materials etc.); damage information (repair and replacement costs for buildings and contents etc.); information about loss reduction (flood mitigation measures, advance warning time etc.) (Elmer et al, 2007). However, the information is not detailed enough to gauge damage to individual constructions.

7.1. Case studies

Three case studies were carried out at this stage in order to gauge the accuracy of the predictions made by the tool. These were selected from the data supplied by AXA insurance on three premises that were flooded in 2007 in the Sheffield area. Unfortunately the data available was not sufficiently detailed to provide a full specification of the works undertaken and the quantities involved, so some assumptions had to be made. The three case studies supplied by AXA insurance considered here are described below.

7.2. Case study 1, Retail outlet with warehouse

7.2.1. Construction

This is a ‘U’ shaped configuration of buildings and the adjacent yard area which adjoin Brightside Lane in Sheffield, South Yorkshire. There is a two storeyed, former dwelling house which has been converted to provide a wine cellar in the lower storey with office accommodation above. This building is of brick construction, with a pitched, tile clad roof, suspended timber intermediate floor and a concrete ground floor. To the rear of this building and bordering the site boundary, there is a single storeyed, brick constructed building with a pitched, tiled roof which accommodates the retail and wholesale trade counter, entrance lobby and offices, whilst along the perimeter at the rear of the site, there is a steel portal framed warehouse, part metal part timber frame-metal profile cladding over concrete block walls with roof cladding with plastic foam insulation boards linings and having a part mezzanine floor, which provides the main storage accommodation on the site. This building backs immediately on to the embankment of the River Don.

Total floor area approx. 700 sq. metres.

The following photographs below show individual buildings.

Figure 6 Case study 1, retail outlet with warehouse

7.2.2. The event

During the afternoon of Monday 25 June 2007, staff alerted the directors to water coming into the warehouse from the rear and, for a period, they endeavoured to lift boxes of wine which were on pallets in the warehouse on to racking but, such was the speed with which the water level arose that they had to evacuate the premises and leave the area, as did those occupiers of surrounding premises.

Following over 24 hours of continuous rainfall, which culminated in some 35mm of rainfall on 25 June 2007, water levels in the River Don rose remorselessly until this overtopped its banks and, when sections of wall along the river bank collapsed, water spread over a wide area adjacent to the river, from quite close to the city centre, right out to and beyond the Meadowhall Centre and this inundated numerous commercial and industrial sites.

Water from the river submerged all the yard area at the risk address, the carriageway outside and it accumulated to a depth of over half a metre in all the buildings on the site. Whereas the water level subsided overnight, considerable damage was occasioned throughout the premises and necessitated extensive remedial works being carried out.

7.2.3. Building reinstatement works

The premises was required to be sanitised and dried out, which involved stripping out areas of plasterwork, flooring, floor screeds and joinery work, together with some internal partitions. These elements were then required to be made good, along with the electrical installation, heating, the shop counter, sanitary equipment and decorative finishes. All of the equipment and fixtures and fittings throughout the ground floor areas were affected..

The following photographs show conditions in the shop, office and warehouse areas.

Figure 7 Case study 1, effects of flooding

7.2.4. Costs of reinstatement

The entire warehouse floor needed to be replaced, and all the floors and affected areas of walls, doors and services in the shop and office needed to be repaired and replaced as necessary. The remaining surfaces of walls and floors throughout needed enhanced cleaning and further expenditure arising here, which, including other sundry related costs aggregated £22, 286.82 served to increase the overall cost of the building work undertaken to £82,741.70. These costs do not include replacement of furnishings and fittings

The model was run with the data from the size and construction characteristics of this building and the nature of the flood event. The calculations and results are summarised in Table 5:

Table 5 Model reinstatement cost prediction for Case Study 1

Characteristic	Type of measurement	Units of measurement	Predicted flood event
Flood depth	In 0.3 metre increments	0.3m – 4.5m	0.9m
Flood duration	2 levels of measurement	Up to 24 hours, more than 24hours	Up to 24 hours
Velocity and Debris content	2 levels of measurement	None, significant amount	None
Types of pollution	2 levels of measurement	Non-hazardous, hazardous	Hazardous

Element construction	Damage repair/Re-placement and drying as % of new-build cost	Duration More than 24 hours	High velocity and debris	Addition for hazardous pollution clean-up	Total % new-build cost	Regional adjust-ment	Square metre, length or number affected	Current new-build cost in £ (per m2 or m or number)	Actual total cost of re-instatement in £
External brick/block cavity wall with mineral quilt insulation, internal plaster	25			45	70		66	120	5544
External solid brick/block walls (warehouse)	62			154	216		75	35	5670
Steel profiled cladding	52			55	107		76	97	7784.25
Internal stud and plasterboard partitions	89			15	104		30	45	1404

Timber external doors	103			6	109		4	440	1918.4
Timber internal doors	103			6	109		8	220	2877.6
Concrete floor, screed	4			63	67		400	84.5	22646
Concrete floor, vinyl finish (office)	4			63	67		200	84.5	11323
Steel cargo doors	4			22	26		2	2500	1300
H % C water supply	5			8	13		200	12.2	317.2
Electric supply office/shop	125			8	133		200	32.28	8586.48
Electrical supply warehouse	120			8	128		400	47.75	14976
Heating installation	21			32	54		204	48	2578.5
								Total	**86,925.43**

The predicted figure of £86,925.43 compares favourably with the actual cost of £82,741.70, which is measured at a level of 95% accuracy.

7.3. Case study 2, 4 storey office building

7.3.1. Construction

The structure is 4 storeys steel framed with cladding walls of brick and block with parts glazed units in metal frames. Floors are concrete over a metal deck with metal enclosed chipboard raised floors over. There are concrete stairs and an enclosed lift with metal doors. The pitched roof is part concrete with built up metal profile sheeting on a steel frame.

Total floor area is approximately 3716 sq. metres over 4 floors, which represents 930 m2 per floor.

Figure 8 Case study 2, 4 storey office building

7.3.2. The event

The loss concerns inundation by floodwater of four storey office block leased to a firm of solicitors. In the course of the incident the ground floor of the premises was inundated to a depth of 400mm as a consequence of the incident on Monday 25 June 2007. As a result, damage was occasioned to the entire ground floor fitting out including raised access floors, partitions, dry-linings to external walls, floor and wall finishes and services located within the floor void. In addition damage occurred to the reception and toilet areas. Externally, some damage occurred to curtain walling units

7.3.3. Building reinstatement works

The raised access floors were replaced, dry linings stripped out and replaced, as were the floor and wall finishes. The electrical and communication services located in the access floor also needed replacement. The reception area finishes, including fittings were damaged beyond repair and were removed and newly fitted out. The damage to the curtain walling was repaired.

7.3.4. Costs of reinstatement

The Insured incurred legal fees from solicitors in respect of drawing up the JCT form of contract totalling £6,654.72

In the event fees from the cladding consultant, cavity wall investigation, asbestos survey, project management, CDM and cost consultancy, structural engineers, mechanical and electrical consultants, architects and environmental consultants were agreed for inclusion in the building claim totalling **£72,726.97** as follows:-

Significant costs were incurred of in respect of the decontamination, clearance and drying out works in respect of the premises totalling **£46,125.84**

The tenants incurred costs of £**11,332.25** in respect of the initial strip out and enabling works relating to buildings. In addition a number of fees were incurred in respect of the project management and quantity surveying duties on the initial works amounting to a figure of **£53,366**.

Of the overall amount submitted there was a sum of **£69,066.42** in respect of expenditure incurred in respect of initial works for which the landlord was responsible, such a clearance, decontamination, enabling works, and professional fees.

The building reinstatement costs therefore totalled **£528,140.59** summarised as follows:

Building reinstatement costs £386,347.20

Professional fees £72,726.97

Tenant direct costs £69,066.42

The model was run with the data from the size and construction characteristics of this building and the nature of the flood event. The calculations and results are summarised in Table 6:

Table 6 Model reinstatement cost prediction for case study 2

Characteristic	Type of measurement	Units of measurement	Predicted flood event
Flood depth	In 0.3 metre increments	0.3m – 4.5m	0.6m
Flood duration	2 levels of measurement	Up to 24 hours, more than 24hours	Over 24 hours
Velocity and Debris content	2 levels of measurement	None, significant amount	None
Types of pollution	2 levels of measurement	Non-hazardous, hazardous	Hazardous

Element construction	Damage repair/Re-placement and drying as % of new-build cost	Duration More than 24 hours	High velocity and debris	Non-Hazardous pollution	Total % new-build cost	Regional adjust-ment	Square metre, length or number affected	Current new-build cost in £ (per m2 or m or number)	Actual total cost of re-instatement in £
External brick/block cavity wall, rigid foam insulation, dry lining	25	5		33	63	0	86	161	8669
Curtain wall	22			12	34		18	450	2754
Windows	25			6	31		34	400	4080
Internal stud and plasterboard partitions	90			15	105		108	65	7371

Metal/glass external doors	22			15	37		4	440	651
Timber internal doors	103	10		6	119		30	220	7854
Raised floor	62			15	82		930	80	61008
Concrete floor, vinyl finish, staircase	118			230	348		98	25	2175
Carpeting	118			216	334		930	25	77655
Water supply h & c	5			20	25		930	12	2790
Electric supply	125			8	133		930	33	40817
Telecommunications	120			8	128		930	5	5952
Heating installation	21	5		6	32		930	48	14284
Lift							2	2000	4000
Drainage	2	2		10	14		930	20	2604
Sanitary facilities	10			25	35		20	120	840
Built-in furnishings							1	3000	3000
								Total	**246,504**

The predicted figure of £246,504 compares unfavourably with the actual cost of £386,347 for the building reinstatement, which ignores the sums for professional fees and tenant direct costs, which bring up the total to £528,505. Taking solely the building reinstatement cost, the prediction presents an unacceptable accuracy of only 63%. When gauged against the complete reported cost, then the percentage is only 46%. Further investigation will be needed to find out the sources of these discrepancies. However, due to insufficiently detailed damage cost data on individual constructions and materials, this has proved difficult to carry out, so the reasons remain unexplained at this point.

7.4. Case study 3, Engineering workshop and offices

River Don River Flooding incident 25 June 2007. There are two similar buildings, the main premises and the tenanted building. Main premises measures 550 sq. metres - tenanted building 230 sq. metres.

7.4.1. Construction

A single storey, steel portal frame workshop building with brick elevation dado walls and profiled metal built-up cladding together with the two single stored extensions to that building which have brick elevation walls and a flat timber and felt clad roof and which serve as offices and mess room. In addition there is a steel portal framed and similarly constructed warehouse building which also has a brick built attached office unit with a flat felt roof and which is separately let to tenants. There are concrete floors throughout.

The premises are highlighted in the photographs below

Figure 9 Case study 3, engineering workshop and offices

7.4.2. The event

Some distance from the site is the River Don which flows through the Hillsborough area towards the City Centre and then out to Brightside and Meadowhall towards Rotherham and Doncaster. At around 3:00pm on Monday 25 June 2007, staff became aware of water accumulating in the yard area at the works and that this was beginning to enter the buildings. They endeavoured to restrict the water penetration but the level rose rapidly and by 3:45pm, water was around 600mm deep, when the decision was taken to vacate the premises, so that staff could safely return home.

Following over 24 hours of continuous rainfall which culminated in some 35mm of rainfall falling on 25 June 2007, water levels in the River Don rose remorselessly until this overtopped its banks in several areas both upstream and downstream of Sheffield City Centre. A significant breach occurred in the Hillsborough area and many industrial premises in the vicinity of the Insured's works and the nearby Hillsborough football ground were inundated.

Whereas the water level dropped considerably overnight and only around 2 inches of water remained when staff were able to again access the premises the following day, considerable damage was occasioned throughout the premises and major refurbishment / reinstatement work was rendered necessary.

Conditions after the flooding are shown below.

Figure 10 Case study 3, effects of flooding

7.4.3. Building reinstatement works

There was standing water in the building for many hours and when this receded, a considerable deposit of silt remained. All affected wall and floor etc. surfaces needed to be cleaned down, sanitised and dried out whilst wall plaster which was wetted had to be hacked off and renewed. Plywood faced doors which were saturated required to be renewed, along with frames, architraves, etc. and kitchen units in the mess room needed to be replaced. Vinyl floor tiles in the office area lifted, electric storage heaters were immersed and the electrical and lighting installations required testing and making good as necessary. Redecoration was required on completion of the structural work.

Similar damage was occasioned to the building tenanted by others and again doors and door frames, wall plaster, electrics and the like were required to be made good whilst cleaning, sanitising, drying and decorating throughout were rendered necessary.

7.4.4. Costs of reinstatement

The Building's claim at £90,070 related to the main unit occupied by the owner and the building in separate tenure. The total amount included £62,240 for the Insured's own unit. The claim was based upon an itemised, priced schedule of the remedial works.

Main premises £62,240

Tenanted Building £27,830

Total £90,070

The model was run with the data from the size and construction characteristics of this building and the nature of the flood event. The calculations and results are summarised in Table 7:

Table 7 Model reinstatement cost prediction for case study 3

Characteristic	Type of measurement	Units of measurement	Predicted flood event
Flood depth	In 0.3 metre increments	0.3m – 4.5m	0.9m
Flood duration	2 levels of measurement	Up to 24 hours, more than 24hours	Up to 24 hours
Velocity and Debris content	2 levels of measurement	None, significant amount	None
Types of pollution	2 levels of measurement	Non-hazardous, hazardous	Non-hazardous

Element construction	Damage repair/Re-placement and drying as % of new-build cost	Duration More than 24 hours	High velocity and debris	Addition for hazardous pollution clean-up	Total % new-build cost	Regional adjust-ment	Square metre, length or number affected	Current new-build cost in £ (per m2 or m or number)	Actual total cost of re-instatement in £
External brick/block cavity wall with rigid foam insulation	25			19	44		72	120	3801
External solid brick/block walls	27			27	54		120	80	5184
Internal stud and plasterboard partitions	89			10	99		72	45	3207

Timber external doors	103			3	106		6	440	2798
Timber internal doors	103			3	106		24	220	5596
Concrete floor, paint finish workshop/office	4			27	31		498	85	13122
Concrete floor, vinyl finish (office)	118			92	210		280	25	14700
Steel cargo doors	4			11	15		4	2500	1500
Water supply	5			4	9		780	12	842
Electric supply office	125			4	129		140	65	11739
Electrical supply prod.	120			4	124		250	59	18290
Telecommunications	120			4	124		280	5	1736
Heating installation	21			3	24		280	48	3325
Built-in furnishings									7000
								Total	**102,840**

The predicted figure of £102,840 compares favourably with the actual cost of £90,070, which is measured at a level of 88% accuracy.

7.5. Sensitivity Analysis

A sensitivity analysis was undertaken to estimate the level of dependency of the results on the values of various flood parameters and thereby provide some basis for assessing which uncertainties in the input data have most weight on the final results. A Case Study 1 was chosen for the sensitivity analysis (see Section 7.2). The variables flood duration, flood velocity and pollution were changed to calculate the sensitivity of the overall repair cost to the characteristics of the flood. The overall repair costs obtained from this analysis are summarised in Table 8.

Table 8 Sensitivity in the overall repair cost to the flood characteristics

Flood duration	Flow velocity	Pollution	Repair cost (£)	Change from base (%)
Less than 24 hours	**Negligible**	**Hazardous**	**86,925.43**	**Base - Case Study 1**
More than 24 hours	Negligible	Hazardous	93,194.93	7.2%
Less than 24 hours	Negligible	Non-Hazardous	60,162.89	-30.8%
Less than 24 hours	High*	Hazardous	92,672.68	6.6%
Less than 24 hours	High*	Non-Hazardous	65,910.14	-24.2%
More than 24 hours	Negligible	Non-Hazardous	66,432.39	-23.6%
More than 24 hours	High*	Non-Hazardous	72,179.64	-17%
More than 24 hours	High*	Hazardous	98,942.18	13.8%

*The database is currently incomplete for the additional repair cost due to high flow speed

Table 8 shows that the repair cost is most sensitive to the type of pollution considered (hazardous/non-hazardous), although it should be noted that the input database on the cost for high flow speed is still incomplete at this stage for many of the building elements. It can be seen in this example that considering pollution as non-hazardous would reduce the overall cost of repair by over 30%.

Further sensitivity analysis is recommended at later stages of development of the tool.

8. Conclusions, recommendations and gap analysis

One of the focuses of the EC 7th Framework Programme project, FloodProBE, is to examine the effects of flooding on critical infrastructure in urban areas, such as power systems, communications, essential supplies, emergency services and healthcare etc. If these infrastructure types are seen as networks, then the nodes are represented by the buildings and concentrated facilities that are connected together by communicating lines of various types (e.g. cables, roads, radio, pipes etc.). The buildings form an important part of critical infrastructure in urban areas, and should provide a measure of protection to the essential services and equipment contained within them, as well as preserving their structural and constructional integrity when exposed to flooding.

Existing damage prediction tools are aimed at producing damage curves for building types and contents, useful for producing a risk assessment for groups of buildings at an urban level rather than individual buildings. They are therefore not precise enough to make reliable predictions about individual buildings. This lack of a flood damage prediction tool for individual non-domestic buildings has made it difficult for owners and managers to estimate the likely extent and costs of damage to their buildings caused by flood events. Without knowing these, it is impossible to make informed judgements on the cost/benefits of introducing flood protection and other mitigation measures to the buildings in order to minimise the costs of these damages and subsequent repairs, and reduce the time that the buildings are inoperable.

The aim of this Task 2.2 in Work Package 2 was to identify the risks to these important buildings posed by flooding, and to develop the methodology for a practical flood damage estimation tool that is particularly designed to calculate the extent and costs of damage of individual infrastructure buildings according to the construction of their various elements. The tool will also be suitable for use on any other type of building, and particularly useful for those built with a variety of construction systems.

As developed in this Task, the prototype tool uses a simple-to-use calculation method, requiring inputs from the user that are related to particular buildings and are readily available and familiar to any construction professional. The tool lends itself to repeated runs for gauging the costs of damage caused by various flood scenarios. This facilitates the calculation of the level of risks to the buildings and their contents, and provides a useful basis on which to calculate the costs and effectiveness of possible flood protection and resistance measures that are being considered. The tool can be used either for existing buildings to calculate the costs of flood damage, to explore the cost savings that might accrue through reduced damage following the introduction of various flood resilience measures to the building (including wet and dry proofing), or to gauge the efficacy of the flood resistant design of new buildings.

This prototype tool provides a basis for further development to devise a comprehensive, tested method of calculating damage costs to individual buildings throughout Europe.

The flood damage estimation tool relies on a range of expert assessments of the scale of damage and costs of repair/replacement of a wide range of building constructions. These assessments can be made more robust by repeated testing against real situations, both in the laboratory and in real life as experienced in past flood events. In order to do this, much more specific information of flood events is required, including detailed data about the effects of different flood characteristics on different building constructions and materials, and itemised costs of necessary repair/replacement works. It has proved difficult to gain this level of detail during this research, partly due to issues of confidentiality, to lack of detailed records of past events, and division of responsibilities during and after the event. This illustrates one of the main findings of this research, namely that the availability of detailed information on the effects of flooding on building construction, which this project is trying to understand and improve, is lacking in most of the literature and difficult to obtain from building owners. It would probably be easier to gain this required level of detail in the data if cases could be tracked in real time, during and after a flood event, thus eliminating the problems of retrieving information sometimes years after the flooding and repair works. Considerable time and resources will have to be allowed for this process.

The range of different constructions and materials presented by the prototype tool is very limited compared with what is available and used throughout Europe. In order for the tool to be widely applicable, a far greater choice of these should be offered in the menus. To provide this requires a major exercise in cataloguing and assessing typical construction methods and materials in the various countries. More research will also be needed to gauge the effect of flooding on these and the extent of repair/replacement required to reinstate them. However, the new-build costs for every type of building material and construction in every country are readily available for use in the calculations. The introduction of new building materials and their combination in new construction systems over time also require additional data to be added to the tool to keep it relevant to present and future building practice.

The further expansion and refinement of this prototype tool should therefore be regarded as an on-going process, and further funding should be sought in order to develop it to a stage where it can be offered to the building professionals. Options should then be considered of how to generate some income from the distribution of the tool that will enable on-going revision, expansion and up-dating to take place. Despite this, the tool should be made widely available at little or no cost to the user, in order to encourage its use in the aim of increasing resilience in the essential urban infrastructures to flood events.

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Appendix 1. State of the art of flood damage estimation methods relevant to buildings

Much research has already been carried out on flood damage prediction methods for residential buildings, with less research on non-domestic buildings. A review of these methods was carried out in order to avoid repeating research and for building on the state of the art in this subject. The most relevant methods to this project are described briefly below, and their possible usefulness for individual non-domestic building flood damage estimation is assessed.

A1.1 ANUFLOOD methodology

This methodology is Australia's most commonly used commercial flood damage estimation model. It uses potential stage-damage curves based on actual data from flooding in Australia and UK. Stage damage curves are categorised into different building sized, types and uses, so a comprehensive survey of the buildings to be assessed should be carried out and the relevant curves applied. However, there is evidence that the data has become outdated and that existing ANUFLOOD stage damage curves should be increased by 60 per cent (State of Victoria, 2000, p19).

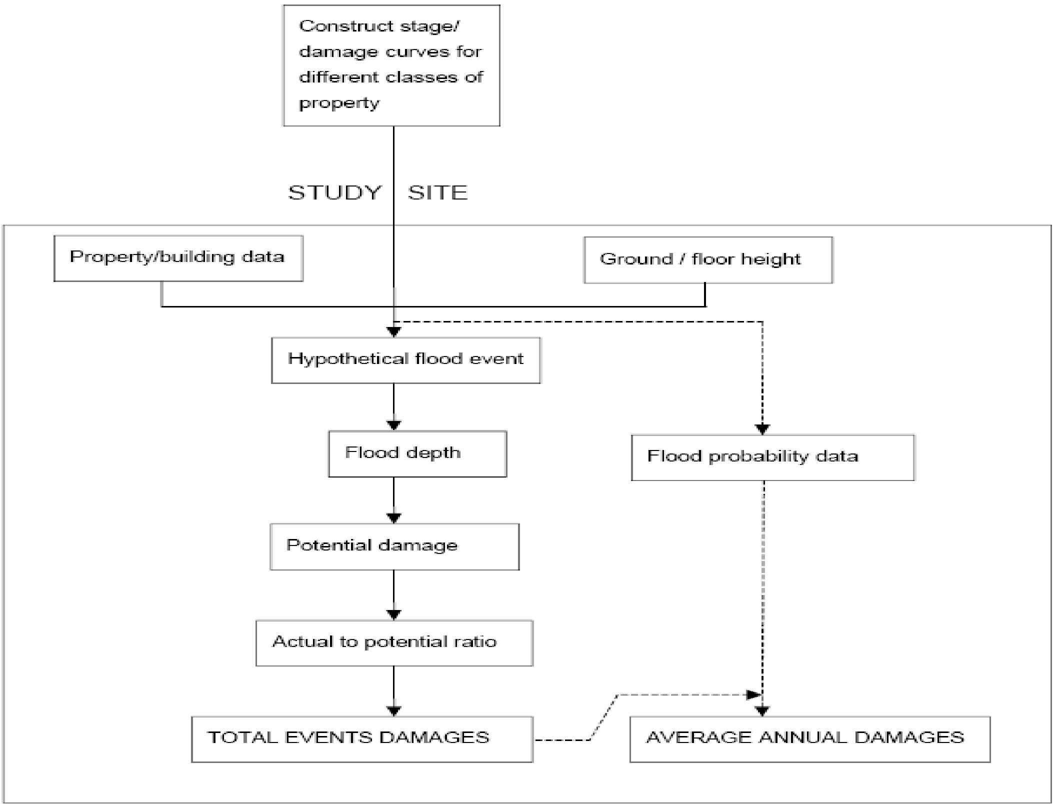


Figure 1.Traditional approach to assessment of flood damages to buildings (e.g. ANUFLOOD) (Government of Victoria, 2000, p15)

The commercial properties in the database are classified by size and value class that reflects the vulnerability to flood damage of the business's contents. The damage is only based on over-floor flood depth. As the datais based on averages, they tend not to reflect the variability of individual buildings. In fact, damages can vary greatly non-residential buildings, and analysts need to ascertain the size and type and content of each building. This is clearly demonstrated in a study carried out by Risk Frontiers on flood damage caused in 2001 to commercial properties in Kempsey, a small rural city located upon the Macleay River in the Mid-North Coast region of New South Wales, Australia. The damage to the individual properties often diverged considerably from the line of regression (see Figure 2).

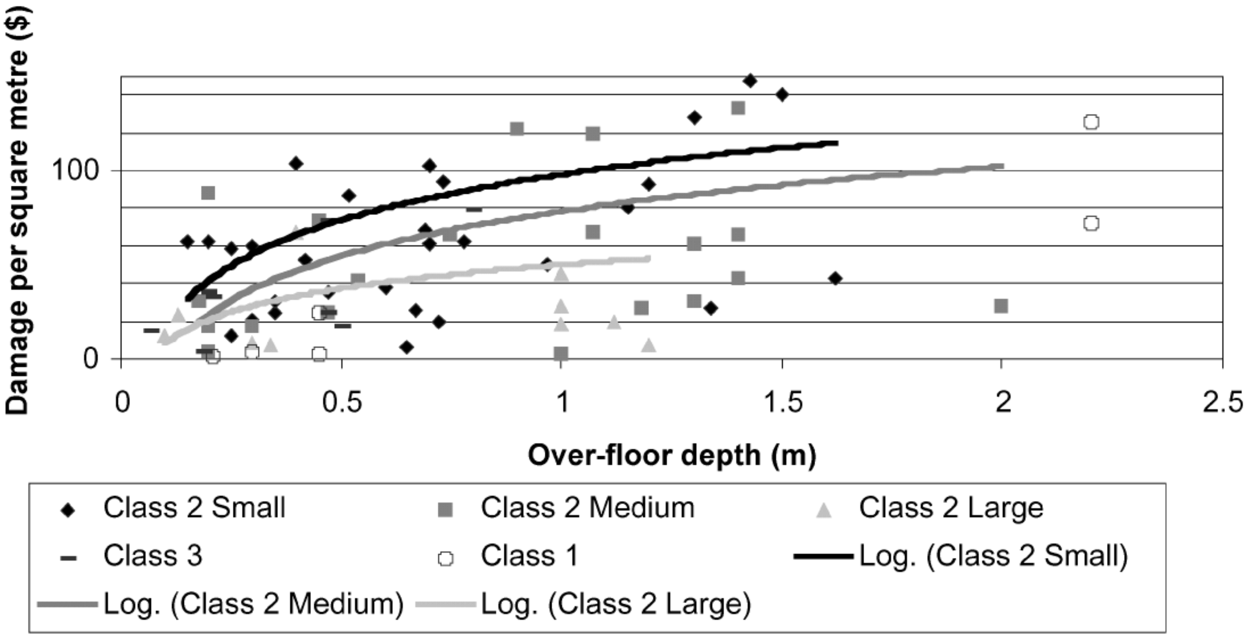
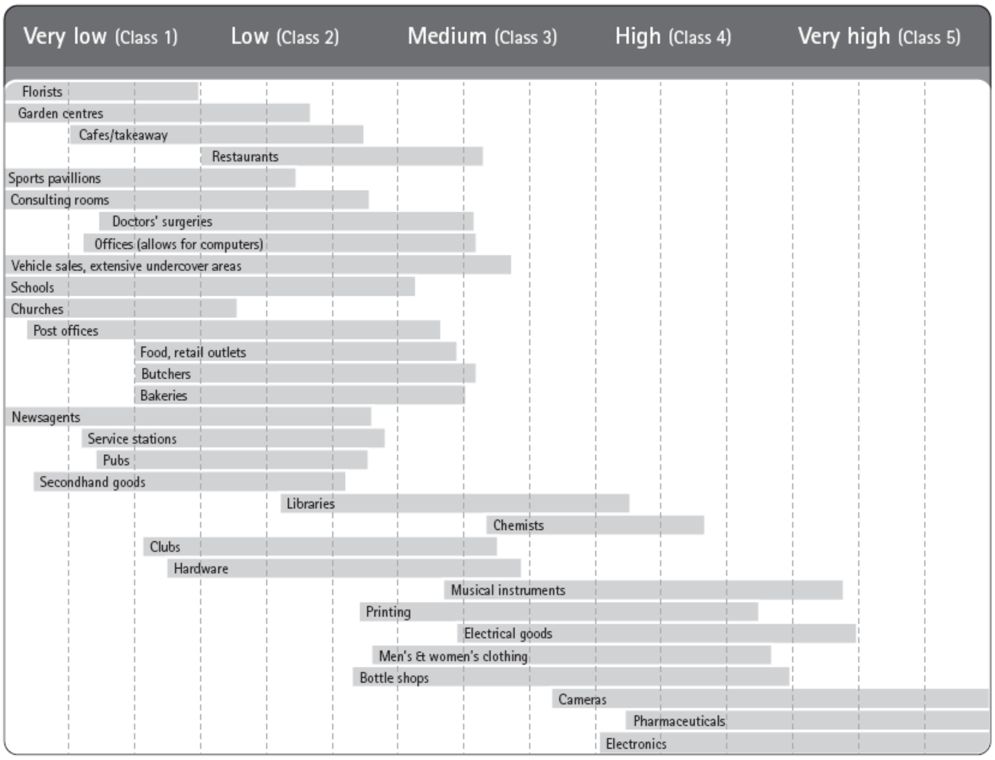


Figure 2. Kempsey value class and size regressions using ANUFLOOD (Gissing, Blong,2004, p219)

The Queensland Government and the Australian National University has published a table, reproduced in Figure 3, that categorises different types of commercial into a range of five damage classes, from very low to very high. Critical infrastructure buildings do not appear on this list, and are generally not seen as a class of buildings in existing studies.



Reproduced from Centre for Resource and Environmental Studies (Australian National University) 1992, ANUFLOOD: A Field Guide, *prepared by D.I. Smith and M.A. Greenaway, Canberra.*

Figure 3. Damage categories for commercial properties (Queensland Government, 2002)

However, Gissing and Blong conclude that:

Commercial flood losses are highly variable owing to the many physical differences between different businesses, survey uncertainty and variations in hazard impact. .... Current loss estimation techniques including averaging techniques and stage-damage analysis fail to take into account the variation within commercial damage data ... hence they are inaccurate (Gissing and Blong, 2004, p221).

The same can be said for critical infrastructure buildings that vary greatly in size, construction and contents.

The damage is only based on over-floor flood depth. As the data is based on averages, they tend not to reflect the variability of individual buildings. In fact, damages can vary greatly in non-residential buildings, and analysts need to ascertain the size and type and content of each building. The damage to the individual properties often diverged considerably from the line of regression, hence the results tend to be inaccurate for individual buildings [1].

A1.2 USACE velocity-damage curves

Floodwater velocity is rarely taken into account in calculating damage curves. The USACE (U.S. Army Corps of Engineers) Portland District velocity-based building collapse curves are one of the few that do (USACE, 1985) [3]. These curves predict the collapse potential of buildings based on their types of construction, i.e. wood frame, masonry and concrete load bearing walls, steel frame, correlated with floodwater depth and floodwater velocity. The only output of the model is at what point the buildings are likely to collapse. There is no estimate of the range of partial damage to the building or costs of repair.

A1.3 HAZUS-MH Flood Model – adaptation of earthquake model

HAZUS-MH (HAZards U.S. Multi-Hazard) is a nationally standardized methodology and risk assessment software program that comprises three models for estimating potential losses from natural disasters (i.e. earthquakes, hurricane winds and floods).The HAZUZ Flood Model is used to characterise riverine and coastal flooding as a basis for damage and loss estimation in relation to buildings. This damage and loss capability includes a library of more than 900 damage curves for use in estimating damage to various types of buildings and infrastructure.

Due to the fact that the National Flood Insurance Program pays claims on the basis of depreciated value of buildings, this adaptation from the earthquake and wind model takes into account the age and condition of the buildings in the evaluation (see Figure 4).

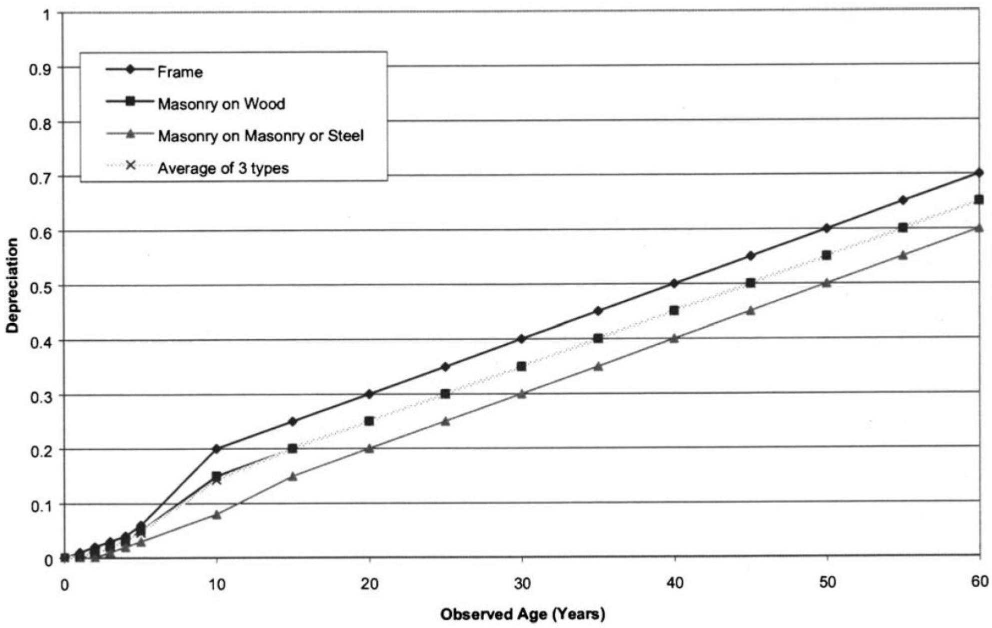


Figure 4.Commercial/industrial/institutional depreciation (FEMA 2003, after Means 2002)

The model uses estimates of flood depth along with depth/damage functions to calculate likely damage to buildings. The building occupancy type and ground floor elevation are required as inputs to make the calculation. The output is in the form of area-weighted estimates of damage as a percentage of replacement cost, at block or individual building scale (Scawthorn et al., 2006). However, the flood damage data and damage curves highest resolution is census block level so damage predictions are more reliable for large groups of buildings. The default depth damage functions are editable by the user to create a specific function for a specific building. Additional modules can be used to calculate direct economic and social losses. The building types are categorised by their construction materials and by range of numbers of storeys and typical number (see Table 1).

			Height			
			Range		Typical	
Number	Label	Description	Name	Stories	Stories	Feet
1	Wood	Wood (light frame and commercial and industrial)		All	1 to 2	14–24
2	Steel	Steel frame structures including those with infill walls or concrete shear walls	Low-rise	1–3	2	24
			Mid-rise	4–7	5	60
			High-rise	8+	13	156
3	Concrete	Concrete frame or shear walls including tilt-up, precast, and infill walls	Low-rise	1–3	2	20
			Mid-rise	4–7	5	50
			High-rise	8+	12	120
4	Masonry	All structures with masonry bearing walls	Low-rise	1–3	2	20
			Mid-rise	4–7	5	50
			High-rise	8+	12	120
5	MH	Mobile homes		All	1	10

Table 1. Flood model building types (Scawthorn et al, 2006, p76)

These are very simplified overall descriptions when considering the construction of actual buildings, and could lead to inaccurate estimates of damage at the single building scale. However, Scawthorne et al. (2006) maintain that the design and quality of construction do not play a major role in the structure's ability to resist damage due to floods on account of the unlikelihood of structural failure. The damage is normally restricted to structural finishes, contents and inventory.

Another feature that has been adapted from the earthquake model, is the calculation of debris generation. Debris is generated by the furniture and other contents being washed away as well a breaking away of building components such as carpets and other flooring, drywalling and other wall finishes. An estimate of the items requiring replacement together with their weights made, according to the percentage of overall damage to the building.

The possible outputs from the HAZUS Flood Model are comprehensive, including direct economic losses, including building repair and replacement costs, building contents losses and building inventory losses that relate directly to the buildings, and time dependent income losses such as losses in income and rental related to the estimated time required to restore or rebuild the building back to functional use. Beyond this, the model has the capability to estimate social losses and induced damage, such as needs for shelter and dislocation of economic sectors through disruption of supply chains and tourism.

For individual critical infrastructure buildings, only the direct economic losses will be relevant, though separate calculations could be made for the wider losses resulting from disruption of the infrastructure networks.

A1.4 Stochastic methodology using Monte Carlo simulation

This stochastic methodology has been developed by Nadal et al (2010) that takes account of flooding hydrodynamics – waves, turbulent bores, debris impacts, time dependent local soil scour as well as depth of flooding. The building vulnerability is modelled using analytical representations of the failure mechanisms of individual building components. The flood actions of recent events have been assessed and compared to the resistance of each building component. Monte Carlo simulation was then used to expand available building data and perform load/resistance analysis and to account for the uncertainty of input parameters. The output estimates the average expected flood damage to individual buildings due to both floodwater depth and velocity on the basis of 10,000 hypothetical buildings. The outputs are expressed as three dimensional functions dependent on floodwater depth and floodwater velocity.

The main feature of this methodology is the important distinction it makes between flood damages caused by hydrodynamic actions and floodwater depth. It shows that floodwater velocity can increase the damage to buildings by up to 100 – 190% depending on the type of event. Although the study concentrates on reinforced concrete frame domestic buildings with infill concrete-block walls (including doors and windows), it could be applied to other structures using the same methodology, but lacks the flexibility to cope with combinations of different construction types and materials in individual buildings.

A1.5 Damage and loss prediction based on and engineering evaluation system of building construction types

A study by Schwarz and Maiwald (2005 and 2008) at the Bauhaus University in Weimar uses an engineering evaluation system in order to predict damage and losses based on the vulnerability of building types. This takes into account the inundation level, flow velocity, duration and building type (Kreibich et al.2009). The buildings are classified into six types by material used for the construction and the structural system. The study was based on data gathered after the flood in Saxony in 2002, which featured some very high water velocities. The dataset included about 1220 residential buildings, most of substantial size with multiple accommodation units. The buildings were categorised into type according to their main construction material. Clay refers to earth construction (cob, adobe or rammed earth), prefabricated presumably to timber panel construction, framework refers to heavy timber frame, and masonry to brick or stone construction.

The different building types were allocated to five flood vulnerability classes. As can be seen in Figure 5, the damage data was not always consistent, so most building types were spread across two or three vulnerability classes, but with one class being cited as the most likely.

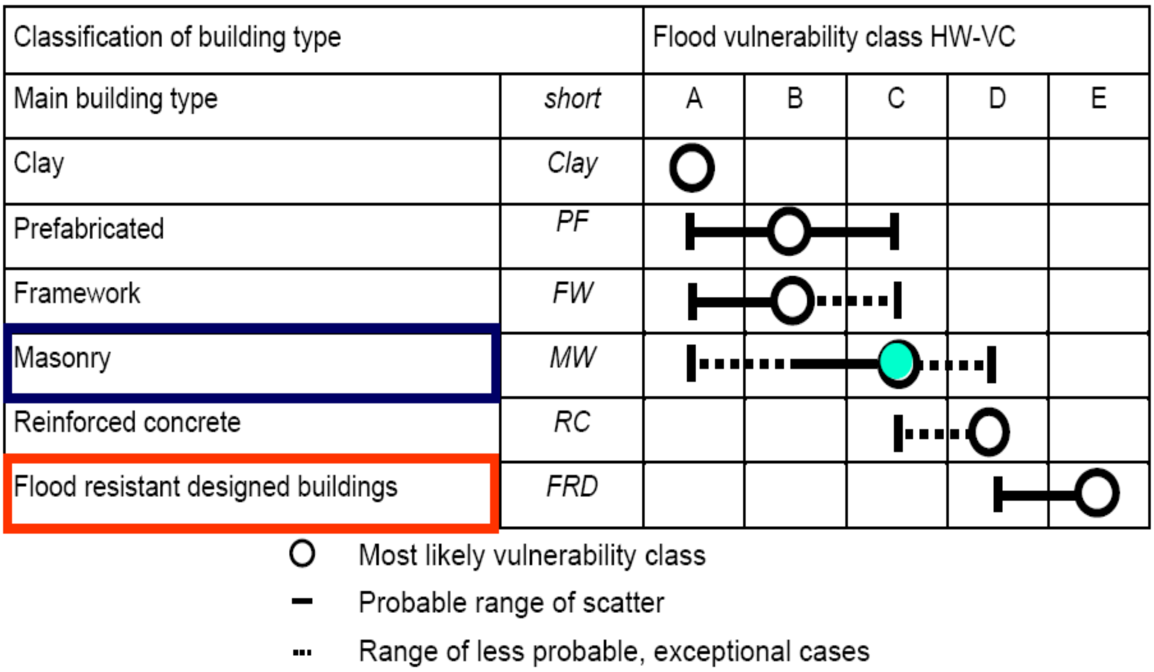


Figure 5. Classification of building types into vulnerability classes **(**Schwarz and Maiwald, 2008)

In addition, a range of damage grades were compiled, from D1, the lowest, to D5 the greatest damage requiring complete rebuilding, as shown in Figure 6. The damage criteria cover physical building, chemical, structural damage and the extent of rehabilitation measures.

Criteria	Observed effect / measure	Damage grade D_i				
		D1	D2	D3	D4	D5
Building physical damage	**Penetration** of supporting and non-structural walls and the floor slabs	💻	×	×	×	×
Chemical damage	**Pollution** (mud, excrements …)	×	×	×	×	×
	Contamination (oil, chemicals)		×	×	×	×
Structural damage	Impressed doors and windows		×	×	×	×
	Slight cracks in structural elements		×	×	×	×
	Major cracks / deformations in structural walls and slabs			💻	×	×
	Settlements			×	×	×
	Partial failure of primary structural elements				💻	×
	Collapse of major parts of the building					💻
Rehabilitation measures	Cleaning of penetrated elements	💻	×	×	×	×
	Replacement of extension elements		💻	×	×	×
	Replacement of non-structural elements			×	×	×
	Replacement of structural elements				×	×
	Demolition of building required					×

„New Step“

Figure 6. Damage grades/inundation level/construction types cases(Schwarz and Maiwald, 2008)

As a result of these categorisations according to building type and damage grade, the cases were analysed to produce depth/damage curves plotting inundation levels to damage grades for the different construction types or vulnerability classes. The damage grades were the means derived from the damage to the actual buildings (see Figure 7). The level of damage to each building type is directly related to the types of construction and flood vulnerability class, and always becomes greater with increasing dept of inundation up to 5 m, only levelling off when damage grade 5 is reached, which is not the case for most.

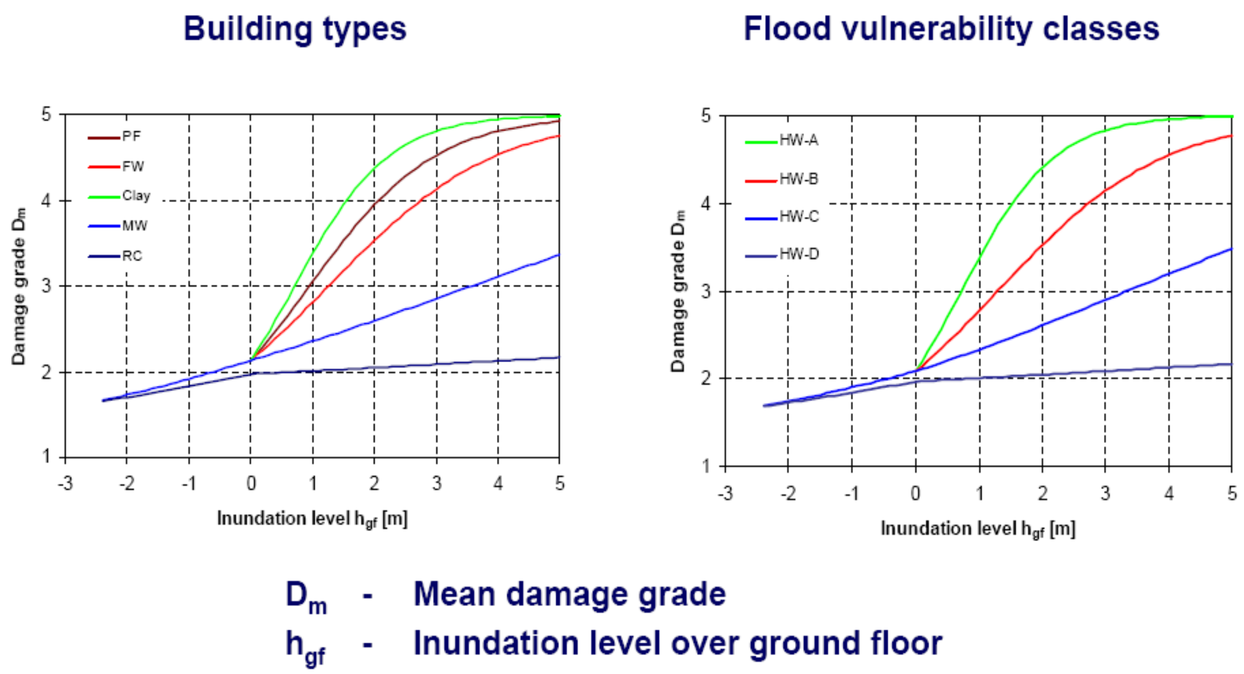


Figure 7. Depth/damage curves or building types and flood vulnerability classes (Schwarz and Maiwald, 2008)

Further damage by grades can be calculated against the specific energy height which is computed from the inundation level over ground level and the flow velocity, as well as losses in percent according to impact parameters. Specific damage functions can then be plotted, for example the losses to a particular vulnerability class of different floor heights against inundation level, or losses by different damage grades related to floor numbers with cellar against inundation level.

The results of basing the damage and loss prediction model on an engineering evaluation system is that it provides a unified definition of global structural damage grades and specific vulnerability classes. The developed tools are suited for damage and loss prediction, and by identifying critical zones, for short and long term disaster management decisions. The predictions are however probably not sufficiently reliable for precise calculations for individual buildings, particularly those featuring several different construction methods.

A1.6 Economic assessment of flood mitigation measures: average annual damages (AAD)

The Queensland Government has produced a guide on the assessment of flood damages that provides a simple explanation of the calculations required to calculate annual damages from flooding expressed in units of currency per year (Government of Queensland, 2002)). This is a common performance indicator used to measure the level of potential damages inflicted by a range of flood magnitudes. These figures can then be used to judge the economic viability of various flood mitigation measures, either at single building level or more generally for groups of buildings or for larger areas.

Calculation of the assessment requires as many potential damage bills for a number of flood sizes – the more cases, the more accurate the assessment. Estimates are needed for the size of the flood event where damage to the property begins, the potential damage for the design event and the potential damages caused from the largest probable flood event (10 000 year recurrence interval). Four steps are required to calculate the AAD;

Estimate potential damage costs from a range of flood sizes

Plot graph of potential damages versus annual exceedance probability

Calculate annual average damage costs from flooding

Calculate potential reduction on annual average damage from flood mitigation activities (G.of Q. 2002, p 14)

The annual exceedance probability for a given flood event is the inverse of the average recurrence interval:

$$\text{Annual exceedance probability} = \frac{1}{\text{Average recurrence interval}}$$

An example of a graph plotting potential damages versus annual exceedance probability is shown in Figure 8. Also plotted are the potential damages after the installation of a levee designed to provide full protection against an estimated 100 year recurrence flood.

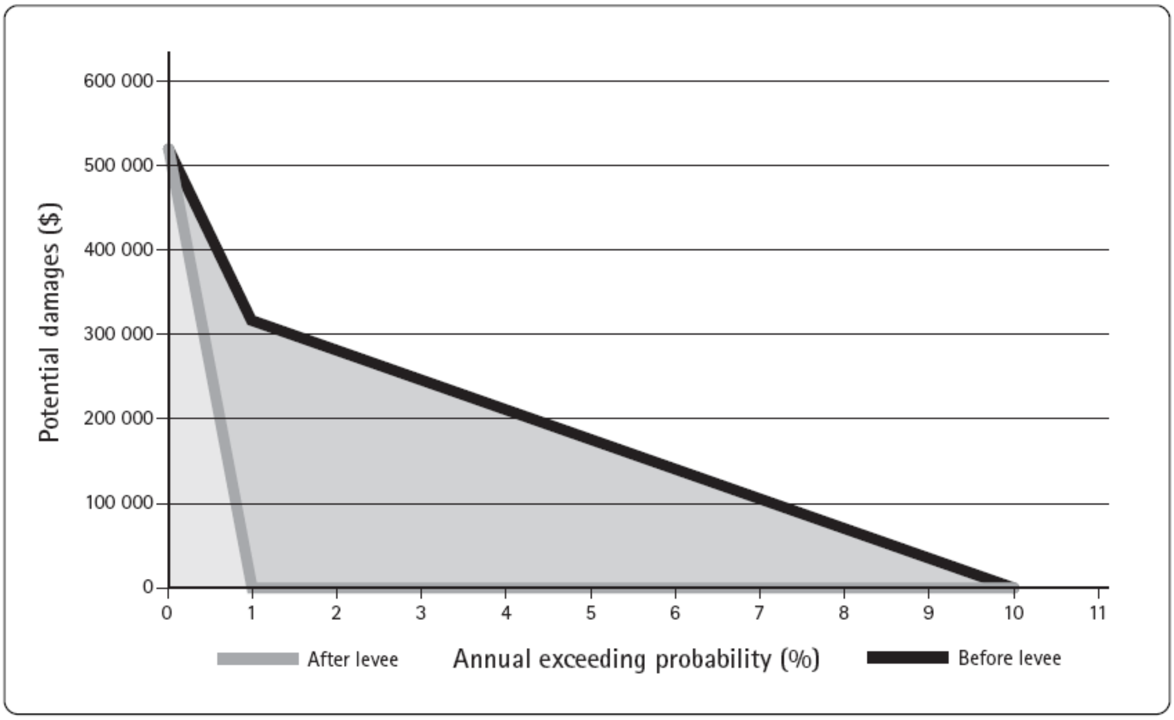


Figure 8. Plot of potential damages versus annual exceedance probability (G. of Q. 2002, p16)

The annual average damage can be calculated by measuring the area underneath the plotted line. In this case it is $16,242 before the levee and 13,642 after the levee is constructed.

If enough damage and flood level detail can be gathered about a particular building, then it should be possible to use this method for estimating the economics of various flood mitigation measures relating the the single building.

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Appendix 2. NRP Survey data

Flood damage assessment in the UK is normally based on the information contained in the 'Multi Coloured Manual' (FHRC, 2005). This provides standard approaches for calculating the flood damage for residential and non-residential properties, based on a large dataset of building stock and experience from major flood events. Although depth/damage curves are available, there are very few that can be considered to be applicable to critical infrastructure buildings, with the majority of the non-residential categories being of a commercial nature (shop or factory). A sample dataset was provided to FloodProBE by The Flood Hazard Research Centre (FHRC), an interdisciplinary centre based at Middlesex University in the School of Science and Technology. The data set, shown below, was the product of a detailed questionnaire on non-residential properties. It had been hoped that this could be tested with the model, to compare its results against the national depth-damage data. However, the details on the building fabric and construction are not sufficient to enable this to be used directly in the model. Work is continuing to try to agree certain assumptions which would allow its use in the future.

MCM Code	Type of Business	Minimum size (m^2)	Maximum size (m^2)	Typical area (m^2)	Basement	First Floor	Ground floor	Second floor	Concentrated production or sales?	When concentrated?	Refurb: Buildings and services	Refurb: Fixtures and Fittings	Refurb: Moveable equipment
211	High street shop	90	12000	220					Y	Mid November to mid-January	No	7 years	5 years
211	High street shop	50	500	350					Y	Run up to Easter- school holidays	5 years	5 years	5 years
211	High street shop	36	135	90					Y	Pre Xmas, mothers and father's day	No	7 years	5 years
211	High street shop			185					Y	Nov-Jan	6 years	4.5 years	4.5 years
211	High street shop	150	1000	300					Y	Christmas and pre-school periods	12.5 years	7 years	3 years
211	High street shop			225					Y	Christmas and Summer sales	3-5 years	5 years	No
211	High street shop	40	500	120					Y	Christmas	8.5 years	8.5 years	5 years
211	High street shop	1000	2500	2000					Y	October to Christmas, Easter and Valentines	9 years	6 years	7.5 years
211	High street shop	185	1115	743					Y	End of October- January	Ad hoc	Ad hoc	Ad hoc
211	High street shop	100	800	600					Y	September to Christmas	4 years	4 years	4 years
211	High street shop	15	2500	1100					Y	August- September, from November to January	10 years	10 years	10 years
211	High street shop	500	10,000	2,000					Y	October- December	7.5 years	7.5 years	7.5 years
211	High street shop	37	1115	65					Y	Increase at Christmas	Ad hoc	Ad hoc	Ad hoc
211	High street shop		929	167		Y	Y		Y	march-July and October/November	17.5 years	7.5 years	5 years
213	Super/hyperstore	280	7500	3251					Y	Easter and Christmas	7.5 years	3 years	annually
213	Super/hyperstore	270	126,000	4050					Y	Easter and Christmas	7.5 years	7.5 years	7.5 years
213	Retail- Superstore			13100					Y	Christmas	5 to 10 years	3 to 5 years	3 to 5 years
213	Retail- Superstore	5040	225	1350					Y	Easter and Christmas	10 to 15 years	3 to 5 years	3 to 5 years
214	Retail warehouse	92	6014	1000					Y	Christmas	0	7.5 years	7.5 years
214	Retail warehouse								Y	Easter and Christmas, early summer	9 years	9 years	9 years
214	Retail warehouse	2415	4180	4180					Y	October to mid-January	10 years	10 years	5 years
214	Retail warehouse	600	2000	1100					Y	October to November is critical	15 year leases	over 15 years	7 years
214	Retail warehouse								Y	Easter and October to end of January	10 year		
221	Garage/vehicle repairs	325	418	400					N		10 years	12.5 years	5 years
222	Filling station	400	1500	600					N		10 years	5 years	5 years
221	Garage/vehicle repairs	300	1000	500					N		10 years	10 years	10 years
222	Filling station			1620					N		10 years	10 years	10 years
223	Car showroom			1000					Y	new car sales peak in March and September. All other activities are fairly evenly spread	10 years	5 years	2 years
223	Car showroom	270	340	305					Y	march and September	10 years	7.5 years	5 years
224	Plant hire			651					Y	less at Easter and Christmas	1.5 years	1.5 years	3 years
231	Hairdresser			108					Y	Thurs- Friday and Christmas and Easter	4.5 years	10 years	4.5 years
234	Pubic house/club	300	1500	500					N		15 years	5 years	5 years
234	Pubic house/club	120	300	150					Y	Summer	4 years	4 years	4 years
235	Restaurant	390	992	631	y	y	y		N		10 years	5 years	3 years
235	Restaurant	372	465	418			y		Y	Christmas, Easter, summer holidays	6 years	6 years	6 years
235	Restaurant	232	465	372	y		y		Y	Christmas, Easter and summer	6 years	6 years	6 years
320	Bank	50	750	350							10 years	10 years	10 years
236	Café/Fast food	200	600	300					y				
236	Café/Fast food	80	130	100					Y	8 weeks prior to Christmas and also school holidays	5 years	5 years	5 years
238	Garden centre			4000			y	y	N		7 years	3 years	6 years
311	Hi-tech office								y		7 years	7 years	7 years
310	Office	70	15000	2500		y	y	y	N		10 years	10 years	10 years
310	Office	1000	5000	4500					n		20 years	20 years	20 years

MCM Code	Type of Business	Minimum size (m^2)	Maximum size (m^2)	Typical area (m^2)	Basement	First Floor	Ground floor	Second floor	Concentrated production or sales?	When concentrated?	Refurb: Buildings and services	Refurb: Fixtures and Fittings	Refurb: Moveable equipment
320	Bank	70	800	250					y	Last 2 months of the year (November and December)	5 years	5 years	7.5 years
320	Bank	80	1000	400	y	y	y		n		9 years	9 years	4.5 years
410	Warehouse	3251	9290	6131					N		10 years	5 years	5 years
410	Warehouse		28000	3700			y		Y	School holidays, summer, weekends for commercial customers			
410	Warehouse			2323		y	y		y	Very seasonal, school holidays (i.e. August)			
411	Warehouse- electrical goods		27000					y	September to December		6.5 years		
412	Warehouse - non-frozen	31000	46450	35000		y	y		y	2 weeks before Christmas, 1 week before Easter	12.5 years	6 years	5 years
413	Warehouse- frozen	15000	15000	15000		y	y		y	two weeks before Christmas, 1 week before Easter	12.5 years	6 years	5 years
511	Hotel	3000	50000	7000					y	Peak September/ November for conferences.	12.5 years	5 years	5 years
513	Caravan- touring			8.4			y		n		20 years	20 years	
514	Caravan- static			27			y				25 years	15 years	
518	Cinema		10000	4500					y	Christmas, Easter holidays	4 years	4 years	7 years
517	Bingo	2000	4000	3000					y	September to May	7 years	7 years	7 years
518	Cinema	100	4000	2500		y	y		y	school holidays, but depends when films are released	5 years		
519	Beach hut			12			y		n			10 years	
519	Beach hut			12			y		n				
523	Sports/ Leisure centre	500	2100	1500		y	y		y	First 6 months of year	5 years	5 years	3 years
523	Sports/ Leisure centre	20000	10000			y	y	y	y	Academic year	5 years	7 years	7 years
523	Sports/ Leisure centre	4000	15000	12000					n		5 years	5 years	5y
610	School/ University/ College	20	8000	2000		y	y	y	y		6 years	10 years	7 years
610	School/ University/ College		980										
610	School/ University/ College		2000			y		Y	School unoccupied in holidays	6.5 years	6.5 year	6.5 years	
610	School			5000		Y	Y		Y	Unoccupied in holidays but contents the same year round	Ad hoc		
620	General Surgery			380		Y	Y		Y	Monday mornings	Varies	4 years	Varies
620	Surgery/ Health centre		300							annually	washing machine		
630	Hall/ community college		525	y	y	y				25 years	15 years	ad hoc	
640	Library	38	1575	500			y		n		17.5 years	7.5 years	5 years
650	Fire/ Ambulance	1000	10000	5500							60 years	20 years	7.5 years
690	Church			650	y		y					15 years	
810	Workshop			3150					n		7 years	10 years	10 years
810	Workshop			2400									
810	Workshop			131					n				
810	Workshop			360					n				
810	Workshop			1828					n		10 years	10 years	10 years
850	Laboratory			50000					n		5 years	6 months	several year

BUILDING AND STRUCTURE

MCM Code	Type of Business	BS Frame	BS Load Bearing	BS Frame Material	BS Frame Infill	BS Load bearing material	Period Buildings	Period buildings %	Structure different for period buildings	Structure different for modern buildings	Typical services	Value of building cost per m2 (£)	Proportion of services below ground (%)	Proportion of services at ground floor (%)	Proportion of services at upper floors (%)	Affected by flood under 12 hrs with no warning	Depth of first damage (m)	Depth of max damage (m)	Damage differ for coastal flooding	Damage differ for flood over 12hrs
211	High street shop	Y	Y	Steel	Masonry	Brick	Yes	5%	Brick or steel		cabling, power supplies, plumbing, heating, water, electronic, air conditioning, lifts and escalators	900				Distributions boars at low level			More corrosive	
211	High street shop	y	Y	Steel/ concrete	Brick (dry linings similar to warehouses)	Brick	10 listed buildings	20%			cabling, power supplies, plumbing, heating, water, electronic, air conditions	1000				Services would be damaged	0.2		No	
211	High street shop	Y		Steel	Brickwork		A few	2-3%		Steel framed	Cabling, power supplies, plumbing, heating, water, electron, air conditions, lighting power, feeds for AC					Plaster board would be damaged. There would be issues with the flooring. Sheet flooring would be damaged if the water got underneath. There would be problems if the electricity which was below the till units was damaged. Timber would be affected: at floor level the skirtings, door frames also.	0.02		No	
211	High street shop		Y			Brick	Grade II listed buildings	3%			cabling, power supplies, plumbing, heating, water, electronic, air conditions, data cabling for computer links, alarm system linked to police station	190,000				All services underground and would be affected, especially computer links- no trading. Alarm system would be out	0.25		No	
211	High street shop	Y	Y	Steel/ concrete	Blockwork and dry linings	Brick /block	Post 1920 and 5% of all properties are listed	25%			Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	920				Fabirc (linings) and services	0.3		More damage, 50% at 0.3m	
211	High street shop		Y			Brick			Brickwork	Concrete framed	Cabling, power supplies, plumbing, heating, water, electronic, air conditions, security cameras, satellite, conveyors, lifts	850				shop floor out of action	0		No	
211	High street shop		Y			Brick	Yes	50%			Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	2,000								
211	High street shop		y			Brick		50%			Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, security alarms, CCTV, mobile phone booster aerials	1000				The electrics, flooring, decorative finishes, plasterwork, doors warping, wooden skirtings would be affected	0		Yes, corrosion	
211	High street shop		Y			Brick	500 out of 715 stores pre- WWII	70%	Load bearing - brick	Steel framed, lightweight infill of breeze blocks	Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	750				Little damage to building structure -lifts damage, electrical services, tiling	0.02		No	
211	High street shop	Y	Y	Steel-concrete	breeze block	Brick	Listed grade I, II	15%	masonry, brick	Sttel concrete	Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	880				Electrics would be affected	0.3		High level of maintenance required	
211	High street shop	Y	Y	Steel/ concrete	Blockwork, glazing		Pre WWII	20%	Listed buildings would have asbestos linings	Modern buildings would have damp proof courses	Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	1100				Basement stockrooms would be badly affected and ground floor services	0.3		No	
211	High street shop	Y		Steel/ concrete				30%			Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	1100				Sale floor/stockroom, electrics and water			Possibly more serious damage	
211	High street shop	y	y	Steel/ concrete		Brick		45%			Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	536	0	40%	60%	Minimal damage, plaster affected but depending on depth, re-wiring necessary	0	2.5		0
211	High street shop		y			Brick		30%			Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	23	0	65	35	Building structure would not be affected but rendering and decoration would be - would need replacing. Power would be affected and cabling	0.07	2.5		0
213	Super/ hyperstore	y	Y	Steel	Mixture	Brick		1%	Predominantly brick	mixture	Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, generators	1133				Power, gas, electric, water	0.1			
213	Super /hyperstore	Y		Concrete/ steel frame	Brick						Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, refrigerators, IT, ventiallation	1133				loss of power supply, loss of refrigeration (stock)		0		
213	Retail- Superstore		Y			Structural steel		0			Cabling, power supplies, plumbing, heating, water, electronic, air conditioning,	1133				All internal ground floor, warehouse, prep's, slaes floor, public toilets, underground ducts would be affected	0.05	3	Generally no major difference in cost, at 3m the decision would be close to knocking the	

MCM Code	Type of Business	BS Frame	BS Load Bearing	BS Frame Material	BS Frame Infill	BS Load bearing material	Period Buildings	Period buildings %	Structure different for period buildings	Structure different for modern buildings	Typical services	Value of building cost per m2 (£)	Proportion of services below ground (%)	Proportion of services at ground floor (%)	Proportion of services at upper floors (%)	Affected by flood under 12 hrs with no warning	Depth of first damage (m)	Depth of max damage (m)	Damage differ for coastal flooding	Damage differ for flood over 12hrs
											refrigeration, boiler plant								building down ... Dependent upon its age	
213	Retail-Superstore	Y		Steel	Brick blockwork		Oldest store is just over 30yrs old, most post 1980				Gas, refrigerant in enclosed pressurised system, standby generator, IT equipment	1166				5 to 10cm would start impacting on branch equipment, fixtures and fittings and communications equipment	0	1.5		
214	Retail warehouse	Y	y	Steel	Concrete	Brick		50%			Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	425					0.1		No	
214	Retail warehouse	Y		Steel	Block work to 2 metres, insulated cladding after that. Industrial retail warehouse		very few, perhaps one or two	1-2%			Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, gas heating supply	750				Low level timber, frames and doors. Stud partitions walls between store and retail. Thermo plastic floor tiles would become loose	0.01		No	
214	Retail warehouse	Y		Steel	Block/ brick cladding						Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, computers and telephone	675				Loss of trade initially. Building fabric water damaged, services at ground level (switch room/generator) damaged	0			
214	Retail warehouse	Y		Portal frame	Clad and/or brick work				Render and plater		Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	750					0.05		No	
214	Retail warehouse	Y		Steel framed and clad			In high street	25%			Cabling, power supplies, plumbing, heating, water, electronic, air conditioning					Some of power is at low level. Affects electrical wire systems and plasterwork and decoration	0		No	
221	Garage/ vehicle repairs	Y		Portal frame	Masonry			20%	traditional structural walls and roof	Steel frame	Cabling, power supplies, plumbing, heating, water, electronic	310				50% of services lost	0		No	
222	Filling station	Y	Y	Steel or timber	Rockwool or similar	Brick		<1%	Traditional brick built	Steel or timber framed	Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, fuel delivery systems	650				Fuel delivery system contamination possible, electrical systems damaged, floor coverings and decorations inside building	0.1		No	
221	Garage/ vehicle repairs	y	y	Steel/ concrete	Brick/block	Brick	10 post 1920	1%	brick masonry	Steel/ concrete frame	Cabling, power supplies, plumbing, heating, water, electronic	700				All electrical circuits would be affected as soon as water came in but LEB services at 20cm Circuit breaks at 80cm, workshop at ground level	0.25		No	
222	Filling station		Y			Brick					Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, Main drainage, petroleum spirit storage tanks underground. 3- phase electricity	416				petrol tanks seals would be breached, contaminating water supplu	0.3		No	
223	Car showroom	Y		Reinforced concrete	Bricks/ showroom window						Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, 3 phase electricity	980				Underground pertrol tanks contaminated and stock written off. Electrics and gas out (all on ground flood) All work eases off	0.1		No	
223	Car showroom	Y		Steel (encased)	Glazing, blockwork, corrugated sheet						Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	1050				Everything is affected by a flood lasting more than five minutes. Building structure would be partially affected, services are 90% underground = badly affected	0.15		Yes, coastal would harm building finishes, damage would be difficult to estimate	
224	Plant hire	y		Steel	Fibre glass/brick		Some	30%	brick	Steel	Cabling, power supplies, plumbing, heating, water, electronic, gas, telephones	768				All services knocked out and main drainage and pumps. Diesel, petrol, chemicals would leak into flood waters, brickwork on ground floor cracked	0		More damage, 50% at 0.3m	
231	Hairdresser		y			Timber and steel	All victorian	100%			Cabling, power supplies, plumbing, heating, water, electronic	925	0	100	0	Plaster and skirtings damage, shop fronts but steel and glass should be ok. Electric circuits affected at 1 metre	0.05	3	No	0
234	Pubic house/club	y		Brick and concrete block			Yes, pre 1940	50%			Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	1500				Service disruption leading to potential full replacement, particularly of electrical services	0.5		No	
234	Pubic house/club		Y			Brick	Pre 20th century	75%			Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, beer lifting equipment, cellar cooling, kitchen equipment	1300				beer cellar flooded. In trading area, damage to timber floros and services and timber partitions	-3		No	
235	Restaurant	y	y	various	various	various	pre 1960s buildings	20%			Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, CCTV, alarm system	1233	10	65	25	Probably loss of power and some re-cabling required. Probably required to strop trading for 12 hours and recovery time	1	3		10
235	Restaurant	y		Steel	Clockwork						Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, alarm system	1076	0	100	0	wood and wood under laminated flood would be affected immediately, plaster and also probably doors. Some underfloor services, cabling and electronicts at low level	0.01	3		0
235	Restaurant		Y			Brick	Most are pre-1960s high street properties	95%	Brick, load bearing	Steel with various in fills	Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, alarm	1,613	50	50	0	Flooring and floor joists, replaster all the walls, replace joists, take off all the plaster. Most AC equipment useless, electrical heating all gone. Electric affected. Even the	0.01	0.08		50

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											system, air extraction systems					excess moisture would affect heating. A lot of pumps, thermostats in basement				
320	Bank		Y			concrete, masonry, breeze block	Pre WWII				Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, hydraulic screens to protect staff and hydraulic tubes for cash transfer	1000				ground floor structures would be affected immediately. Skirtings and the bottom of screens and cupboards, and carpets would be affected straightaway. It would be after about 100mm above the height of the skirting before the walls would be affected by damp. The screed floro of 50mm could be affected by water standing on it. The electrical services and computer cables were the most vulnerable component but these were mostly dropped from voids in the walls not underfloor. Services damage would depend on where services came into the building and this varied.	0.25		No	
236	Café/ Fast food	y		Steel	Lightweight materials, sandwiched materials		100-150 buildings	12%	Varied brick and others	Steel framed- pre fabricated units	Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	1000				Anything deeper than 200mm to 300mm within building would require closure period and cause significant damage	0.75		No	
236	Café/ Fast food	y	y	Steel/ concrete	brick or block	Brick	Listed buildings	20%	half the listed buildings have original timber panelled interiors		Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	1200				60% of floors are timber and these would be damaged after the ingress of water. Duration time of some relevance	0.3		No	
238	Garden centre	y		steel	Brick						Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, sprinklers and pumps for irringation, bottled/tank gas, total value likely to be about 500,000	400	0	95	5	Not too bad, skirting and plasterboard only likely to cost £3- 5,000. Interiros are mostly exposed brickwork, limied lasting damage. Maybe 20% damage at 3m. Most electrics are at waist- ceiling height- but very high density/value. Many sockets etc so 40% losses by 1 metre. Sprinkletrs and pumps at ground level so expect losses from only a few cms	0.02	3	Corrosion	0
311	Hi-tech office	y		steel	breezeblock						Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	1850				Shorting out of electrical supply, loss of service to customers	0.5		No	
310	Office	Y		steel	block/ glass		About pre- 1960s	19%			Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, telec9om equipment, computer room with servers	200	0	30	70	Structure was not affected by floods but it would depend on the force of the water. Once up to the window sill level and glazed sectiosn, there would be damage as the sill is loose. There would be a total write off of ground floor cables and IT systemss at a low level of water. Server room with computers is just off floor with cabling below	0.2	3	No	0
310	Office	y	y	steel encased in concrete	Brick, clock, glazing	Brick/ masonry					Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	2080				Basements- all electrical and electronics written off	0.1		Even worse	
320	Bank		y			Brick	Pre WWII	70%			Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, lifts, hoists from basement, security alarm systms, cabling in the skirtking	1300				Buildings would typically be affected immediately and at below ground level because flood waters would get into the basement storing rooms in a typical branch. The storing rooms do not have flood proof doors and are not watertights. Tiles, decorations and clockwork might be damaged by the flood water. The power, lighting, doors and security alarms would be damaged.	-2.4		50% worse with salt water	
320	Bank	y	y	Concrete	Block/ brickwork	Block/ brick		70%	traditional brick, block and timber construction	Greater use of concrete	Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	750	5	75	20	Limited after drying out- only plastered walls and drylinings	0.5	4	No	5
410	Warehouse	y		Steel	Brick		A few 1940s and 1950s	10%	Brick.concrete framed	Steel/ brick	Cabling, power supplies, plumbing, heating, water, electronic, lifts	450				Most services would be lost, alarm system might be ok as higher up. No underground cabling, lifts would be affected as motors are in pits	0		contamination risk and damage to building fabric. Greater cleaning costs and inspection costs	
410	Warehouse	y		Steel	Cladding					steel	Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, telephones	176	0	100	0	Would need to redecorate offices, all electrical services, telephones etc written off	0.1	2	No	0
410	Warehouse	y	y	Steel and concrete		Brick		50%	Brick load bearing	steel and concrete framed	Cabling, power supplies, plumbing, heating, water, electronic, air conditioning			95	5					
411	Warehouse- electrical goods	y		steel	light weight plastic coated sheeting						Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, CCTV, alarm system	370				Flood damage would occur failry quickly as there is a wire guidance system for product retrieval in the floor of the warehouse. The vehicles would not be able to run as a result and that system would be damaged. In the office block the power supply is under the floor. It would be contaminated	0		No	

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																and would need replacement				
412	Warehouse - non-frozen	y		steel	composite		The oldest is late 1960s, most 70s, 80s and later	0%			Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, diesel fuel tanks below ground level but watertight	800	0	87.5	12.5	Water damage to the panels would be significant. Complete replacement of anything below ground level e.g. cabling. At the very least, would have to be tested. In new buildings cables are underground but in watertight pipes but where enter buildings , where supply courses in, would be vulnerable	0.01	3	No	0
413	Warehouse- frozen	y		steel	composite						Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, diesel fuel tanks below ground level but watertight	2000	0	87.5	12.5	Significant water damage to panels. Complete replacement of anything below ground level e.g. cabling etc. at least would have to be tested.	0.01	3	No	0
511	Hotel	y	y	steel concrete	Panels, glass, brickwork	brick		10%	load bearing and also other framed		Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	1000				Reception areas, dining, kitchens, hallroom	0.25		No	
513	Caravan-touring	y		aluminium	Aluminium skin and plastic inside				earlier models = wood frame and panels		Plumbing, heating, water, electronic, pump for connecting plumbing to external water supply	1785	0	100	0	No damage below 0.5m as raised on wheels. Floor should survive brief flood. Possibly sides too, as designed to be driven in wet conditions. Longer flood might allow water into seams between panels. Water above base of caravan would damage pump and some electrics. Sockets at waist heigh would be hit next and finally ceiling lights	0.5	3	Salt water might have worse effects especially if longer duration, maybe 30-40%	0
514	Caravan-static	y		aluminium	aluminium, pvc, chipboard interior						Power supplies, plumbing, heating, water, electronic, gas cylinders	667	0	100	0	Frame might be ok but chipboard interiro/ particition walls would be ruined. Gas cylinders might be ok in short duration but the rest lost, so 80% damages by 1m or so, given wires and plumbing also at low level	0		Corrosive	0
518	Cinema	y		steel	concrete floors, block walls						Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	1400				Closure of cinema. Building and services unusable. No damage to sevices but damage to walls, stud partition, but services are at high level	0		No	
517	Bingo	y	y	Steel portal	brick cladding	Brick	Period cinemas	70%			Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	1500				Older buildings have cellars. Floor level timber decking and floor boards, skirting and MDF composite boards	0		No	
518	Cinema	y		steel	composite			50%	Brick load bearing	1985 onwards, steel framed	Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, lifts	850	0	85	15	Minimal impact- internal partition walls affected and office suite. Boiler problems, electrics affected, air conditioning in some places, lifts and cabling	0.5	1	No	0
519	Beach hut	y		wood	wood						soak away, bottled gas, communal stand pipes of site	167	0	100	0	Unless moving water/waves, should survive immersion for short duration. Bottled gas would be ok but lose battery if flood reaches 1m, as raised on shelf at 1m. Soakaway pipes should be ok- not damaged by water	0.3	1.1	assumes coastal flooding	0
519	Beach hut	y		wood	wood						Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	125	0	100	0	all wood- up to 3ft should be ok if short duration. However, weak 'pegging' not deep, so moving water might easily move it	0.1		assumes coastal flooding	0
523	Sports/ Leisure centre	y	y	steel	brickwork	brick		25%	concrete load bearing, also brick structures		Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, lifts	650	0	80	20	timber floors, timber doors would be damaged. Electrical and AC seriously affected. Under floor cabling on ground floor. Most stuff is ground floor level	0.01	0.05	No	0
523	Sports/ Leisure centre		y			brick and steel		70%	load bearing brickwork, solid walls	Steel frame	Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	1500				basement unusable for 2 months, ground floor unusuable for 2 weeks. Shutdown of all electrical cabling. Purging of water supply. Re-testing	0.5	4	No	
523	Sports/ Leisure centre	y		steel	Brick/block		1	2%	traditional construction	steel frame	Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, pressure sets, plate heat exchangers, boilers, underfloor cabling	1000				pool plant, lift pits, boiler plan and drainage generally	0.25		increased costs	
610	School/ University/ College		y			Brick	Pre 1940	25%	load bearing brickwork, solid walls	steel frame	Cabling, power supplies, plumbing, heating, water, electronic	1500				basement/ground floor damage…to stock, plastering and redecoration required. Our of action for between one day and two weeks depending on which service affected	1	4	No	
610	School/ University/ College		y			Brick					Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	773				Decorating and boiler and display boards and electrics, computer cablings, floor of hall would need replacing (wood_	0		No	
610	School/ University/ College		y			Brickwork		75%	very mixed, brick and framed buildings	steel framed	Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, door	2400	0	100	0	Plastering, decoration would be effected, wood block floors would go, pipework insulation. Would clear out the building and start again	0.025	3	No	0

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											closers, underfloor cabling									
610	School	Y		Concrete	Block, brick	Brick	10 out of 17, part pre 60s including listed buildings, but most have some modern buildings, so typical building is modern	59%	Brick, but some framed concrete	Concrete on steel frame with brick on block infill	Cabling, plumbing, water, air conditioning, power supplies, heating, electrical, CCTV/security alarm, lifts, self closing doors, some underfloor heating	600	0	60	40	it would depend on what it was built on. There would not be much damage to the structure, decoration would be damaged. Dam,age might start almost immediately, although some items e.g. Boilers and pumps were on a raised base 30cm up	0.02	3		0
620	General Surgery	Y	Y	Timber	Brick	Steel	Yes, Approximately 1/4 is Victorian but extension is 5 years old	25%	Timber window and door frames	Plastic framews	Cabling, plumbing, water, air conditioning, gas power supplies, heating, electrical, broadband internet, liquid nitrogen cylinders	3000	0	75	25	Concrete floors in new parts would need to be dried out. Low skirting and plasterboard/chipboard would need replacing	0	3		0
620	Surgery/ Health centre		y			Brick	This is a period building				Cabling, power supplies, plumbing, heating, water, electronic, loop system for hard of hearing, TV points in all rooms, extra telephone points	666					0		No	
630	Hall/ community college		y			Timber sections with brick	This is a period building	100%			Cabling, power supplies, plumbing, heating, water, electronic, oump for organ, air circulation		2	92	6	Internal plaster and skirting in offices, wooden floor for church badly damaged. Damage to pump room too but main structure (brick) ok, plus very high. Pump ruined, elect4rictal fuses at 50cm ruined. Higher cabling would be ok	-3	3	Slightly worse	2
640	Library		y			Brick		60%	Various, 1950 system built	Brick built	Cabling, power supplies, plumbing, heating, water, electronic, lifts	1500	0	100	0	Replace floor covering, repair floor screed in a bad flood. Replastering depending on the age of building and how polluted water is. Wiring and cabling would need stripping out. Lifts overhauled. Heating depends on type. Lifts would in a pit	0.01	2	No	0
650	Fire/ Ambulance		y			Brick	Most over 30 years old				Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	1030				all appliances, equipment, offices and communications infrastructure would be affected. Generally, only mess room facilities and larger offices are accommodated at first floor leve and above due to emergency response requirements	0		No	
690	Church		y			Brick	all pre-war	100%			Cabling, power supplies, plumbing, heating, water, electronic	460	1	99	0	Plaster and skirting damage in corridors. Wood panelling in main hall might not survive, nor wooden floors. Convection heaters lost if above 25cm. Fuse bos is only 30cm above floor, so easily damaged. Toilets should be ok though	0.2	2	Salt might ruin wood floors and panels	1
810	Workshop		y			Brick					Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, air extraction, substantial dust extraction, compressed air supply, drains	800				flooring largely write oof. Electrics 90% write off once the boxes have gone. Plumbing needs cleaning. Extraction 100%. Boilers weakened 100%	0		No	
810	Workshop	y	y	steel	brick and block	brick					Cabling, power supplies, plumbing, heating, water, electronic, computed data, electrical wiring	625				Doors affected, electrical sockets, computer poitns, septic tanks	0.1		if salt water flooding, would have to hack off and renew the plaster	
810	Workshop	y		Concrete	block						Cabling, power supplies, plumbing, heating, water, electronic, air conditioning	950								
810	Workshop	y		steek	blockwork						Cabling, power supplies, plumbing, heating, water, electronic	665				damage to doors, cabling			No	
810	Workshop	y		metal cladding	breeze block						Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, printing machinery	164					0.01		No	
850	Laboratory	y	y	Steel	concrete, brick	Concrete/ steel					Cabling, power supplies, plumbing, heating, water, electronic, air conditioning, flammable liquids,	1500				As soon as they get hit but flooding, all parts affected			No	

FIXTURES AND FITTINGS													
MCM Code	Type of Business	What fixtures and fittings	Value	Proportion under ground (%)	Proportion at ground level (%)	Proportion at upper floors (%)	Position height, minimum (m)	Position height, maximum (m)	Affected by flood under 12hrs with no warning	Depth of first damage (m)	Depth of max damage (m)	Damage differ for coastal flooding	Damage differ for coastal flooding
211	High street shop	Floor covering, non moveable clothing fixtures, wall coverings	500				0		All floor coverings, plasters lifts and warps and hardboard goes. These would need to be removed and replaced and very quickly wall fixtures and coverings replaced or substantially repaird (repair is difficult).	0	1.5	No	No
211	High street shop	Shelving, racking, carpets and counters	86				0.25	3		0.25	2	No	Dependent on height
211	High street shop	Stock display shelving and brackets, back of house stock racking, staff room cupboard and sink units	222				0.2	2.4	Would wrtie off anything touched by the water. A lot of shop floor fixtrues are timber and would be written off.	0.02	2.5	No	No
211	High street shop	Wall displays, computers, carpets and wooden flooring, light fittings, shelving, bathroom equipment, safe on floor with cash	324				0		everything from ground floor up probably written off, much wooden	0	0.5		
211	High street shop	Wall mounted display cabinets, carpets, seating, cash desk	250				0.3	2	Height of flood is more relevant than duration	0.3	2	No	No
211	High street shop	Counters, wall shelf units, gondolas, shelf units with goods on both sides, air conditioning, security cameras, overheard door heaters, carpets	888				0		Typical damage	0	3	No	No
211	High street shop	Shopfit, all items	1250				0	3.5	They would get wet, resulting in total loss	0	3.5	No	No
211	High street shop	carpets, flooring, lights and electrics, suspended ceilings, wall units, display units, alarms burglar and fire, safes, till points	659				0	3	Carpets	0	0.75	No	No
211	High street shop	Shelving, fridges, storage units for cosmetics, electric face plates, high cabintes in pharmacy stores, wooden floor covering	14				0.05	2	Chipboard displays and till stands written off and fridges shelving would be removed, cleaned and re-cycled	0.05	1.2	No	No
211	High street shop	Desks, all unitary fittings (prefabircated shelving), floor coverings, computers, air conditioning system	75				0.3		Less duration, less damage to wood floors	0.3	1.25	No	No
211	High street shop	Store furniture (counters) cash, display fittings, stock racking, refrigerated cabinets, plasma screens, metal fixtures	315				0.1		Electrical equipment would be written off. Metal fixtures would be relatively unaffected i.e. they could be cleaned up	0.3	1	No	No
211	High street shop	Gondala stands, service desks	1100				1.5		Total loss	0.1	0.5	No	No
211	High street shop	Carpets, vinyl floor covering, fixed furnitye shelving	36	0	95	5			All written off	0	1.5		
211	High street shop	Carpets, shelving, cafes, lights	90	0	75	25	0	2.5	Carpets, shelving written off	0.07	2.5		
213	Super/ hyperstore	Display shelving, furniture, racking, display refrigeration	500										
213	Super /hyperstore	Checkouts/ computing, coutners, scales, baking equipment and catering (dishwashers), electrical switch gear					0.25		Contamination, electrical damage	0	1	With electrical, more potential for permanent damge	
213	Retail-Superstore	Shopfitting to walls, automatic doors, fire prevention equipment, tills, checkouts, lifts	400				0.05	2	All would be affected	0.02	2.5	No	No
213	Retail-Superstore	Tills, computer equipment, bakery ovens, meat prep - rotisseries, dry cleaning equipment, photo processing equipment, craches, canteen equipment	1770					1.2	Electronically driven = shourtout, affective drying out, hygiene and safety issues from contamination	0.04	0.5		
214	Retail warehouse	Racking, display equipment, internal partitioning, flooring materials, suspended ceiling	750				0	3	Probable write off	0.1	0.2	Metal racking would not be salvageable	No
214	Retail warehouse	Racking, shelving, signage, display material, price stickers	15					2	All would be affected by flood standing at floor level	0	2	No	No
214	Retail warehouse	Shelving and racking. Shop fittings, timber and metal construction	240				0		Majority would be written off	0	3	No	No
214	Retail warehouse	Racking, demountable offices, display cabinets	250				0	2.8	Scrap lot because sewage contamination at 1 to 1.5m. Power jet for less. Time element is paramount.	0.2	1.5	Salt corrodes	no
214	Retail warehouse	Display cabinets, shelving, plinthes, floor coverings					0	3	shelving (metal) could be salvaged if under 12 hours. Some repair, some write off	0			
221	Garage/ vehicle repairs	Reception desk, counter, racking, post lifts	144						Racking ok- would just clean, but post lifts- clean, check, calibrate and load test. Reception write off furniture and fittings	0	3	No	No
222	Filling station	Display equipment, refrigeration, counters, pumps, forecourt equipment, car wash, computers, drinks machines, food preparation equipment, wall posters, signage	150				0		Electrical equipment would be destroyed, other equipment damaged and would need certain replacement and cleaning	0.15	1.5	No	No
221	Garage/ vehicle repairs	Workshop- balancing equipment, vehicle lifts (ramps), tyre changing machinery, racking for exahusts and tyres, counters, furniture, benches	150				0.1	2	Once under water everything would be written off except the vehicle lifts	0.2	1.5	No	No
222	Filling station	freezers, petrol pumps	111				0.15		Sealed mechanical pump, pulleys damaged	0.6	1	50% more damage to metal components. Would need to be stripped down	No
223	Car showroom	Shop fridges, coffee machine, underground safes					0		Fridges /coffee machine written off	0.1	0.5	No	No
223	Car showroom	Office furniture, ramps, MOT safe 9underground), MOT testers, air conditioning units, racking for tyres, balancing equipment, tyre changing equipment	296				0.1	2	Everything would be written off- except the ramps and the safe	0.2	1.5	damage would be greater i.e. nothing could be restored	no
224	Plant hire	Paint spray booth, lays, drills, welding, gas heater, toilets, shelving	77				0		All written off	1	2	yes, higher	No
231	Hairdresser	Expensive flooring, workstations (metal and glass), cupboards, sinks, washer/tumble drier, kitchen units	370	0	100	0	0	3	Write off cupboards and kitchen untis (MDF), otherwise fittings are metal/glass. Flooring might be ok for short duration	0.1	2	Salt water might damage workstations (metal and mirrors)	Longer duration would write off flooring
234	Pubic house/club	Curtains, carpets, pictures, kitchen equipments, bar	100				0	1.5	Limited damage, apart from carpet	0	2		
234	Pubic house/club	Shelves and fridges	136				0		Written off, not economical to repair mass produced furniture	-3	3	No	No
235	Restaurant	Fridge, freezer, cupboards, shelves, pictures, light fittings, carpets, curtains, cooling and dispense of beer equipment	272	20	60	20	0	4	They would require restoration, clean and dry or replacement	0	10		
235	Restaurant	Fridges, freezers, table equipment, ice makers, wooden laminated floors, fixed furniture	598	0	100	0	0.02	2	Flooring would be damaged. At 6 to 8 inches, would damage freezers and fixed furniture	0.01	3		
235	Restaurant	Fridges, freezers, kitchen equipments, ice machines, wooden laminated floors, fixed furniture	672	20	80	0	-1.2	2	Electric hand sryers in basement toilets, computers at desk height, flooring on ground floor, 6-8 inches in the kitchen would damage freezers and fridges	-1.2	2		

MCM Code	Type of Business	What fixtures and fittings	Value	Proportion under ground (%)	Proportion at ground level (%)	Proportion at upper floors (%)	Position height, minimum (m)	Position height, maximum (m)	Affected by flood under 12hrs with no warning	Depth of first damage (m)	Depth of max damage (m)	Damage differ for coastal flooding	Damage differ for coastal flooding
320	Bank	Counters, ATMs, shelving, partitioning for interview rooms, hardwood doors, floor finishings such as floor tiles.	380				0.25	2	A lot of the fixtures are floor mounted and would be damaged immediately. Largescale removal would be required	0	2		
236	Café/ Fast food	Shelving, fixed tables, counters	167				0		Timber, steel and walls affected	0.1	0.15	No	No
236	Café/ Fast food	Racking, counters, coffee machines	200				0.1	1	70% would be affected by a flood lasting les than 12 hours	0.3	3	No	Complete write off, 100% loss
238	Garden centre	Restaurant counters and larger tables, cooking equipments and fridges, shelving, larger stands, carpets	187	0	90	10	0	2	50% write off, easily value of carpets, cookers and chipboard, shelving.stands	0.02	3	Some corrosion, maybe + 10%	
311	Hi-tech office	Kitchens, carpets, ceiling tiles, partitioning					0.01			0.01	0.25	No	No
310	Office	Executive offices on top floor have furniture, carpets, dividing panels between offices	95	0	33	66			Partitioning would be damaged, carpet depends on level of flood.	0.01	3	No	No
310	Office	office equipment	2				0.3		No difference	0.3	1	No	No
320	Bank	NAC cabinets (computers), ATMs, counter line, interview room partitions, counselling position desks screwed to the wall, writing shelves, queueing rails, marketting panels and suspended ceilings.	400				0		there would be sustaining a high level of loss from the start as the bases would be water damaged. If pedestals were water damaged they would write them off (100%) loss. ATMs would be submerged at 1.5 m. where there were glazed aluminium panels separating customer service areas from other areas these would survive.	0	3	No	No
320	Bank	Shelving, floor coverings											
410	Warehouse	Hydraulic lifts and motors, electric gates, shop fittings, shelving, counter , carpets					0		Carpets, shelving, counters etc would be scrapped, electric gates/lifts damaged-need to be repaired	0	0.3	No	No
410	Warehouse	Carpets	0.27	0	100	0	0	0	Written off	0.02	0.02	No	No
410	Warehouse	Kitchen, toilets, office fixtures. Racking of aluminium for paper containers	21.5	0	100	0	0.01	10	Weight of wet paper would collapse racking. It would be twisted and structure would go. The kitchen would be written off at 0.75m and most office fixtures	0.01	2	Slightly higher damages	No
411	Warehouse-electrical goods	Racking, kitchen equipment for cafeteria, fridges, cookers, boilers, generator at ground level, security devices, cameras, seonsors, AC plan, dock levellers	74				0.25	2	The largest slice of the racking would be unaffected by a 3m flood and as the racking is steel it would be unaffected and could be retreived. Generator would be lost at 0.2m. Some boilers on a low plinth would be lost at 0.2m. Cabling at ground floor level might withstand a flood.	0.25	2	Slightly higher damages	No
412	Warehouse - non-frozen	Metal racking, computer servers, lift equipment, lorry bays, metal stairways. Fuel suplies and equipment.	214	0	95	5	0.1	17.5	Would depend on the pressure of wter and whether it would bend the racking and damage it. Depends on velocity of flood, if structural damage. Electrical equipment and motores cleaned and refurbished. Similarly racking cleaned up if not damaged	0.05	3	No	No
413	Warehouse-frozen	metal racking, computer servers, lift equipments, fuel pump equipment	214	0	95	5	0.1	17.5	Would depend on the pressure of wter and whether it would bend the racking and damage it. Depends on velocity of flood, if structural damage. Electrical equipment and motores cleaned and refurbished. Similarly racking cleaned up if not damaged	0.05	3	No	No
511	Hotel	Curtains, carpets, bed, cupboards, banqueting equipment	214.28				0.1		no difference	0.1	1	No	No
513	Caravan-touring	Shelving, fridge, cooker, bathroom, carpet, cupboard units	357	0	100	0	0.5	2.5	very badly damaged chipboard units and electrical items. Bathroom units, sink, toilet ok in short flood so only 80% loss	0.5	2.5	No	No
514	Caravan-static	carpet, beds, cupboards, fixed seating, oven, bathroom	111	0	100	0	0.8	3.3	bathroom might be ok, all else lost, especially chipboard furniture	0.8	2.1	No	No
518	Cinema	Walk in cold rooms, seats (lots of) racking, concession stands, counters, box office, carpets	1005						Auditorium: seats robust, fine line between repairs and write off. Not worth repairs in these circumstances. Foyer: chip board and carpets written off	0		No	No
517	Bingo	carpets, seats, tables, bars, mechanised cash bingo, slot machines	1300				0		Carpet loss and seats come in at 0.6m	0	3	No	No
518	Cinema	Surface finishes, carpets, beech floors, seating, screens, acoustic panels, curtains	320	0	100	0	0	5	Damaged and written off	0.25	5	No	No
519	Beach hut	mdf kitchen unit and sink, built in. Some fixed seating, one shelf	82	0	100	0	0	2	A few cms rise would start to damage units (mdf). 1m rise would write-off 90%. Shelf is at 2m	0.3	2	assumes coastal flooding	No
519	Beach hut	Curtain rails, hooks, shelf	8.3	0	100	0	0.7	0	no damage til 0.7 when straw saturated	0.7	2	assumes coastal flooding	Write off everything
523	Sports/ Leisure centre	Suana, aroma therapy room, lockers, showers, floor finishings e.g. tiles, partition walls	400	0	80	20	0.01	2.7	Everything would be affected to some extent	0.01	3	No	No
523	Sports/ Leisure centre	Carpets, light fittings, shelving and racking	0.25	0	50	50	0	3	Total loss	0.2	3	No	No
523	Sports/ Leisure centre	bar equipment, reception equipment, TVs, catering, refrigeration equipment					0	3	All would need strip, clean and test. Possible write off costs for electric operated fixtures and fittings	0.25	3	Increased costs	No
610	School/ University/ College	Shelving, carpets, light fittings, sanitary ware, fixed desking/counters	120	5	50	45	0	1	80% loss	0.1	1.5	No	No
610	School/ University/ College	kitchen, electricals in kitchen and staff and classroom fitted cupboards					0		Write off, cost of removing and clean up off sites, makes repair improbable	0	3	No	No
610	School/ University/ College	Storage cupboard, sinks, WCs, kitchen fittings	3000	0	100	0	0	1.2	They would possibly salvage the sanitary ware but it might not be worth the effort and the rest would be lost	0.025	3	No	No
610	School	Floor coverings, cupboards, sanitary ware, doors, kitchen cupboards	300	0	65	35	0	2	Fixtures will absorb moisture at bottome, at floor level. They thought it likely that everything would be ripped out, even sanitary fixtures as it would cost more to take out and repair than replace	0.02	3		
620	General Surgery	Fixed consulting desks, bulky examination couches, vaccine fridges, shelving, carpet (tiles)	220	0	75	25	0	3	Fridges might survive, couches should be ok, Doctors chairs are wook so they would be ok, but MDF office furniture and carpets not ok and written off. Probably 2/3 lost in deep, short flood	0.05	3		90% lost at 2m in a longer flood, 50% lost during first few cm: carpets. 2/3 lost in a short duration flood
620	Surgery/ Health centre	Carpets, boiler, stairlift	66.66				0		Would have to close home down with no stair lift	0	0.28	No	No
630	Hall/ community college	Choir stalls, fixed pens, PA System, stone pulpit, lectern, organ, built in cupboards, office furniture, filling cabinets, safe for silver, carpets	380	2	93	5	0	6	Solid oak furniture and stone - should be ok for under 12 hours. Organ lost if above 30cm (raised on plinth)	0.1	6	No	No
640	Library	Shelving, metal and wood, computer benching, computers, enquiry desks	100	0	100	0	0.01	2	Metal shelving could be hosed down, disinfected, wood shelving and other things would warp and be written off	0.01	1	No	No
650	Fire/ Ambulance	lockers, showers, network cabinets, alarm systems	14				0.25	1.5	All contaminated fixtures and fittings would have to be replaced	0.25	1.5	No	No
690	Church	Large fixed kitchen, all raised 30cm above floor on plinths,	46	0	100	0	0	3	Very badly - buckling/warping of wood panels, loss of kitchen equipment.	0	2	No	No

MCM Code	Type of Business	What fixtures and fittings	Value	Proportion under ground (%)	Proportion at ground level (%)	Proportion at upper floors (%)	Position height, minimum (m)	Position height, maximum (m)	Affected by flood under 12hrs with no warning	Depth of first damage (m)	Depth of max damage (m)	Damage differ for coastal flooding	Damage differ for coastal flooding
		sinks, fridges, cookers, washer dryer, large tables, ladies and gents and disabled toilets, carpet for stage, stage curtains, boiler							However, little damage delow 0.3m				
810	Workshop	benches, carpets, spotlighting in showroom, partition walls, plant and machinery	254				0	2	carpet would go immediately, and partitions	0	1	No	No
810	Workshop	Press breaks, guillotines, ring rolling equipment	10.42				0.1	3	electrical motors have to be stripped out and replaced with new parts, other parts to be cleaned and reoiled	0.1	3	No	No
810	Workshop	kitchen sink unit, fridge, racking	15.27				0	1.5	Damage would start at a few inches because the kitchen sink unit was at ground level and its chipboard would be damaged even with a little water. Maximum damage would be reached at 1.5m when the fridge and sink unity would be written off			No	No
810	Workshop	wood working and joinery machines					0		machines would have to be replaced	0.1	0.1	No	No
810	Workshop	heavy machinery	547				0	1.5	electrics, circuit boars	0	1.5	No	No
850	Laboratory	Paperwork, cable trays, controls, distortion boars, lighting	100				1	2	depends whether you shut them down or not (warnings)	1	2	No	No

STOCK												
MCM Code	Type of Business	Stock	Value per m2 (£)	Proportion below ground	Proportion at ground level	Proportion at upper floors	Position, minimum (m)	Position Maximum (m)	Damage differ for flood under 12 hrs with no warning	Depth of first damage (m)	Depth of max damage (m)	Damage differ for coastal flooding
211	High street shop	Clothing, accessories and all finished goods	250				0.25		Underwear- if any flooding these, get rid for hygiene reasons. But keep outdoor garments and synthetics, if not touched by water. Any item touched will be written off or some salvage value	0.25	2	
211	High street shop	DVDs, video cassettes, consumables, some DVD and video players	43				0.1	2	Depends on height of water. Quite a lot of stock would 'not be tarnished' evem of waters stayed 12 hours or more	0.1	2	No
211	High street shop	General products	667				0.05	2	Stock would be written off even if just splashed.	0	2.5	No
211	High street shop	Mobile phones and accessories	378				0.5		Depend on depth	0.75	2.5	No
211	High street shop	Shoes, some electronic equipment for staff	166				0.3		Any stock touched by water would be written off	0.3	2.25	No
211	High street shop	Electrical goods, TVs, computers					0			0	3	No
211	High street shop	Computers, office tables	6400				0	4		0.5		
211	High street shop	Varies considerably	1174				-2.75	0.75	paper is very vulnerable, also clothing. Once damaged with stains from water: written off. Goods are stored on shelves in the basement. Boxes of paper on the floor. In the basement there would be flooding from above and threefore it would be likely that everything would be damaged. Over a third of the stock is kept in the basement usually so that would go as the basement filled up from the ground floor level.			
211	High street shop	Cosmetics, toiletries, other merchandise, confectionery, drinks, sandwiches, pharmaceutical products in some stores	1223				0.3	1.8	Any in contact with flood waters would be written off and maybe those just above floodwaters. All foodstuffs in fridges written off but not confectionary at ambient temperatures	0.3	1.8	No
211	High street shop	Books	150				0.15			0.15	3	No
211	High street shop	Stock is all finished products	227				0.1	2	All stock would be written off due to possible contamination and raised moisture content	0.1	2	No
211	High street shop	Clothing, entertainment, toys, sweets	160				0	2	packaging and contents damage	0.1	0.5	No
211	High street shop	Mobile telephones and accessories	43	0	100	0	0	1.8	All written off if boxes damaged	0	1.6	
211	High street shop	Brochures, money and travellers cheques	36	0	90	10	0.05	0.75	written off	0.05	0.6	
213	Super/ hyperstore	Goods for sale	1,500				0.1	2	Totally destroyed	0.3	2	
213	Super /hyperstore	Goods for sale, food stuff, electrical, soft furnishings, clothes, dry groceries, fresh foods					1		Contamination	0.1	1	
213	Retail-Superstore	Any product stored on warehouse racking, shelving, cold/frozen storage rooms	200				0.01	3				
213	Retail-Superstore	All finished goods, food stuff and allied products	740				0	3	Traditional card/paper packaging			
214	Retail warehouse	All goods for sale to customers	750				0	3	Total loss of stock after around 2 hours	0.1	0.2	No
214	Retail warehouse	Wide range of goods on sale and small stands.					0.01	2	Would find some salvage value but would discrad all affected stcok as flood damaged	0.01	3	No
214	Retail warehouse	Sales area and pre sales (storeroom) stock	600				0.25	6	written off	0.25	6	
214	Retail warehouse	Vehicle component, bikes etc	375				0.2		High value items on ground (e.g. in car DVD, TV systems), cycles on display	0.2	1.5	no
214	Retail warehouse	Electrical goods household domestic appliances					0		Goods rejected for sale.	0	3	No
221	Garage/ vehicle repairs	Tyres, exhausts, brake pads, caskets	75				0.1	4	Lose all tyres and exhausts, total scrap, mashed or burnt, recycled via collection centre. Pay to be scrapped at £1 per tyre			No
222	Filling station	Shop retail goods, fuel supplues					0		Shop goods lost, possible fuel contamination	0	0.5	No
221	Garage/ vehicle repairs	Tyres, exhausts, brake pads, oil	100				0.3	3	Everything will be written off except tyres but these will not be sold	0.3	1.5	No
222	Filling station	Petroleum spirit, diesle, cars, convenience store stock	222				0.3		Ruined! Contamination	0	0.3	0.3 write off (underside of cars)
223	Car showroom	Petrol stocks, forecourt stocks	50				0		All written off if boxes damaged	0.1	0.2	No
223	Car showroom	parts- entire range for cars, tyres	131				0.3	3	A small percentage is affected	0.3	3	damage would be greater i.e. nothing could be restored
224	Plant hire	Pils in containers, protective clothing, tools, lawn mowers, boats, small items in shop	237				0.5		All oil and stock lost	0	2.5	Higher
231	Hairdresser	Shampoo, hair products, tints, perm lotion etc	32	0	100	0	0.2	1	95% of stock is not for sale- used for clients instead. All in sealed containers should be fine. 5% for retail sales, probably written off or sold at 1/2 price	0.2	1	50% more damage for salt
234	Pubic house/club	Food, kegs, bottle beer	50				0.1		Damage beyond salvation	0.1	1	`
234	Pubic house/club	Beer and spirits, crisps and nuts, food and glassware	36				-3		Total write off, public health regulations	-3		No
235	Restaurant	Food and drink and consumable goods	15.85	45	50	5	0	2	Destroyed and written off unless removed prior to flood	0	3	
235	Restaurant	Food, drink, main value is in spirits	60	0	100	0	0.01	2.4	Beer in sealed bottles not affected. All food would og. Would try to save valuable spirits	0.01	2.4	
235	Restaurant	Food, drink, main value is in spirits	67	90	10	0	-2.4	2.4	All food would be lost, apart from tins. Beer vats would not be affected. Sealed bottles could be cleaned.	0.02	1.2	
320	Bank	Money, wrapped in plastic bags, paper, publicity materials, display material, cheques, letterd headed and computer paper and documents.	0				2	3	Stocks mostly held above ground floor so limited damage			
236	Café/ Fast food	Food stuffs, drinks	37				0		Everything would be written off	0	0.1	No
236	Café/ Fast food	Cpffe beans, foodstuffs (consumables), paper products	32				0.5	2		0.5	2	No
238	Garden centre	Plants, retail items, garden furniture 9much wood), ornaments, furniture, gravel, stoneware, kitchenware, gifts, stationary	20	0	100	0	0	2	50% value reduction of boxed retail items. No damage to outside plants unless moving or salt water. Write off for indoor plants if submerged	0.02	2	90% outside losses
311	Hi-tech office	desk top boxes, keyboards, supplies for the networsk (small stocks)					0.03	6	Any goods touched by the flood waters would be written off. Even if only the boxes were wet, as electrical goods with processors in them, they would have to go back to the manufacturers to be checked.	0.03	6	
310	Office	Stock is simply stationary and printed material.	0.4	0	100	0	0.01	1.5	Immediately, would write it off. Damp and easier to throw out in flood.	0.01	0.1	No
310	Office	Electronic equipment	30,000,000				0.3	1	neither duration nor warnings are relevant	0.3	1	No

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320	Bank	coins and paper money, paper, publicity material	8				0.1	1.8	Coins would survive, paper money would be replaced by bank of England. Paper stock could be in basement but is low quality/easily replaced	0.1	1.8	No
320	Bank	No raw materials										
410	Warehouse	Merchandise, bubblewrap, boxes, sellotape	0.33				0		Would be written off with a few inches of flood water, would be damaged by splashing	0.05	0.2	No
410	Warehouse	Packing materials, bubblewrap, cartons	7	0	100	0	0.25	6	written off	0.25	2	No
410	Warehouse	Domestic effects, commercial furniture, commercial records.	5166	0	100	0	0.01	8.6	Water damage, moisture damage and curtains, paper	0.06	2	No
411	Warehouse-electrical goods	Boxed consumer good, from small tape recorders, TVs, Digital cameras, HiFi CD players, in car entertainment, speakers, computer display screens, recording media, batteries	3703				0	10	They would have to write off anything that the flood touched even if it was only the cardboard box. As they were dealing in electrical goods there was a safety issue involved in the goods being even in damp surroundings and possibly having water/damp penetration. Even some goods near the flood waters. others would have to be rigorously checked before they could be passed for sale for safety reasons. The problem of water vapour- there is a danger that if TV or electronics were wet or in a wet environment then they might be dangerous.	0	10	Slight increase in damage
412	Warehouse - non-frozen	Food, tins, dry goods, household, cleaning, chemists goods, beer, wine, spirits, high value. Fruit and veg comes in overnight, health and beauty (high value).	286	0	100	0	0.05	17.5	If physically in contact with water, would be disposed of. Fresh fruit, veg, fresh goods written off. Otherwise salvage. Boxes are wrapped in plastic, bottles etc might be ok	0.05	17.5	No
413	Warehouse-frozen	Frozen food in carboard coxes	933	0	100	0	0.05	17.5	Frozen food stays frozen for 3-4 hours and then starts to deteriorate. If power were off for more than 3-4 hours, then would lose all stock. Equipment that drives the freezers is 5 metres up but it runs on electrical power supply.	0.075	3	No
511	Hotel	food, stationary, linen	35				0.1		No difference	0.1	0.3	No
513	Caravan-touring											
514	Caravan-static											
518	Cinema	Sweets, pop, ice cream, popcorn, etc	40	20			0	1.5	health regulations- destroyed	0	1.5	No
517	Bingo	Minimal amount of beers, wines and spirits. Also prizes	40000				0		Totalled because of health and safety. Written off as soon as polluted water appears in premises	0	0.3	No
518	Cinema	Film (high value), foodstuff, retail stcok, popcorn, sweets	26	0	100	0	0	2	All foods written off, films damaged- written off	0.25	2	No
519	Beach hut											
519	Beach hut											
523	Sports/ Leisure centre	merchandising material, cleaning material, beauty materials, paper, brochures, office stuff, toilet paper	6.6	0	80	20	0.01	1	All destroyed as standing on ground	0.01	1	No
523	Sports/ Leisure centre											
523	Sports/ Leisure centre											
610	School/ University/ College											
610	School/ University/ College	Books and stationary					0		Not just damage, it affects if damp, smells, dirty, despite depth. Paper soaks up damp.	0	0.5	No
610	School/ University/ College	Paper, paints, books	5.25	0	100	0	0	2	All lost	0.025	3	No
610	School	Food in kitchens, freezer, dry goods, tins, tuck shop, papers, materials for wood and metal work, booklets, short printed materials	7	0	60	40	0	1.5	With damp, paper will go. Would not rescue food in freezers or other places			
620	General Surgery	Disposables (dressings, needles etc), £3-4k value of childrens vaccines (wall mounted)	16	0	100	0	0.1	3	All would be destroyed/unausable			
620	Surgery/ Health centre	food, pads, freezer in garage	2.5				0.1			0.1	0.15	No
630	Hall/ community college	Communion wine, altar bread, candles	0.5	0	100	0	1	2	Wine fine (bottled), candles would dry but bread damaged	1	2	
640	Library	Books, videos, dvds, cds, computer, stamps	504	0	100	0	0.45	2	Written off due to potential contamination	0	2	No
650	Fire/ Ambulance											
690	Church											
810	Workshop	timber, boards, beneers, nan made board, work programmes, finished goods	635				0	1		0	1	No
810	Workshop	steel tube, aluminium extrusions, sheet steel sections, polythene sheeting and plastic netting					0.15	2.5		0.15	2.5	salt water would make a dramatic difference- would have to write off the steel tubing
810	Workshop	work in progress stock and raw materials, motors, drivers, printed circuit boards	610				0	3	Condensation issue, stock would have to be written off.	0	3	Corrosion major issue
810	Workshop	hard and soft wood.					0		Stock would be warped and unusable	0	2	
810	Workshop	Paper, ink, chemicals, finished goods	87.5				0.01			0.01	1	
850	Laboratory	packaging, active ingredients, component parts, keys, fibre board, solvents, liquitds, bottled gas	2000				0		completely- even with good containers- written off. If very valuable, may try to recover, but generally 100% loss	0	0.25	No

Appendix 3. Building elements analysis and pricing

Element	Type of Construction	Description	Notes	Demoli-tions cost £/m2	New Build Cost £/m2
External Walls	Masonry monolithic structure				
		Solid machine made facing brick, 225mm, 3 coat plaster inside, emulsion		34.00	80.00
			As above but cement rendered outside	38.00	93.50
			As above but with applied external insulation system – glued foam insulation boards, specialist self-coloured render.	42.00	130.50
		Solid concrete blockwork 200mm		28.00	35.00
			As above but cement rendered outside	32.00	48.50
			As above but with applied external insulation system – glued foam insulation boards, specialist self-coloured render.	36.00	85.50
	Cavity wall				
		Machine made facing brick 112mm, gap25mm, glassfibre		37.00	120.00

		batts 25mm, aerated block 100mm, 3 coat plaster, paint			
Element	**Type of Construction**	**Description**	**Notes**	**Demoli-tions cost £/m2**	**New Build Cost £/m2**
			As above, but cement rendered outside	40.00	133.50
			As above, but blow-in fibre/vermiculite of full fill fibre insulation	40.00	146.00
			As above but drylined inside with gypsum plasterboard, skim, emulsion	42.00	161.00
	Concrete				
		Solid reinforced basement wall, fairfaced		75.00	300.00
			As above, softwood battened, fibre batt insulation 75mm, plasterboard, skim, emulsion	80.00	347.00
		Cavity, precast storey height unit with integrated polystyrene foamed insulation and plasterboard, skim, emulsion interior finish		40.00	110.00
	Steel				
		Built-up cladding - external trapezoidal coated steel sheet, galvanised z cladding rails, mineral fibre batt insulation 150mm, internal coated steel		30.00	97.00

		sheet			
		Composite cladding – sealed insulated units with weather-sealed joints on galvanised z cladding rails		30.00	115.00
Element	**Type of Construction**	**Description**	**Notes**	**Demoli-tions cost £/m2**	**New Build Cost £/m2**
		Light steel framing, insulated sheathing board on outside face (Celotex) 100mm, plasterboard lining internally, with brick external cladding		30.00	145.00
			As above but with fibre batt insulation 100mm between steel studs plus insulated sheathing board 25mm on outside of studs	35.00	175.00
			As above, but with timber hardwood weatherboard cladding	35.00	225.00
			As above but with PVC board cladding	35.00	220.00
	Curtain wall				
		Aluminium/steel framed, double glazed units, spandrel frame		39.00	450.00
			Ditto, but storey height glazing panels	39.00	500.00

		Timber framed, laminated softwood timber, with glazing options as above		39.00	450.00
		Structural glass facade system		50.00	1000.00
	Timber				
		Timber framed open panel, mineral fibre insulation, vapour barrier, plasterboard lining, emulsion. Semi-permeable membrane, brick cladding.		30.00	108.00
Element	**Type of Construction**	**Description**	**Notes**	**Demoli-tions cost £/m2**	**New Build Cost £/m2**
			As above but with timber board cladding	30.00	100.00
			As above but with PVC cladding	30.00	95.00
Internal walls					
	Fixed				
		Lightweight blockwork, plastered both sides.		22.00	56.00
			As above, drylined both sides		60.00
		Timber stud partitions, plasterboard both sides		12.00	45.00
			As above but with fibre quilt sound insulation infill		55.00
		Galvanised steel stud partitioning, plasterboard both		13.50	55.00

		sides			
			As above but with fibre quilt sound insulation inside	15.50	65.00
		Glass blocks		35.00	225.00
		Glazed panels, aluminium framed		35.00	195.00
			As above but painted softwood framed	35.00	135.00
	Demountable				
		Solid panels		12.00	180.00
		Glazed panels		12.00	200.00
Floors					
	Solid floor				
Element	**Type of Construction**	**Description**	**Notes**	**Demoli-tions cost £/m2**	**New Build Cost £/m2**
		DPM, ground supported concrete slab, screed, painted wearing surface		30.00	84.50
		Ground supported concrete slab, DPM, extruded foam insulation boards, vapour barrier, floating chipboard floor finish		35.00	122.50
	Suspended floor				
		Reinforced concrete slab, plastered below, screeded above		30.00	125.00

		Timber joists, plasterboard below, chipboard flooring above		8.50	55.00
			As above but with rigid insulation boards between joists supported on battens (suspended ground floor)	8.50	63.00
		Beam and block (concrete), extruded foam insulation boards, vapour barrier, chipboard flooring		30.00	70.00
		Steel composite (profiled steel sheet with concrete poured on top)		30.00	85.00
		Steel mesh	more info required to provide a firm price	-	-
		Glass	inquiry's out to specialist suppliers	-	-
Element	**Type of Construction**	**Description**	**Notes**	**Demoli-tions cost £/m2**	**New Build Cost £/m2**
		Raised floor – steel supports, steel framed panels with ply infill.		11.00	80.00
Windows					
	Metal (steel, aluminium, bronze)			35.00	400.00
	Plastic (PVC)			35.00	250.00
	Wooden (softwood, laminated, hardwood)	softwood window		35.00	350.00

		hardwood window		35.00	460.00
		laminated window		35.00	320.00
External doors					
(nr)	Personnel doors – timber, PVC, steel				
		Timber		12.00	440.00
		Steel		35.00	485.00
		PVC		12.00	250.00
	Cargo doors		more info required to provide a firm price	2500.00	-
Stairs					
	Timber			133.00	817.50
	Concrete		assumed as pre-cast staircase, however examples have been found at higher rates	260.00	4,200.00
	Steel			190.00	6,100.00
Element	**Type of Construction**	**Description**	**Notes**	**Demoli-tions cost £/m2**	**New Build Cost £/m2**
Services					
	Electric supply				
			typical warehouse rate range from £51.00 - £66.00		58.50
			typical office area range (for office up to 3000m2, incl category A fit out) from £56.10 - £73.00		64.55

			typical retail outlet £83.00 - £110.00		96.50
	Alarm systems				
			security alarm systems range from £1.90 - £2.60		2.25
	Hot water supply				
			hot & cold water installations, complete; industrial, leisure, shopping malls and the like range from £10.60 to £13.80		12.20
			hot & cold water installations, complete; office, hotels, residential and the like range from £29.00 to £38.00		33.50
	Heating system				
			LTHW heating rate range from £41.50 - £54.00		47.75
	Boiler				
		30.00 kW output; supply & fit	Unit cost for supply and fix		650.00
	Ventilation and air conditioning				
			4 pipe fan coil for office building up to 3000m2 range from £65.00 - £85.00		75.00
Element	**Type of Construction**	**Description**	**Notes**	**Demoli-tions cost £/m2**	**New Build Cost £/m2**
	Drainage				
			site drainage range from £9.60 - £12.40		11.00
			building drainage range from £8.50 - 11.00		9.75

Finishes					
	Floor finishes				
		Concrete screed		10.00	25.00
		Stone		20.00	100.00
		Timber		4.00	60.00
		Chipboard		7.00	25.00
		Ceramic floor tiles		10.00	90.00
		Carpet		2.00	25.00
		Raised floor (steel composite panels, timber composite panels)		1.00	80.00
	Wall internal finishes				
		Plaster		5.00	15.00
		Cement render		8.00	30.00
		Stone			350.00
		Timber		4.00	500.00
		Ceramic tiles		11.00	80.00
		Cladding / panels	Unpriceable without type of cladding stated	-	-
Element	**Type of Construction**	**Description**	**Notes**	**Demoli-tions cost £/m2**	**New Build Cost £/m2**
	Wall external finishes				

		Rainscreen cladding		30.00	190.00
		Metal mesh screens		9.00	34.00
		Metal	Aluminium over cladding system rain screen £195.00 - £250.00	30.00	222.50
		Glass (panels, blocks)	Glass block panel range from £200.00 - £500.00	35.00	350.00
		Concrete		56.00	120.00
		Masonry		54.00	105.00
		Plastics and composites		10.00	45.00
		Timber		10.00	95.00
		Stone		50.00	350.00
		Render (cement, lime)		8.00	40.00
Insulation					
	Polyurethane (panels, foam)		Polyurethane faced acoustic insulation - source Caley Marine	2.00	150.00
	Expanded/extruded polystyrene (panels, foam)		Expanded polyurethane faced acoustic insulation - source Caley Marine	2.00	160.00
	Insulating concrete forms (polystyrene or polyurethane modular units filled with concrete)		Cost of installation labour, reinforcement, bracing, and concrete placement will be additional	20.00	40.00
	Mineral fibres (glass, min. wool)		Rockwool Flexi Insulation Slab - insulation express	2.00	26.00
Element	**Type of Construction**	**Description**	**Notes**	**Demoli-tions cost**	**New Build Cost**

				£/m2	£/m2
	Wood fibres (loose-fill, rigid panels)		Steico Flex Wood Fibre Insulation	2.00	36.00
	Vacuum insulated panels		inquiry's out to specialist suppliers	-	-
	Structural insulated panels		Paroc Structural Insulated Panels	10.00	30.00
	Aerogels		inquire to specialist suppliers	-	-

Appendix 4. Drying rates

Qualifications:

It must be emphasized that the cost advice given is an average and that costs can vary considerably from contract to contract depending on individual contractors, site conditions, type and extent of contamination, methods if working and various other factors as diverse as difficulty of site access and distance from approved tips

Drying Rates

The following workings are based on the assumption that most properties are dried in 1 – 3 weeks and general rule is 1 dehumidifier and 1 air mover for every 30 cubic metres of building

3 weeks = 21 Days

Drying Equipment	Daily Rate £	Days of Drying	Total Rate £	Comment
Air Mover	£ 7.15	21.00	£ 150.15	Rates provided by Restoration UK
Large Desiccant Dehumidifier	£ 18.00	21.00	£ 378.00	Rates provided by Restoration UK
			£ 528.15	

Contractor Prelims	£ 79.22	Say, 15%
Sub-Total	£ 607.37	
Typical drying space for 1 Air remover/Dehumidifier	30	m3
Total	£ 20.25	m3

Appendix 5. Cleaning/disposal of pollution

Cleaning/Disposal of pollution			
Typical 2010 tipping charges (excluding landfill tax) as Spons 2012			
Waste classification	Charges (£/tonne)	£/tonne, say	
Non- hazardous wastes (debris/silt)	£10.00 - £25.00	£ 17.50	
Hazardous Wastes	£25.00 - £85.00	£ 55.00	
Contaminated Liquid	£40.00 - £75.00	£ 57.50	
Contaminated Sludge	£55.00 - £200.00	£ 127.50	
Waste classification	Assumptions for Cleaning Times	Unit	m2/hr
Non- hazardous wastes (debris/silt)	5.00	min/m2	12.00
Hazardous Wastes	10.00	min/m2	6.00
Contaminated Liquid	10.00	min/m2	6.00
Contaminated Sludge	15.00	min/m2	4.00
Non-Hazardous Wastes	Rate	Unit	Total
Initial Call Out Charge	90.00	1.00	£ 90.00
Technician/hour (x2)	35.00	2.00	£ 70.00
Heavy duty pressure Washer	2.10	1.00	£ 2.10
Truck Mounted Extraction Unit	55.00	1.00	£ 55.00
Safe Disposal	21.00	1.00	£ 21.00

Sub-Total			£ 238.10
Preliminaries			£ 35.72
Total (£/hr.)			£ 273.82
Cleaning of surface in m2/hr. (assumption)			12.00
Total (£/m2)			£ 22.82
Hazardous Wastes	Rate	Unit	Total
Initial Call Out Charge	90.00	1.00	£ 90.00
Technician/hour (x2)	35.00	2.00	£ 70.00
Heavy duty pressure Washer	2.10	1.00	£ 2.10
Truck Mounted Extraction Unit	55.00	1.00	£ 55.00
Safe Disposal	66.00	1.00	£ 66.00
Sub-Total			£ 283.10
Preliminaries			£ 42.47
Total (£/hr.)			£ 325.57
Cleaning of surface in m2/hr. (assumption)			6.00
Total (£/m2)			£ 54.26
Contaminated Liquid	Rate	Unit	Total
Initial Call Out Charge	90.00	1.00	£ 90.00
Technician/hour (x2)	35.00	2.00	£ 70.00
Heavy duty pressure Washer	2.10	1.00	£ 2.10
Truck Mounted Extraction	55.00	1.00	£ 55.00

Unit			
Safe Disposal	69.00	1.00	£ 69.00
Sub-Total			£ 286.10
Preliminaries			£ 42.92
Total (£/hr.)			£ 329.02
Cleaning of surface in m2/hr. (assumption)			6.00
Total (£/m2)			£ 54.84
Contaminated Sludge	Rate	Unit	Total
Initial Call Out Charge	90.00	1.00	£ 90.00
Technician/hour (x2)	35.00	2.00	£ 70.00
Heavy duty pressure Washer	2.10	1.00	£ 2.10
Truck Mounted Extraction Unit	55.00	1.00	£ 55.00
Safe Disposal	153.00	1.00	£ 153.00
Sub-Total			£ 370.10
Preliminaries			£ 55.52
Total (£/hr.)			£ 425.62
Cleaning of surface in m2/hr. (assumption)			4.00
Total (£/m2)			£ 106.40