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12 November 2015

**The Next Big UK Flood:
Britain Under Water**

Professor Carolyn Roberts

Good evening everyone, and welcome to the second of my Gresham College lectures for this year. We shall see if it attracts the same numbers as the audience for my first lecture last month, on murder enquiries and bodies in rivers, which clearly demonstrated that referring to sex and violence attracts large numbers – I am bearing that in mind for all future lectures.

Tonight, I am turning my attention to the more traditional, but potentially no less deadly water theme of flooding. Both include death, and uncertainty. I want to explore such questions as “Are the catastrophic Summer 2007 floods in the English Midlands and the recent events of southeast England harbingers of worse to come, particularly as the climate shifts? What are the odds that events will conspire to put London under water during the next few years?” and “Does flooding pose a major challenge to the UK's security?” I am going to review some of the UK's recent experiences, and then consider whether science, technology and collaboration can really reduce our vulnerability to floods, or whether we are actually wasting our time, and are doomed to experience more death and destruction. Flooding is a wicked and dark problem, and it is important that we have in mind that decisions about how we protect ourselves, otherwise, are not abstract, but have a very real impact. Capturing this, particularly if you have not experienced extreme flooding yourself, can be challenging, so I am going to play you an extract from a 2007 disaster movie – a simulation of an individual experience. As I suggested in my last lecture, if you are of a nervous disposition, avert your eyes now.

This is a terrifying prospect.

Flooding is also one of the world’s largest problems. In recent reviews by the World Economic Forum, McKinsey and others, flood hazard appears near the top of global economic risks. It is very likely to happen, and has significant economic impact. In combination with failure to adapt to climate change, something to which I shall return later, it has major impact. It is a nasty business, a risk to life and limb, to the infrastructure that maintains our standard of living, to production of our food, to housing, to businesses, to our health service and to the insurance industry in the City to name just a few elements. Not only is it expensive (and its price depends at least in part on how we cost human life – of a child, an elderly person, a poor person and so on), but it is a relatively frequent occurrence; somewhere in the world experiences catastrophic flooding every few weeks or months. The worst events stay with us, of course; the Boxing Day tsunami of 2004 that followed a fault line shift in the earth’s crust is estimated to have killed 300,000 people around the Indian Ocean, disproportionately women and children, and I have been told personal stories of how people on the Indian coastline saw the wave coming and ran inland towards a road embankment, carrying those children that were too young to walk, but having to abandon some young children and older people; people typically have large families with several toddlers.

More recently, the magnitude 9.0 quake (8.4 on the JMA seismic intensity scale) eighty-one miles off the east coast of Tōhoku, Japan at 5.45am on 11th March 2011, also created a tsunami. This was the most powerful earthquake to hit Japan in recorded history and the fifth most powerful earthquake on Earth since modern record-keeping began in 1900. A wave of up to 10 metres developed on the coastal shelf, the subsequent devastation was terrific, and courtesy of mobile phone footage we had the dreadful spectacle of cars rolling and people drowning in front of our eyes. The wave again propagated across the Pacific Ocean. Some 16,000 people died in Japan, and the Fukushima nuclear meltdown that followed is also significant. And expensive.

More predictable, but similarly expensive was the flooding following Hurricane Katrina in August 2005, New Orleans, where a storm surge drove up to six miles inland and is widely recorded as creating over 50 breaches in what were expected to be ‘flood proof’ levees, or barriers along the deltaic channels of the Mississippi in Louisiana. Storm surges are usually a combination of high tides, large waves, low pressure and driving winds, which force water suddenly into narrowing estuaries and deltas where they overwhelm areas of land. Property damage from Katrina was estimated at £71 Billion (American Society of Civil Engineers, 2007). Despite the activities of the US Corps of Engineers, the fact is that 49% of New Orleans was built on land lower than sea level, and any breach of defences was likely to be catastrophic, even without a legacy of poor construction and inadequate maintenance – a disaster waiting to happen. Critique of the management arrangements following the forecasting of the event, and the obvious problems with evacuation, followed the deaths of between 1000 and 2000 inhabitants; the uncertainty of these fatalities again reflects the difficulty of enumerating the preferentially poor and dispossessed. This truly appalling event nevertheless pales into insignificance in comparison with the flooding of the Yangtze River in Central China in 1931 following prolonged heavy rain, snowmelt and cyclones, where somewhere between a million and four million people drowned – beyond ready comprehension.

Turning to the UK, we too may have had tsunami, albeit small and infrequently. At about 9am on 30th January 1607, for example, there are records of ‘huge and mighty hills of water’ rushing up the Severn estuary, far larger than the typical Severn bore, wiping out up to 2000 people together with their livestock, and eroding the salt marsh. Researchers have disputed whether it was a tsunami, or a tidal surge, but the engraved pictures and the quotes of the time have an astonishing resonance with those that we saw more recently in the Far East. The water flowed faster than a greyhound could run, up to four miles inland from the sea. Mistress Vann tried to climb up onto her roof, but drowned – no rescue helicopters, or emergency services. The disaster movie I showed concerned a storm surge, but Mistress Vann, ‘a gentlewoman of good sort with an income of £100’ trying to climb to the top of her house, has resonance.

For some it nevertheless provides business opportunities. Just in case you forget about those, I cannot help but draw to your attention to a distasteful advertisement from a US insurance company that insures householders against natural disasters, and which clearly draws upon the same iconography and the same human fears, as our disaster movie. Noah’s Ark, is another example, whatever other stories it tells. In terms of human misery, flooding has been a significant problem throughout human history, and as such it has featured in diaries, news reports, disaster movies, paintings, poetry, and so on. It can be completely terrifying when it occurs suddenly, but even insidious rising waters or temporary shallow inundation can create longstanding problems that are difficult to characterise – for mental health, for example, or for the stability of buildings. If we look at the catastrophic coastal flood of Eastern England on Saturday night, 31st January 1953, several of these characteristics can be seen and heard. I’m going to play an extract of a woman talking about her shocking experiences in Canvey Island, a peninsula in the Thames Estuary close to London, sixty years earlier, when sea level reached about 5 or 6 metres above the average, with waves on top. Other places in Lincolnshire, East Anglia, and more particularly in the Netherlands and Belgium, had similar experiences as the photographs suggest. Over three hundred people died in the UK, and almost two thousand in mainland Europe around the North Sea.

There may be people in the audience today who remember that event, after World War II, where low-lying communities were unaware of the imminent threat of storm surge, coastal barriers had been neglected in the face of other priorities, and no systematic warning systems existed. 32,000 people were successfully evacuated and the economic damage was less, perhaps a couple of billion pounds in today’s values, as people owned less than most do today. Now we do have better coastal flood forecasting, from two to five days ahead, and at least within the environmental parameters that we know about currently, but we are still reliant on barriers, a theme to which I will return at the end of the lecture.

UK flooding more commonly has other causes, each with its own characteristics. Many other serious floods happened in the last twenty years– in fact events do seem to cluster together statistically into periods of enhanced flooding – Boscastle in Cornwall in 2004 (this is the one with exceptional rainfall and streamflow washing cars into the sea), Carlisle in 2005, Cornwall in 2010, a lot of areas of the UK in 2012 and 2013, Somerset in 2014 and others. Not London, at least not extensively. As I drafted this lecture earlier this week, I hesitated to refer to the ‘most recent flooding event’ since last week we have experienced relatively heavy rainfall (for the UK) and stormy weather, and it was quite possible that the currency of my talk would be overtaken by events. Clearly flooding usually follows periods of inclement weather, where water from rivers and streams, fields and paved areas, the ground and sewers, and ends up in places where it is not usually to be found. We read of ‘rivers bursting their banks’, or the sea breaking through defences or overtopping them.

The main cause of flood damage in the UK is from rivers (fluvial flooding, the most significant in terms of likely damage now, and in the future) at approximately £0.5 Bn insured damage per year. Coastal damage is reckoned at about £320M per annum, by contrast, assuming that the Thames barrier and the associated embankments continue to operate effectively but surface water (flash flooding from compacted soil in fields and impermeable urban surfaces) typically contributes about £260M per annum and groundwater (clearwater flooding) adds an estimated further £210M to the damage, mainly incurred in areas of permeable rocks – Ulster and Scotland will escape this, except very locally. There are also a few areas where rising groundwater levels create some problems….. I will return to these estimates in a few minutes as they are confounded by uncertainties.

In practice, of course, these effects can occur together, as we think happened in the 2007 floods in the Severn catchment of Midland England. These were part of a wider event across England and Wales, in which thirteen people died, but fortunately far fewer than in a similar event in 1947. Many of you may recall the iconic photographs of Tewkesbury Abbey with the waters lapping into the graveyard, inundated shops, houses, fields, roads and railway lines. This was an unusual event, triggered by a prolonged wet period then an intense and extensive frontal rainfall event on a mixture of geologies both permeable and impermeable, and over catchments of different sizes. It is also an important event because through the Pitt Review, it led to major changes in the way we funded science, and in the administrative responsibilities which became more vested at local level. I was the technical advisor to Gloucestershire County Council after the event, and assisted with the inquiries.

In practice our knowledge of flood events is provisional because of deficiencies in the data about what actually happened, both in terms of the science, and the flooding that resulted – completing a postal questionnaire from the Council about whether or not their house had flooded, and how, is probably not someone’s first thought when faced with the legacy of a metre or so of water and sewage in their kitchen. Where did the water enter, and where did it come from? Was it river water or groundwater or surface water or all of the above? What was the damage, and how much did it cost? And in this instance we should bear in mind that the biggest immediate impact was not the inundation itself, or the damage to houses and businesses significant though that was, but the damage that followed from the failure in the water supply to almost half a million people for up to three weeks. You cannot run a business, a hospital, a care home, a shop without a toilet, even if you are not standing in water. So the damage was much more extensive that might first be thought, probably about £3.8Bn insured, and much more in terms of side effects.

So, we are left with uncertainties that have to be tackled before we can start to move forward on management decisions.

What actually happened this time, where, and why? Let’s stick for now to the natural sciences elements of this particular event. We need to know how much rain fell, and rain gauges can capture only a point in time, and may only be read every day, so may not give us the data we need to see to work out, for instance, the intensity of rainfall. Today we have satellites, and radar that can give us more data, earlier, which helps to extend and sharpen the raw data that still comes from rain gauges. Similarly, we have a fair network of river level gauges, with their level recorders, and the information that helps to turn their data into flow, or discharge. There is still a problem in establishing the return period of events when we have only short periods of records, as the illustration of the River Isbourne here shows, and maths helps us to extend data sequences assuming that the background circumstances of these flows remain unchanged – we will return to that in a minute. In the case of the Severn Flooding in 2007, we can be pretty sure that these were unusual events, to the extent that they might be expected only once in 400 years, or 500 years, or 1000 years perhaps.

We also have a growing set of geospatial information, much of it generated since 2007, on the detail of ground levels, buildings and so on, that helps to define the ground base for subsequent mathematical modelling. Plus we have more detailed information on individual flood events that have occurred, including, interestingly, a growing body of information based on ‘citizen science’ – timed and dated photographs taken by an (often ageing) army of the interested and concerned, using mobile phones, for instance. (Fine, until the batteries are exhausted, and the power is off, but certainly better than nothing).

Addressing the second group of uncertainties associated with flooding has been, in my view, an amazing success story for UK environmental science. Researchers from a wide range of our universities and research institutions have tackled many of the data collection and modelling challenges, such that we are infinitely better placed today than we were a decade ago. Complex models have taken basic hydrological data such as rainfall, used it to develop mathematical models for particular catchments at a variety of scales in space and time, and generalised from these into new areas to address the major issue of which areas of the UK are liable to flooding, and what is the chance of that occurring. Flood risk is clearly an issue of probability, which is something that needs to be understood by decision makers when deciding where to develop houses and other infrastructure, but a few pictures will illustrate some of the techniques that have developed. What we now also need is real-time models that take meteorological data from satellites, generate forecasts and convert them into likely flooded areas, so that we can develop strategies to prevent the flooding, or reduce the damage, at the time. We are making some progress there too.

The diagrams show examples of attempts to measure flooding developing on floodplains from satellites, using radar to establish extent of flooding and algorithms to route water down river floodplains (in extreme events), detailed analyses of the channels themselves, testing analyses using data from real events (this one in the North of England), and turning these into the types of interactive probability maps that can be explored online, at different levels of flooding. This latter is a series of three images showing a predicted relatively frequent flood, a more extreme flood, and an overall map of the area. You can where not to take out a mortgage, or build new houses, at least not without appropriate protection.

I will just touch, for a minute or two, on this issue of flood protection. Addressing existing flood risk can be tackled in many different ways. Basically, we can try to keep out the water by building dams or barriers along river banks (permanent or temporary) and coasts, by flood-proofing, that is building walls and other barriers such as sandbags around buildings, and by building diversion channels for the water (overground, like the Jubilee River on the Thames at Eton but not at Slough, or underground as in Tokyo). We can also dredge river channels deeper, but the river will always require maintenance, or repeated ‘assault’, as many people would regard dredging. Or we can try to reduce the amount of water running off the river basin upstream, by altering the land use (by particular types of afforestation, for example, or by stimulating peat land growth), altering the ground surface (permeable pavement, for instance), or the way the land is managed (don’t grow spring onions on steep hills, or you will flood adjacent property during heavy rain, as people who live near me will testify). In urban and near-urban areas this latter approach is called Sustainable Drainage – SUDS – and it is a very important weapon in our armoury. We can also use sacrificial areas of floodplain, with sluices and bunds, to store floodwater temporarily on one place, allowing the rest to continue downstream in smaller amounts. These are all structural methods of flood management – building something.

The other approach is to try to manage the damage that the flood creates, through economic means. We can offer insurance to people in floodable areas, or conversely we can refuse insurance in the hope that they will be persuaded not to build on them at all. We can take on the insured risk at state level, or through private company/City collaboration as Flood Re is attempting at the moment. We can, and do, provide emergency relief through the state and through public appeals. All of these are non-structural responses.

The wicked problem is that most of these methods have unintended consequences. Many structural responses increase the risk of flooding downstream by routing floodwater on elsewhere, faster. Dredging and straightening rivers causes ecological damages, that raise tempers amongst politicians, farmers, and in the case of the Somerset Levels, prompts sympathy amongst others. Insurance systems can leave the poor in worse situations than they were beforehand, by encouraging private rather than state responsibility and leaving the weaker unprotected. Barriers can cause water to be retained on floodplains longer than would have been the case otherwise, as it cannot flow back into the channel. And all of these methods can unintentionally encourage people to develop land on floodplains, live on them, and otherwise use them intensively, unless we are very vigilant about our land use planning system. If people are somehow encouraged to live on floodplains, then there will inevitably be disasters because flooding is a statistical certainty somewhere, at some time, whether defences are overtopped by a larger event than the design allowed for, or through a failure of the technology.

The last area to which I want to direct my attention tonight is to the changing picture of climate change. Climate change is now a very visible elephant in the potentially damp room, which will have major effect on our future experience of flooding in the UK. A new report (this week) concerns the projections of future flood risk in the UK, based on the latest science in the Climate Change Risk Assessment of 2012 (the next is due in 2017), and was prepared for the UK Committee on Climate Change. It is a remarkable synthesis, I think, and makes for some very disturbing reading.

Most people in the audience today will perhaps be aware that the Paris Climate negotiations are attempting to secure agreement on a global level of carbon dioxide emissions from domestic, industrial and agricultural sources, that maintains the average increase in global temperature to 2 degrees Centigrade – or more specifically that scientists think we have a 60% chance of maintaining the average increase in global temperature to 2 Degrees. It is estimated, again with some uncertainties, that if we succeed, the overall risk of UK flooding will rise by 50%. If, by contrast, we can only constrain the temperature rise to 4 Degrees, then the risk of flooding will increase by 150%. Let’s hold those two figures of two degrees and four degrees in our heads, because the higher projections, in excess of 4 degrees, are likely to be so catastrophic that they are almost impossible to comprehend – a six fold increase in risk or worse. It is likely to be worse elsewhere in the world too – so no wonder it is being called the ‘Last Tango in Paris’.

Although a significant trend in extreme river flows has not yet been observed, twice as many river flow maxima occurred in Europe between 1981 and 2000 than between 1961 and 1980. Since 1990, 259 major river floods have been reported in Europe, of which 165 have been reported since 2000. The rise in the reported number of flood events over recent decades results mainly from better reporting and land-use changes. Nevertheless, global warming is projected to intensify the hydrological cycle and increase the occurrence and frequency of flood events in large parts of Europe, although estimates of changes in flood frequency and magnitude remain highly uncertain.

The changes in the UK are likely to be felt differentially across the UK, dependent on the specific climate circumstances and the innate susceptibility to different types flooding. Some regions will probably experience three times the increase in risk than others. For that 4 degree temperature increase, for example, we would expect an additional 0.5m on current sea levels, and even without increased storminess this would make about 200km of coastal defences very vulnerable to failure. That is 20% of all our current defences, and some 300,000 houses subject to something like the events of 1953 in Essex. Can we actually assume that we can maintain all of this length, perfectly, or is some form of ‘managed retreat’ actually inevitable?

The diagrams show some of the scenarios that have come from detailed analysis of different types of flooding, over different timescales, with different assumptions about temperature changes, different assumptions about population growth, and different assumptions about whether or not we continue to invest in defences – structural schemes. Overall, it is estimated that the damages from flooding from all sources would increase in the UK from some £1.1Bn to £1.7Bn per annum by the 2080s when some of our children will still be alive, and to £2.8Bn if there is a 4 degree change. That is an average; in any one year the damage could be much worse, and the impact on non-property damage almost inestimable. We would expect, by 2080, that the current 1.8 million people who live with a 1 in 75 year flood event threatening them, would grow to 2.5million or 3.5 million people for 2 degrees or 4 degrees respectively. We will lose more electricity substations, roads, railway lines and stations, food producing land, shops, factories and houses than before. As ever, it is the most deprived communities that seem likely to experience the greatest damage.

Those are averages. In order to understand the detailed risk of flooding, at different dates, we also need to know where people are living and working and how many of us there are who live in flood prone areas. Population growth in the UK is a controversial subject itself, but based on estimates of population growth, and on demography (how many care homes will there be on floodplains, for example?) and what we keep in our houses (how wealthy will we be – how many large screen TVs and cars will we own, and where will we keep them?) it is believed that population growth is a less significant creator of increased risk than the shift in climate patterns that follow from some of the climate change projections. We are now in the geological epoch that is being termed the Anthropocene. Let’s look at this in more detail. I should perhaps say that I am a firm believer in anthropogenic impact on climate change, not as a sole cause of climate change, but as a significant input through the increased emissions of carbon dioxide and some shorter-lived but even more intense ‘greenhouse gases’ that have occurred since the industrial revolution. Led by the so-called developed countries, we have created a problem through our use of fossil fuels, and our removal of forests and soil carbon stores, and we now hope that we can reverse this before the damage becomes too serious. I have little sympathy with climate change deniers, and the first academic analyses are now showing that the ‘signal’ of increased flooding is starting to appear in the highly fluctuating river flow patterns in the UK. Mean sea level is also rising around the UK and around the world, driven by increasing temperature, and by melting ice caps – but that is likely to be a punctuated shift with periods of apparent stability followed by periods of sudden change as, for example, ice shelves collapse into the ocean. We also recognise that some change is inevitable (indeed even if human-induced additions were not present, we would be looking at this), and that even with moves towards a low-carbon economy, we will need adaptation methods to cope with the summer heat, the extremes, and the other consequences including changes in flooding and sea level rise.

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Sea level has probably already risen by 19cm from 1901 to 2013, with a recent acceleration, and even higher rates if we look at satellite results. The figures for the future, by 2300, are complicated, but could be as high as 3 metres or more. Some areas are still lower, as a result of isostatic rebound after the ice age, but the UK south and east of England are probably sinking. High water levels appear to be increasing in many areas of Europe. For fun, I am showing you the implications for flooding in the UK; reality could be lower, again if we do nothing about climate change.

Will any or all of the flood adaptation methods work? I am pessimistic. We might, if we take things seriously but continue to adapt in the way we are doing today, be able to adapt to reduce the flood risk for the 2 degree temperature scenario. But beyond that, the effects are likely to be unstoppable. With a 4 degree change, we will need to step up our investment in a variety of flood-proofing methods, including defences, managed retreat on the coast, catchment management to reduce runoff, and urban runoff management through SUDS, very dramatically to be able to reduce the risk. We MUST stop building on floodplains. And much of this response will have to be by centralised authorities as they are not something to which individuals can respond effectively to the most extreme events. Retrofitting property is appropriate in the short term, but cannot replace more strategic moves such as spatial planning – avoiding building on floodplains. There is a long lead time, and we are bedevilled by communication problems and ridiculous arguments.

Finally, London. Without the Thames barrier, areas below a substantial storm surge’s theoretical limits are South Bank, Shakespeare’s Globe, Tate Modern, Waterloo, the Westminster Parliament (which is known to have flooded in 1236, as men apparently rowed around the Great Hall in boats), Buckingham Palace, Charing Cross, Tate Britain and a good chunk of the underground; Bank, the City and theatre land could be affected too. Will this happen?

In case that is not enough, the most terrifying research into flooding that I have seen relates to underground shopping malls, in Japanese cities. Here we see analysis of the water depths and velocities that are enough to sweep people, particularly elderly Professors, off our feet. This final map, ladies and gentlemen, is a map of the timing of death of elderly women, who would struggle the most to escape the rising waters that would arrive whilst they trawled the rails of the boutiques. I hope our politicians, developers and planners will bear this in mind when they apply for, and permit, future developments in and under our floodplains.

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