



1947 U.K. RIVER FLOODS: 60-YEAR RETROSPECTIVE

RMS SPECIAL REPORT



Risk Management Solutions

INTRODUCTION

In the second half of March 1947, the most catastrophic river floods for at least 200 years occurred in the United Kingdom. The flooding, which inundated nearly all the main rivers in the South, Midlands, and the Northeast of England, was notable for its origins, regional extent, and duration. Impacting thirty out of forty English counties over a two week period, around 700,000 acres of land were underwater. Tens of thousands of people were temporarily displaced from their homes, and thousands of acres of crops were lost.

The flooding was triggered by the rapid thaw of deep snow that covered much of the country after one of the coldest and snowiest winters on record. The thaw was triggered by the arrival of a succession of southwesterly depressions, each bringing significant additional rainfall. During this period, flooding was not only widespread in the U.K., but also extended across Europe. In Spain, Germany, Poland and the Czech Republic, rivers across the continent burst their banks as meltwater and heavy rainfall combined.

As the event occurred before the era of flood insurance, and in the immediate aftermath of the Second World War to a backdrop of rationing and significant post-war deprivation, the overall economic impact of the catastrophe was not fully assessed at the time as impacts were considered local rather than national. Sixty years after the event, this retrospective reviews the events of March 1947 and assesses the economic and insurance costs that would be associated with a repeat of the same event in 2007.



Figure 1: Flooding of Albert Street in Windsor, one of many towns impacted by the 1947 river floods

(Courtesy of P. Wells from the Royal Windsor website:

<http://www.thamesweb.co.uk/windsor/windsorhistory/floods47.html>)

THE 1947 U.K. RIVER FLOODS

The snow thaw began on March 9, 1947 as Britain started to recover from an extreme winter with heavy snowfall and persistent freezing temperatures. As milder weather finally arrived, heavy rain began to fall, causing snow across the country to melt rapidly. After weeks of frost, the ground was frozen hard and unable to soak up any moisture forcing the meltwater and rain to drain off into rivers. From March 11 through March 24, multiple river systems flooded throughout England and the eastern edge of Wales. Figure 2 shows the progression of the 1947 floods, highlighting the major rivers that flooded over the course of the event.

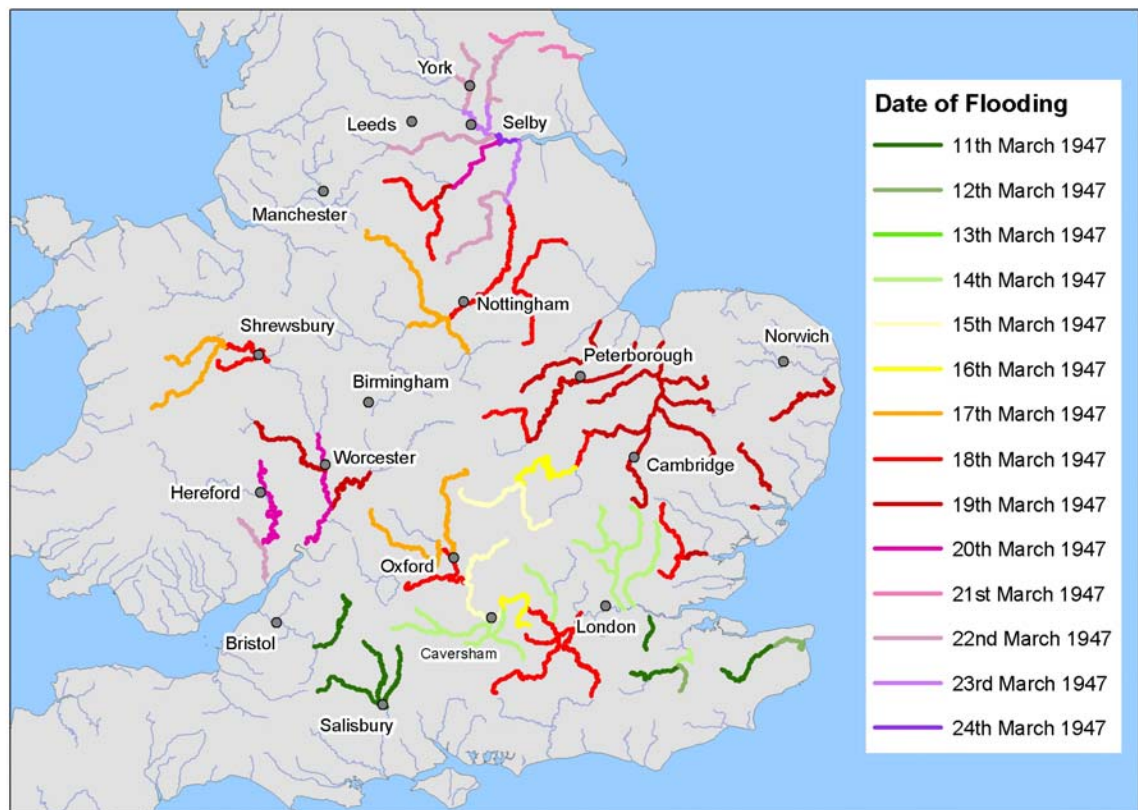


Figure 2: Map of major rivers that flooded during the 1947 event with date of first flooding

Flooding began across the South of England, from Somerset to Kent, as rivers such as the Avon in Somerset and Wiltshire, and the Medway and Great Stour in Kent overflowed. Parts of west and northeast London were inundated on March 14 and 15 as the River Thames and other surrounding rivers overflowed. Over 1,600 homes flooded at Caversham near Reading, and flood levels peaked in the Lea Valley to the east of London on March 16. The flooding of the filter beds along the River Lea to the northeast of London meant that water supplies had to be cut off to more than a million people living in east and northeast London.

As a large Atlantic depression tracked across England bringing warmer temperatures, flooding extended to rivers further north. In East Anglia, the strong southwesterly winds associated with the storm of March 16 caused waves to pound the dykes that breached and flooded large areas of the low-lying Fenland. Water overflowed the channel of the River Trent on March 17, causing severe flooding in Nottingham with over 3,000 homes and 85 factories under water (Figure 3). A further 4,000 properties were reported flooded southwest of Nottingham in Long Eaton and Beeston, while more than 2,000 homes flooded in West Bridgford. Flooding peaked on March 18 and 19 when there was major flooding to the north in Yorkshire, along with continued peak flooding in parts of the Midlands and Southeast. In the Midlands, rivers flooded in Herefordshire and Gloucestershire as meltwater from the Welsh mountains ran into the Wye and Severn river basins. There were reports in Worcester of the River Severn rising 3 m (10 ft) in 24 hours. Closer to London, 1,400 homes in Maidenhead, 3,000 homes in Oxford, and 1,350 homes in Windsor were flooded.



Figure 3: Flooding of Wilford Lane in Wilford, Nottingham as the River Trent burst its banks (Courtesy of Nottinghamshire Local Studies and www.picturethepast.org.uk)

As river levels in the South and West of England started to recede after March 20, water levels were still rising in the Northeast, with widespread flooding extending to the rivers Wharfe, Derwent, Ouse and Aire. Almost the whole of the town of Selby, south of York, was inundated with over 70% of all properties flooded. The Lower Trent Valley was also inundated as the flood wave reached the tidal part of the river where it was impeded by a spring tide. Finally, on March 24, the River Ouse in Yorkshire peaked as the waters continued to recede in the southern part of the country.

CAUSE OF FLOODING

The meteorological conditions at the beginning of 1947 in England and Wales were predeterminants of the widespread and severe flooding in March. Starting in January 1947, unprecedented 'continental' winter weather conditions more familiar in Scandinavia or Eastern Europe hit the U.K., uninterrupted by any spells of warmer Atlantic origin conditions. Not only were these months extremely cold, but they included high levels of precipitation in the form of rain, snow and sleet. The mean maximum temperature during February 1947 in England was -0.7°C with the mean minimum of -3.8°C , as compared to the climatological average of 6.9°C and 1.0°C , respectively. Temperatures as low as -21°C were recorded at Woburn in Bedfordshire and over 2 million sheep and lambs and 30,000 cattle perished during this freezing period. While cold winters had been known in the U.K. through the 17th and 18th centuries, cold weather was usually accompanied by reduced precipitation. However, from January to March 1947, the average precipitation for the country was 31.1 cm (12.2 in), nearly 150% of the long-term average.

SNOW ACCUMULATION

February 1947 was an extremely cold month, characterized by heavy snowfall in the Eastern and Midland districts of England (Figure 4). Snow lay over much of the country throughout February and early March. Around 30 cm (12 in) of 'level' snow persisted across areas of Durham, Yorkshire, Lincolnshire, and the East Midlands during this period. In some areas, snow lay on the ground in excess of 30 days. Persistent easterly winds, which were strong at times, led to significant snow drifts.

The cold weather continued into March. On March 4, a deep depression moved through the English Channel, triggering more heavy snowfall over most of England and Wales with further severe drifting (Figure 5). During these wintry months, the snow reached its deepest level on March 6 in the amount of 42 cm (16.5 in), while the heaviest snowfall on a single day was 17 cm (6.7 in) on March 12, during a final blizzard in the Midlands.



Figure 4: Deep snow along the road between Batham Gate and Peak Dale, southwest of Sheffield (Courtesy of Derbyshire Local Studies and www.picturethepast.org.uk)



Figure 5: Deep snow drifts in Wales in early March 1947 (Courtesy of Carolyn Ellis)

THE GREAT THAW

A storm crossing southern England on March 10 caused more snowfall, turning to rain on March 11. As the low pressure system moved east, it allowed relatively warm, moist air from the southwest to flow across the region and cause the snow to thaw. A daily weather report from the Meteorological Office on March 12, 1947 suggests that snow cover on this day in many southern parts of the country had reached its lowest levels since January. As the snow cover continued to diminish rapidly, meteorological stations started to report ground flooding in the South and West of England.

PERSISTENT HEAVY RAIN

Further rain was generated on the evening and night of March 16, as a storm with widespread, severe gales swept across the U.K. The windstorm had an ENE track that ran from the southern coast of Ireland across to the Humber estuary in Northeast England, with a pressure nadir of 972 mb. The storm had a bent back occlusion with very high windspeeds at the southern tip of the scorpion's tail front (as is typical of a 'sting jet'), reaching a 44 m/s (98 mph) peak gust at Mildenhall Cambridgeshire, while winds across South Wales and the Midlands were generally in the range of 31 to 36 m/s (70 to 80 mph). Across a swath from Bath to Nottingham, there were widespread reports of roads blocked by fallen trees and damage to buildings, including in London.

Severe weather conditions persisted until March 24. The excessive rainfall, combining with milder temperatures, contributed to rapid snow melt across the country. By March 21, almost all of the main volume of snow lying on the ground had gone. Temperatures by March 22 were peaking at 11.1 °C, and reached 12.2 °C by the end of the month. Rainfall over the final ten days of the month was exceptional, breaking records for March rainfall across many parts of the country. The Royal Meteorological Society reported that the rainfall total in March 1947 was 13.2 cm (5.2 in) at Greenwich, which was the highest figure since 1815 (when the total was 11.8 cm (4.0 in)). In some locations, such as Petersfield in Hampshire and Kew in London, the monthly total was more than three times the March average.

THE 1947 EVENT IN 2007

For the 60th anniversary of the 1947 U.K. river floods, RMS evaluated the potential impacts if the event were to re-occur again today. The work presented here was first undertaken in 2001 as part of the development of the first generation RMS[®] U.K. River Flood model, and has been updated to reflect the economic and exposure conditions in 2007. The first stage of the event reconstruction was to ascertain the extent of all the separate areas of flooding in 1947. These footprints were then employed to calculate the number of flooded properties in 2007. In recognition of the significant improvements in flood defenses for many of the towns affected in 1947, the final stage of the procedure concerned an assessment of what proportion of the areas flooded in 1947 would be expected to be inundated today, relating the probability of defense failure to the return period of the associated river flows.

1947 FLOOD EXTENT

No pre-existing study has attempted to map and collate all of the areas flooded in the 1947 event. Therefore, a principal purpose of the 2001 study was to compile all available records in order to create an overall footprint. Information relating to the areas flooded during the 1947 event was collated from a wide range of data sources, including the government report on the flooding (Barker, 1948), material held by the Environment Agency (Hatfield, Wallingford & Frimley EA offices) concerning the mapped flood extent for certain river sectors produced by the local waterboard authorities, and reports of the flooding in numerous national and local newspaper articles (e.g., *The Times*). The aim of this intensive research was to collect as much detail as possible about flooded locations, time of flooding, number of inundated properties and impacted people to reconstruct a flood footprint. Maps already available for parts of the Lea, Thames, and Lower Trent valleys were included in the compilation.

Based on the available information, a database was compiled that listed all postcode sectors which contained areas of flooding during the 1947 event, and if available, information on the number of flooded properties. Very little information exists on the flood depths in each specific sector. In some cases, flooded sectors were inferred. For example, if there was no reported flooding on a segment for which flooding had been reported both upstream and downstream, it was assumed that the middle segment also flooded. There may also be additional rural areas of low population not reported as flooded at the time, which have since urbanized and therefore may be missing from this assessment (e.g., parts of Bedford and Slough). Once all the flooded postcode sectors were identified, they were compiled into a single map to provide an overall flood footprint of the 1947 event.

To refine the footprint further, and ascertain which areas of each postcode sector were flooded, Thames and Lea Valley flood extent maps obtained from the Environment Agency were compared to the maximum flood extent maps for key return periods from the RMS[®] U.K. River Flood model, without including any implied protection from flood defenses. This information was developed at seven digit postcode unit resolution. Based on this analysis, it was concluded that the return period for the Thames and Lea floodplains in the 1947 event was slightly greater than 100 years. For a number of other rivers which had the greatest concentration of flooded properties, including the rivers Trent and Ouse, flow return periods also approximated to a 100-year return period.

For the principal rivers, the 100-year modeled flood extent was then overlaid with the reconstructed postcode sector flood footprint in order to estimate the extent of the flooded area in each affected sector. (It should be noted that flows on some rivers to the west were of shorter return periods, but in the flat-lying floodplains of the rivers of central and eastern England, there is little difference in the extent of flooding at 50- and 100-year return periods.)

NUMBER OF FLOODED PROPERTIES IN 1947

Postcode unit files, containing the number of postal delivery points (i.e., the physical location at which mail delivery can occur) for each postcode unit, were combined with the 1947 reconstructed flood extent to estimate the number of delivery points that would be located in the flood footprint. In the absence of quantitative information relating the number of delivery points to the number of properties, it is assumed that one delivery point equals one property. Based on this assumption, it is estimated that in 2007, around 276,000 properties would be within the original 1947 reconstructed flood footprint.

Building stock information was used to assess the number of flooded properties in 1947 by counting only Victorian and inter-war properties (i.e. properties built between World War I and World War II, or 1919 to 1939). It is estimated that just over 100,000 properties were flooded at the time of the event. For regions where there are reports of the number of flooded properties (about one-quarter of the total), the estimated number of inundated properties was compared to reported values (Table 1). As the geographic extent of the cities and towns is not always clear, a range of modeled values was calculated in some cases.

Table 1: A comparison of the number of flooded properties in 1947 as reported and as modeled; this comparison is limited to areas where the number of flooded properties was reported

Town	Reported flooded properties	Modeled flooded properties
Windsor	1,350	390 – 840*
Nottingham district	14,000	13,450
West Bridgford	2,000	2,180
Maidenhead	1,400	1,760
Gainsborough district	2,500	1,370
Selby	2,000	2,300 – 2,420
Caversham and Reading	1,600	1,650 – 1,920**
Bedford	500	1,680
Bentley	830	580 – 940**
TOTAL	27,010	25,800 – 27,930

* upper bound includes Old Windsor

** depending on boundary definitions

ROLE OF FLOOD DEFENSES

Since 1947, improvements have been made to flood defenses along many rivers in the U.K., in particular where passing through principal concentrations of population. However, for preserving amenity values it has not always been simple to create such defenses, and many towns along the River Thames, for example, remain relatively poorly protected. The role of these defenses needs to be incorporated in order to calculate the number of flooded properties if the same concurrence of river flows seen in March 1947 were to occur today. No national database is available which contains the type, height, design level, and maintenance conditions of U.K. river flood defenses even for main rivers. Therefore, the probabilistic defense assumptions as utilized in the RMS® U.K. River Flood model have been employed to include the mitigating impact of flood defenses. This approach assigns defense levels relative to the return period of river flow according to the value of the exposure at risk.

For a 100-year flow, all defenses are expected to fail where they protect rural areas or small towns with low property density. However, defenses for large urbanized areas (including Inner London) have been built and maintained to a better standard, and therefore continue to offer protection. For the values of property in the floodplains passing through medium-sized towns, it is assumed that the level of protection is likely to fail for river flows with return periods of around 100 years.

As there is clearly a range of uncertainty around the level of protection for medium-sized towns, different assumptions about defense performance have been modeled to reflect the range of uncertainty for defense failure at a return period of 100 years. In particular, the following assumptions have been explored:

- A. 70% of the defenses hold for medium-sized towns
- B. 50% of the defenses hold for medium-sized towns
- C. 30% of the defenses hold for medium-sized towns

NUMBER OF FLOODED PROPERTIES IN 2007

For each of the three scenarios outlined above, the total number of properties that would be flooded if the same event occurred today was calculated. The number of properties was separated into residential and commercial lines of business, based on industry postcode sector splits in the 2006 RMS Industry Exposure Database (IED) for the U.K. Flood defenses reduce the number of flooded properties by over 50% in the three scenarios (Table 2). Assuming scenario B, where 50% of the medium-sized towns are protected by their defenses, approximately 95,000 properties would flood if the event occurred in 2007, compared to the 276,000 that would be flooded if no improvements had been made to the defenses. Figure 6 displays the flooded regions with and without defenses by postcode sector.

Table 2: Number of flooded properties from major river inundation for a repeat of the 1947 event in 2007 (considering uncertainty around defense assumptions of medium-sized towns)

Line of Business	No improvement in flood defenses	Scenario A (70% protection for medium-sized towns)	Scenario B (50% protection for medium-sized towns)	Scenario C (30% protection for medium-sized towns)
Residential	248,540	74,600	86,160	97,710
Commercial	28,000	7,730	9,310	10,890
TOTAL	276,540	82,330	95,470	108,600



Figure 6: Reconstruction of the 1947 flood footprint, where blue areas indicate postcode sectors where there is significant river flooding in 2007, green areas indicate sectors that flooded in 1947 but would not in 2007 due to flood defenses, and orange areas indicate sectors which could flood in 2007 given the uncertainty in flood defenses for these regions

INSURED LOSS ESTIMATES

ON-FLOODPLAIN LOSSES

Having investigated the uncertainty around the number of flooded properties based on a range of defense assumptions for medium-sized towns, insured losses are estimated by multiplying the number of damaged properties by an average loss. According to the Association of British Insurers (ABI), the average repair costs to residential properties are £15,000 - £30,000 (US\$29,500 – US\$58,900) for building and contents (ABI, 2005). Based on this assumption, an average value of £25,000 (US\$49,000) is used to calculate the total insured losses for residential properties in a recurrence of the 1947 flooding event. For commercial properties, the average loss is calculated by applying the residential loss ratio (for a loss of £25,000 or US\$49,000) to the average commercial exposure value, which results in an average loss of £175,000 (US\$344,000). The value for the average commercial loss was compared to claims collected by RMS after the 1998 Easter Floods which, after taking into consideration inflation since 1998, showed reasonable agreement.

The average residential and commercial building and contents damage losses are applied to the number of flooded properties in Table 2 to provide loss estimates for direct property damage in the floodplain for a repeat of the river flows experienced in 1947. From this calculation, it is estimated that the total on-floodplain losses range from £3.0 to £4.5 billion (US\$5.9 billion to US\$8.8 billion).

OFF-FLOODPLAIN LOSSES

The discussion so far has focused on inundation in the floodplain of the major rivers affected by the 1947 event. However, in an event of this magnitude, with high run-off as a result of the frozen ground, there will have been additional sources of flooding from sheet flow and the flooding of minor rivers and streams. It is difficult to reconstruct those locations affected by flooding outside the major river floodplains. To factor these impacts into the loss calculations, the off-floodplain component of the RMS[®] U.K. River Flood model was used to provide an estimate of the likely contribution of off-floodplain losses to a repeat of the 1947 event.

The relative contribution of on-floodplain and off-floodplain sources on loss has been evaluated from a range of recent major floods in the U.K. for which comprehensive high resolution insurance claims data are available. This reveals the simple underlying principle that the more extreme the flooding and the longer the return period of river flows, the greater the proportion of the loss comes from on-floodplain flooding relative to off-floodplain flooding. This relativity is itself built into the RMS[®] U.K. River Flood model.

The on-floodplain losses of £3.0 billion to £4.5 billion (US\$5.9 billion to US\$8.8 billion) for a repeat of the 1947 event can be compared with the return periods of the RMS[®] U.K. River Flood Industry Loss Curve (ILC) for on-floodplain losses only. Analysis results comparing the contribution of on- and off-floodplain losses to the total loss at key return periods were used to assign the expected percentage of off-floodplain losses for the 1947 event return period. The 1947 on-floodplain loss estimates were found to have a return period of approximately 200 years, and the expected split between on- and off-floodplain losses at this return period was found to be approximately 80:20 (on-floodplain: off-floodplain). These additional off-floodplain losses would cause the overall loss for the 1947 flooding event to be projected between £4.0 billion and £5.5 billion (US\$7.9 billion and US\$10.8 billion).

TOTAL INSURED LOSSES

In order to determine the total insured losses from a repeat of the 1947 flooding event, time-element coverages must be considered. Additional living expenses (ALE) and Business Interruption (BI) add a further 5% to residential losses and 15% to commercial properties, respectively. As shown in Table 3, the final loss estimate if the 1947 U.K. river floods were to occur in 2007 is between £4.5 billion and £6.0 billion (US\$8.8 billion and US\$11.8 billion). This total includes the representation of the uncertainty around the performance of defenses protecting the principal towns and the additional off-floodplain losses. Notably, the BI factors were determined from the RMS® U.K. River Flood model for a return period of 200 years as previously discussed.

Table 3: Total insured losses for a repeat of the 1947 event in 2007 (in £ billion)

Line of Business	No improvement in flood defenses	Scenario A (70% protection for medium-sized towns)	Scenario B (50% protection for medium-sized towns)	Scenario C (30% protection for medium-sized towns)
Residential	8.0	2.5	2.8	3.0
Commercial	7.5	2.0	2.5	3.0
TOTAL	15.5	4.5	5.3	6.0

One factor not included in this analysis is the additional loss due to wind damage, as widespread gales were reported between March 16 and March 24, 1947. This windstorm had windspeeds in the range of 30 to 40 m/s (67 to 89 mph) across the English Midlands, and is likely to have caused insured losses in excess of £0.5 billion (US\$1 billion). The loss from the March 16, 1947 storm is believed to be higher than that of Windstorm Kyrill, which affected much of the southern half of the U.K. from Liverpool to London in January 2007 with inland wind gusts on the order of 30 to 35 m/s (67 to 78 mph).

THIS EVENT IN PERSPECTIVE

The estimated insured loss from a repeat of the 1947 U.K. river floods is an order of magnitude greater than the more recent major river flood events witnessed in the U.K. During the 1998 Easter Floods, widespread flooding in the Midlands caused £167 million (US\$328 million) in loss in today's values. Similarly, the Autumn 2000 floods affected rivers in the Northeast around York, and the Southeast, causing £876 million (US\$1.72 billion) in loss in today's values. Another notable event was the arctic weather of December 1991/January 1992, including severe blizzards which affected the whole country. A rapid thaw caused major floods around Gloucester, York and Selby and resulted in a loss equivalent to £568 million (US\$1.12 billion) in today's values. The common factor between all of these large loss events, including 1947, has been the widespread nature of flooding, affecting several major river catchments simultaneously, rather than focused on very high exposure concentrations, such as London, which have the highest level of defense standards in the country.

According to the Association of British Insurers, approximately half of all housing units built since World War II have been placed in areas prone to flooding. Although the Environment Agency (EA) has objected to tens of thousands of planning proposals each year, around 20% of them have been approved. Planning regulations have recently been tightened to make consultation with the EA a requirement, rather than a recommendation (PPG25 in 2001 was replaced with Planning Policy Statement (PPS) 25 introduced in December 2006 by Communities and Local Government). However, the continuing demands for new housing, commercial premises and high-value projects in the Southeast will continue to put pressure on floodplains for development. The most notable example of this is the Thames Gateway regeneration project, covering an area stretching 64 km (40 mi) along the estuary from Canary Wharf in London to Southend in Essex and Sittingbourne in Kent, with 160,000 additional homes projected to be built by 2016 (equivalent to 5% of the homes that currently exist in the whole of London). The EA has launched its Thames Estuary 2100 project, designed to identify the range of solutions necessary to reduce this risk and the impact of any flood that occurs.

The 2012 Summer Olympic Games will be held in the Thames Gateway, directly to the west of Stratford on the Lower Lea Valley, an area designated as "High Risk" (flood zone 3 under the PPG25 definition) from flooding. By 2012, more than 30,000 homes are planned within the area surrounding the Olympic Park. As shown in Figure 7, the Hackney Marshes were extensively flooded during the 1947 flood, showing the potential vulnerability of this region. Although flood defenses through London have been greatly enhanced since this time (after the 1953 East Coast storm surge), defenses on tributaries to the Thames have not been designed as high as those on the Thames itself, and parts of the area currently are designated at "Actual Risk" meaning risk from 1-in-100 year events.

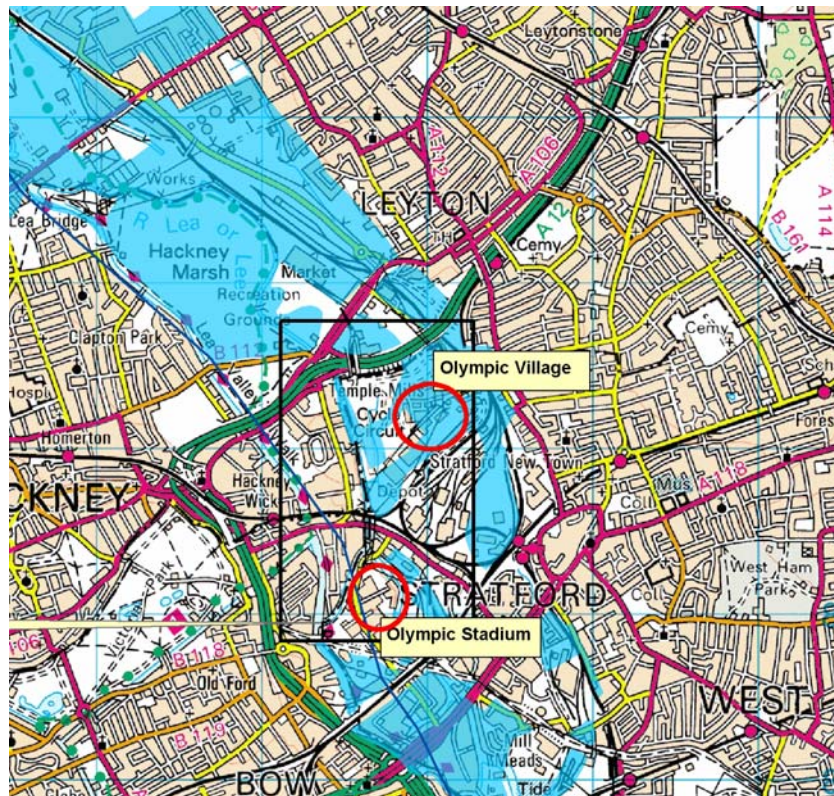


Figure 7: The 2012 Olympic site is situated within the footprint of the 1947 flooding event, as indicated in blue areas issued by the Environment Agency for the Lower Lea Valley (London street map courtesy of the Ordnance Survey)

In addition to increasing exposed property values at risk, the baseline risk of flooding may also change in the future. As recognized in the IPCC 4th report on Climate Change (IPCC, 2007), rainfall patterns over Europe are changing and are predicted to continue to change, with northerly areas subject to wetter winters and southern Europe to drier ones. However, the likely temperature increases that Europe is likely to see mean that the likelihood of this specific type of event – the root cause of which was extreme snowfall – is less likely to happen. In fact, the changing rainfall patterns may mean that the proportion of flash, or off-floodplain flooding, compared to that on the major floodplains may increase. To date, a direct correlation between increased rainfall and increased river flooding has not been proven per se. In fact, river flooding responds more to changes in land use (e.g., in catchments etc.), making planning laws even more important to minimize upstream impacts on flood risk, as well as downstream impacts of increased property at risk.

Insurance coverage in the U.K. is unusual in that flood cover is typically included as standard within property insurance policies. Members of the ABI are committed to continuing the provision of cover as long as sustained and sufficient investment in flood defenses continues. As this report shows, the potential for a large loss far greater than has been seen in the last ten years exists. RMS remains committed to providing sophisticated tools for the industry to price and manage their flood risk accumulations.

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