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The Hull floods of 2007: implications for the governance and management of urban drainage systems

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Abstract

On 25 June, the City of Hull suffered from extensive pluvial flooding, causing damage to over 8600 homes and 1300 businesses. Over 100 mm of rain fell over a 24-h period, rapidly overwhelming the city's drainage system. Hull is especially vulnerable to flooding as it is largely below sea level and relies on a pumped drainage system with no natural ways of drainage. The causes of the flooding can be locally attributed to blocked roadside gulleys but in the main were due to issues with the conveyance of drained water in sewers and the performance of the three pumping stations. In particular, an extensive redesign of the system in 2001 increased flood storage and reduced the pumping capacity. In 2004, remodelling of the 2001 system indicated that it may be underpredicting flood volumes by 100% and decommissioned pumping stations were re-activated to rectify matters. Subsequent modelling showed that the performance of the drainage system in 2007 was slightly worse than its 2001 configuration. The floods also revealed a series of key weaknesses in how urban drainage systems are managed. There is no system of warning from surface water flooding in the United Kingdom, despite there being an extensive warning system for coastal and fluvial flooding. Urban drainage is largely designed to accommodate 1 in 30-year events, but this level is not appropriate in all areas, especially low-lying regions with little or no natural drainage such as Hull. Finally, the structure of the UK water industry postprivatisation, with Local Authority, the Environment Agency and the Water Utility all having control over separate parts of the system, left no single agency with lead control or responsibility for urban surface water flooding.

Introduction

On 25 June 2007, the City of Hull, located on the north bank of the Humber Estuary in the north east of England, suffered significant damage from pluvial flooding, with over 20 000 residents' homes damaged by floodwater. Following the floods, several studies were commissioned into the impacts and causes of the floods in Hull and across the United Kingdom. These include a Hull City Council-appointed Independent Review Body (IRB), which published interim and final reports in September and November 2007 (Coulthard *et al*., 2007a, b), a review of Yorkshire Waters operations by the consultants Ove Arup & Partners Ltd (Yorkshire Water, 2007), the UK Government-appointed Pitt Review (Pitt, 2007, 2008), the UK Government Commons Select Committee report (House of Commons EFRA Select Committee, 2008) and a report into the Hull floods by the Office of Water Services (OFWAT, 2008). This paper draws upon these and other sources to 1. examine the context of Hull and its drainage system; 2. describe the impacts of the floods; 3. establish the causes; and 4. look at the implications of the 2007 floods for the governance, management and design of urban drainage systems.

Context and history of Hull's drainage system

The topographic position of Hull leaves it highly susceptible to flooding from fluvial, pluvial and marine sources. It is low lying, with most of its area below the level of mean high water (Figure 1). To the West, the villages of Cottingham, Willerby and Hessle are situated upon higher ground, which drains eastwards towards the city (Figure 1). The River Hull is the main water course and runs north to south through the centre of the city, conveying water from a substantial catchment to the north, much of which is low-lying

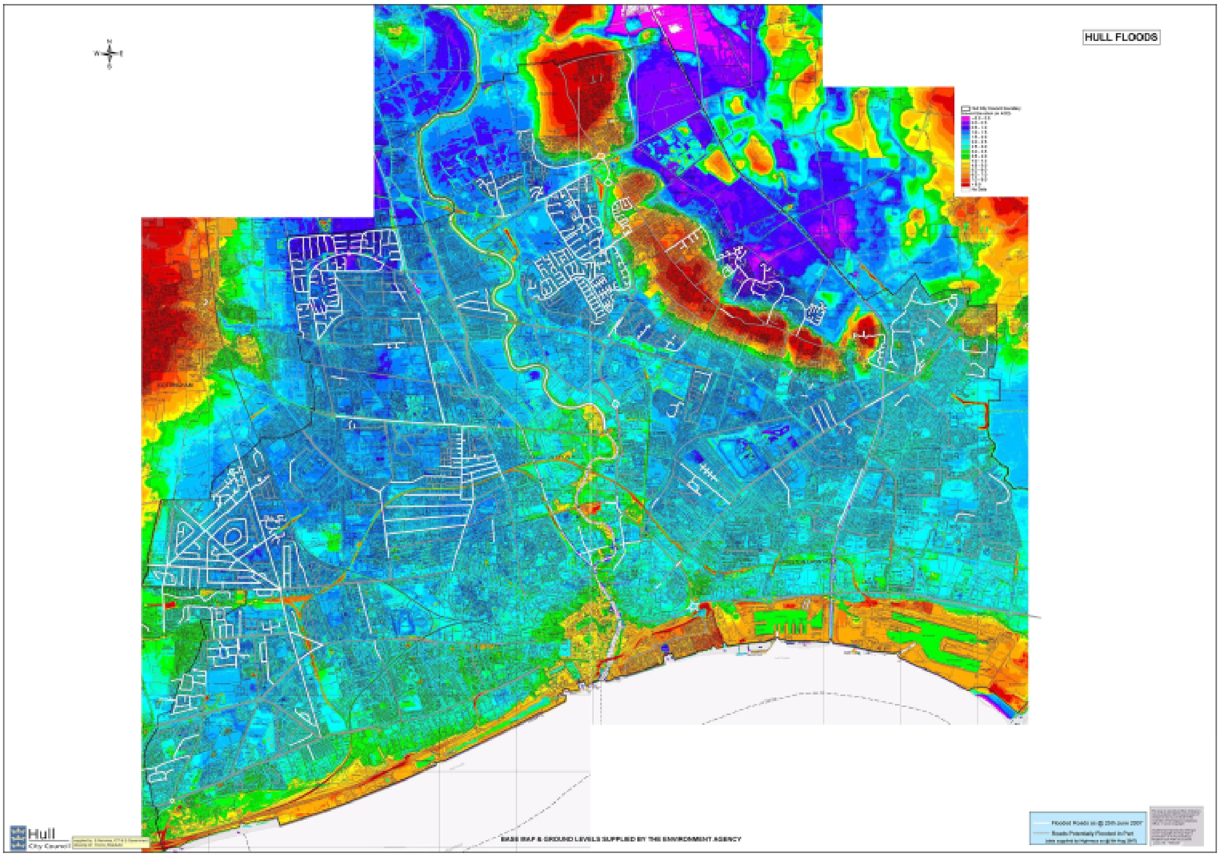

Figure 1 Elevation map of Hull.

reclaimed wetland now used for agriculture. Within Hull, the river is embanked, with levees providing protection from fluvial flooding from an above 1 in 100-year flood event. Therefore, the River Hull does not drain any of the catchment areas inside the city boundaries. Much of Hull is also built upon reclaimed marshland that was drained during the 18th and especially the late 19th century via a series of ditches and land drains to provide areas for development. These drains were all gravity driven, with tidal sluice gates at outlets into the Humber estuary that closed during high tides. During the early and mid-20th century, regular flooding events in certain parts of Hull (notably the Old Town areas) resulted in an extensive redesign of Hull's drainage system. In the 1950s, 1960s and 1970s, under the control of the 'Hull Corporation' (the local municipal body), the open drains were largely replaced with gravity-fed trunk combined effluent and storm water sewers (Figure 2). These sewers were substantial (up to 3.2 m in diameter) and were evacuated by two large pumping stations at West and East Hull, with actual pumping capacities of c. 32 and 20 m^3/s. Therefore, compared with other historical UK cities, Hull has had a modern sewage and surface water drainage system for the past 30 years.

However, the combined system, with a mixing of foul and surface waters, led to largely untreated sewage (loosely screened) being pumped into the Humber at both the West and the East Hull pumping station outlets. To partially resolve this situation, from 1996 to 2001, Yorkshire Water (the Company responsible for sewerage and sewage processing following water utility privatisation in 1989) invested heavily in the 'Humbercare' system, which saw the construction of a 10.5 km 3.4 m diameter trunk sewer running across the city from the West Hull pumping station, to East Hull and into a new wastewater treatment works to the East of the city at Saltend. The new Saltend plant had pumps with a combined potential capacity of 22 m^3/s and the pumping stations at East and West Hull were mothballed. This led to a significant reduction in pumping capacity for Hull from 52 to 22 m^3/s, but the software used in designing the system indicated that the new storage afforded within the Humbercare transfer tunnel itself led to a 1 in 30 year level of protection.

From 2001 to 2004, following incidences of sewers becoming unusually surcharged in West Hull, two internal Yorkshire Water reports were commissioned into the operation and capacity of the Humbercare system (Coulthard

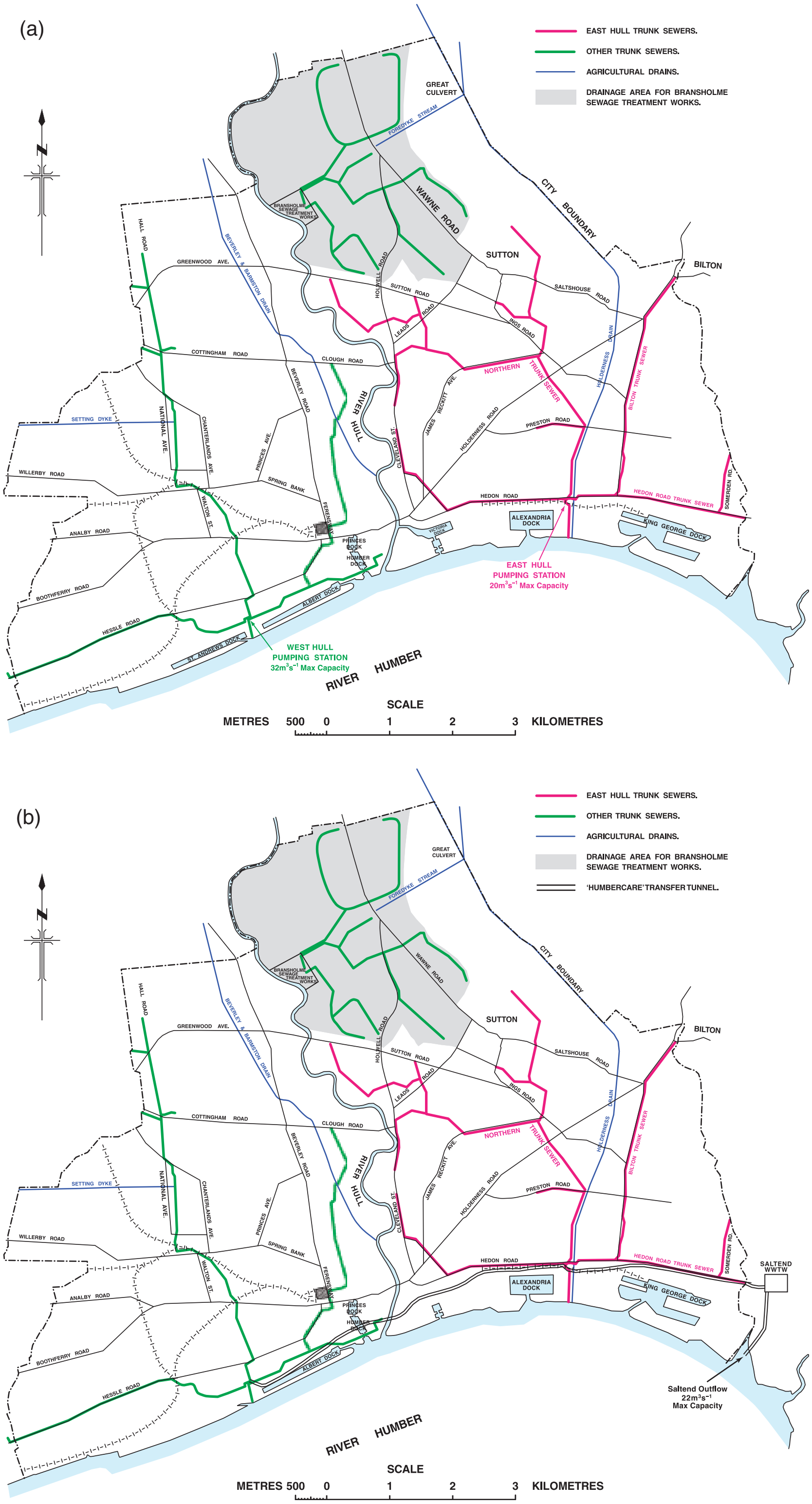

Figure 2 Map of the drain and sewer network in 1972 and 2001. The pumping stations and capacities are marked.

et al., 2007a, b). These remodelled the post-Humbercare system using updated software and indicated that for long-duration 1 in 30-year events, the original design under-estimated flood peaks by 10% and the volume of water to be evacuated by 100%. These reports stated that the post-Humbercare system had a capacity to cope with only 1 in 2- to 1 in 5-year events. In reaction to these reports, the West and East Hull pumping stations were partially re-opened to provide additional pumping capacity and resilience in case of failure of the transfer tunnel. Therefore, at the time of the 2007 floods, Hull had a combination of the old and new pumped systems, and there was no firm indication as to the exact capability of the system.

The exception to the above system is the area of Bransholme and Kingswood, which has a separate storm water drainage system. Constructed in the 1950s, a pumping station discharges storm water directly into the River Hull according to consent agreements with the Environment Agency (EA), with the option to store water in a lagoon if river levels are high. Sewage was treated at this site, but is now transferred directly to Saltend. The potential capacity of the pumps at Bransholme is 7.2 m^3/s, but the actual capacity is restricted to 5.4 m^3/s due to the outflow configuration.

The floods of 25 June 2007

June 2007 was the wettest month recorded in Yorkshire since 1882 (Met office/EA). On 25 June 2007, a deepening depression became slow moving across the United Kingdom, bringing sustained heavy rainfall to Lincolnshire, Yorkshire and the Midlands, resulting in widespread flooding across these regions. There are three local records of rainfall from that day including 96 mm at the River Hull in Hull (EA) and c. 105 mm at Saltend WWTW. An uncalibrated rain gauge at the Geography Department, University of Hull, recorded 110 mm on 25 June and over 250 mm in the month (Figures 3 and 4). On the 25th, Figure 4 shows that the rainfall was heavy and sustained, with intensities of over 6 mm/h between 8 a.m. and 5 p.m. There are no local records of soil moisture or groundwater levels in Hull, but it is likely that there was high antecedence following a rainfall event on 15 June (itself >1 in 30 recurrence) that also caused some local flooding. The return period of the 25 June event was estimated at 1 in 150 years (CEH Flood Estimation Handbook, Yorkshire Water pers. comm.) and >1 in 200 years (Hanna *et al.*, 2008).

After 6 a.m. on the morning of 25 July, telemetry data from the transfer tunnel sump at West Hull showed that the levels of water were rising rapidly. At 8 a.m., the additional pumps at old East and West Hull pumping stations were operated. By 10 a.m., reports of localised flooding were coming into the fire and rescue service in Hull, and throughout the day, these calls increased, reflecting the widespread flooding that occurred across the city.

Obtaining a precise map of the areas flooded has proved very difficult. There were no satellite overpasses of suitable resolution at that time and there are limited oblique aerial photographs taken by the BGS on 27 June. Door-to-door surveys by Hull City Council operatives showed that over 8500 homes were affected by floodwater incursion and these, with roads flooded, are shown in Figure 5. It is likely, however, that Figure 5 provides an underestimate of the surface area that was flooded, as there were many unrecorded gardens, parks, fields, car parks and other areas under water. On 25 June, the pumps at Saltend WWTW, West Hull and East Hull pumping stations worked continuously, although there were some periods when the pumps were inoperative for maintenance. At the Bransholme and

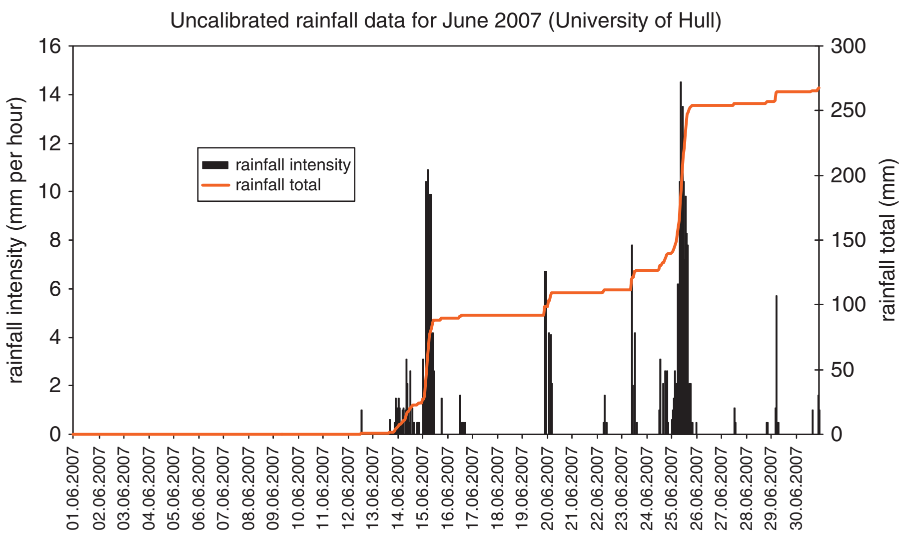

Figure 3 Rainfall for June 2007. Data from an uncalibrated rain gauge on the Cohen Building, University of Hull.

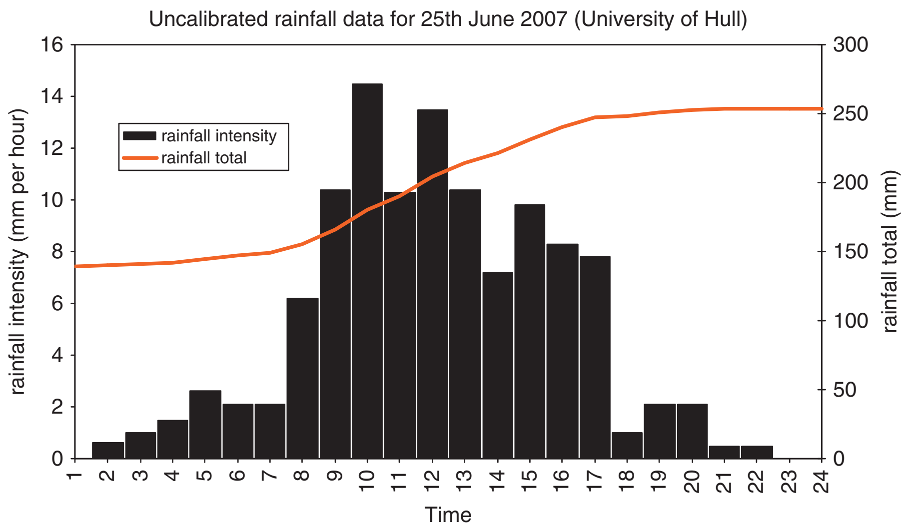

Figure 4 Rainfall for 25 June 2007. Data from an uncalibrated rain gauge on the Cohen Building, University of Hull.

Figure 5 Areas in Hull flooded. Lines correspond to flooded roads and dots show flooded properties.

Kingswood pumping station, the pumps were in operation continuously until approximately 6 a.m. on the morning of 26 June, when they failed as a result of the pumps themselves being inundated.

The nature and patterns of flooding

Within the City of Hull, the flooding was largely due to heavy and prolonged rainfall falling on a catchment already saturated (pluvial flooding). Of the watercourses and open land drains in the area, only the Setting Dyke (to the West of Hull) burst its banks briefly on 25 June (EA pers. comm.). The River Hull, while experiencing elevated levels, did not overtop its defences and while in operation, the Bransholme and Kingswood pumping station was able to pump water into the river at all times. The pluvial nature of the flooding and very low surface gradients led to slow rises in floodwater across the city as opposed to rapid inundation associated with point source flooding such as a breach of flood banks. In many cases, floodwaters rose up beneath houses through the underfloor cavities and foundations. Under these circumstances, sandbags, although widely deployed, are of limited use.

Analysis of the spatial distribution of flooding shows that in East Hull, the problems were largely concentrated around the Bransholme and Kingswood areas that are served by their own pumping station. Inundation was more widespread in West Hull, with large areas of Orchard Park (north), Newland Avenue and the Avenues (north/central), Priory Road/East Ella and Anlaby Park (west) flooded. There is a partial correlation between the areas flooded (Figure 5) and elevation (Figure 1), with the lowest areas being among those inundated. But flooding was not restricted to the lowest areas of Hull, suggesting that factors other than topography were also controlling flooding.

The levels of floodwaters were locally up to 3 m deep, but for most affected areas, floodwaters were < 1 m. Many damaged homes were only flooded by < 50 cm of water. Following the recession of the floodwaters, there were also numerous cases of houses where water had not entered the living space, but had damaged the foundations and underfloor areas. This led to flood damage being discovered several months after the flooding, dubbed 'secondary flooding'. There were also significant local health concerns associated with the flooding, as Hull has a combined sewerage system and some floodwaters were contaminated with sewage.

Factors contributing to the flooding

Because of its low elevation, Hull relies on a pumped drainage system. Therefore, the flooding was caused by the inability of this system to remove rain/storm water rapidly enough. More specifically, the flooding was caused by difficulties in water: (a) entering the drainage system, (b) being conveyed through the drainage system and/or (c) being pumped from the drainage system. The following section explores these three areas in more depth.

Immediately following the flooding, there was considerable speculation as to whether blocked roadside gullies had caused or contributed to the flooding by preventing water from entering the drainage system (Crichton, 2007). Indeed, gullies historically fitted to Hull's road network were smaller than those found in other parts of the Unite Kingdom and Crichton (2007) suggested that they were blocked with leaves and grass clippings. Coulthard *et al.* (2007a) examined Hull City Council's records of gulley maintenance and found that in the 12 months before the June 2007 floods, 4952 of 13 175 gullies had been cleared/cleaned and 0.57% of the 4952 were found to be blocked or slow running. In some areas, blocked gullies may have caused or contributed to some local flooding but based on these data, it would appear that gullies were not a major cause of the flooding in Hull. Notably, one of the main flooded areas (Newland Avenue) had new larger gullies fitted in the 6 months before the flooding. Furthermore, it should be noted that the 'symptoms' of a blocked gulley are very similar to those where water cannot be transferred through the drain and sewers downstream of the gulley.

If blocked gullies were not a major contributory factor in the flooding, this suggests the rate of water conveyance and pumping as problem areas. At the time of the June 2007 floods, the only data collected by Yorkshire Water on sewer flow levels were telemetry information on sewer levels at the inlet and outlet of the Humbercare transfer tunnel. It is therefore difficult to determine with certainty whether or not the sewers around Hull were fully surcharged. However, throughout the floods, the pumping stations at Saltend, East Hull and West Hull were operating at full capacity, which suggests that there was no shortage of supply to the pumping stations. In addition, there are photographs, video clips and eye witness accounts of water forcing up through and dislodging manhole covers, indicating that the system was surcharged, although this could have been caused by local obstructions. In contrast, pressure oscillations that were reported in the transfer tunnel on the 25th indicate that there may have been short-term reductions in pressure and thus water delivery to the transfer tunnel (Yorkshire Water, 2007).

Examining pumping, we have already described how the configuration and capacity of the system in Hull was extensively modified in 2001, with a significant reduction in pumping capability, and was subsequently modified after weaknesses were identified in 2004 and 2006. The IRB reports (Coulthard *et al.*, 2007a, b) raised concerns as to whether the modified system was of sufficient capacity as well as outlining operational issues. For example, the pumps and infrastructure at East and West Hull pumping stations were up to 50 years old and were not designed to be operated in tandem with the new Humbercare system. Furthermore, because of the age of the infrastructure, the pumping station at West Hull took an hour to bring on stream and individual pumps had to be periodically brought off stream for maintenance. The IRB final report (Coulthard *et al.*, 2007a, b) suggested that these factors may have led to a reduced pumping capability and may thus have exacerbated the floods in certain areas. A key question therefore is what the capacity of the pumped system was in June 2007 and how it compared with the pre-2001 configuration.

Following the floods, Yorkshire Water were asked by OFWAT (2008) to examine the performance of the drainage system in Hull (Yorkshire Water, 2008a). They carried out a limited modelling study, simulating pre-Humbercare drainage, the configuration in June 2007, a future scenario (Autumn 2009) including updates to the system and finally a free discharge setting – equivalent to having no pumps – where water could drain freely from the sewer outlets. Model performance was assessed in terms of model 'nodes' that were flooded rather than areas or houses flooded. This showed that for the free discharge scenario, 4.8% of nodes flooded for a 1 in 30 flood. As this situation has free drainage (implying an infinite pumping capacity), this suggests that constraints within the sewer network rather than the pumps account for some of the flooding. For the pre-Humbercare system, the number of flooded nodes increases to 5.4%. For the post-Humbercare, June 2007 scenario, the number increased to 7.5%, which suggests that the modification of the drainage system led to a 2.1% increase in nodes flooded. This study shows that the Humbercare system, in place in June 2007, caused a small increase in the number of nodes flooded compared with the previous drainage configuration. However, this is only for a 1 in 30-year event and does not model the effects of a c. 1 in 200-year event as occurred in June 2007. In addition, nodes flooded are not readily transferrable to increased water depths or inundation extents. Since the 2007 floods, Yorkshire Water have invested £16–20 million in updating the pumping stations at East and West Hull to improve their reliability and resilience.

The area of Bransholme and Kingswood in the North of Hull has its own surface water drainage system and the sole pumping station operated continuously until it was inundated at approximately 6 a.m. on the morning of 26 June. Here, this would indicate that the pumping capacity was insufficient to cope with the rate of water delivery (assuming that the floodwaters that inundated the station were from the sewer network).

Discussion 1. System design

One of the main issues that the 2007 floods in Hull have highlighted is the need for a different approach when designing and legislating for flood protection in low-lying coastal areas such as Hull. Within existing urban drainage designs, combined sewer overflows provide design resilience by using existing surface drainage channels or pathways during flood events that exceed design capacity. In areas such as Hull, there is simply nowhere else for the excess water to go and this needs to be factored into new designs or retro fitted to the existing system. This could be through the use of flood retention areas or 'aquagreens' as is already being investigated by officials in Hull (Hull City Council, 2008). More importantly, low-lying areas, such as Hull, may need alternative specifications or regulation for drainage design in order to afford a greater level of conveyance within the drainage system. This may include the construction of larger sewers and pumps. Furthermore, because of the reliance on pumped drainage systems, the resilience of these pumps should be ensured, with suitable backup provided to prevent system failures. In Hull, these issues have now been addressed through the addition of 100% backup capacity at the Bransholme pumping station, and the previously mentioned refurbishment of the East and West Hull pumping stations (Yorkshire Water, 2008b).

An important issue when considering the level of flood protection is climate change, and to ensure that designs are updated to accommodate for any changes. The Foresight research programme (Evans *et al.*, 2004) indicated that climate change for the United Kingsom may mean a shift towards increasing storminess, and OFWAT (2008) report that many sewer managers can give examples of atypical rainfall experienced in the last 3 or 4 years. As the designed level of protection (e.g. a 1 in 30-year event) is based on a probability, this should be continuously updated to accommodate any changes in flood patterns. For example, the events of 15 June and 25 June 2007 in Hull were estimated as representing 1 in 30-year and 1 in 200-year flood events, respectively. The occurrence of two such large floods in a short period of time will lead to a significant change in the magnitude of a 1 in 30-year event. Additionally, when using probabilistic forecasting methods for designing drainage systems, it is important to account for possible shifts in the nature of rainfall not just volumes. Shifting climates may provide more intense short-duration events or a greater frequency of long-duration low-magnitude events.

Discussion 2. Governance and management

At a national level, the 2007 floods revealed several shortcomings in the management and governance of flooding and flood risk in the United Kingdom. We believe that this can be traced back to the disaggregation of the water industry following privatisation in 1989. In 1973, the UK Water Act created 10 regional water authorities that had general responsibility for watercourses and land drainage. The responsibility for highway drainage and some land drainage functions lay with the local authority, providing a clear division of duties and responsibilities. The 1989 Water Act led to the privatisation of the water authorities, which saw a greater division of responsibilities. For example, in Hull, Yorkshire Water became responsible for sewerage, water supply and treatment; the Council for road and gulley drainage; and river management was transferred to a new body, the National Rivers Authority (NRA). In 1995, the NRA was amalgamated with other agencies to become the EA. For the city of Hull, this meant that responsibility for drainage function passed from one organisation (the local authority from 1973 to 1989) to three organisations (Hull City Council, Yorkshire Water and the NRA/EA). This situation was repeated across England and Wales.

In Hull, the IRB reports (Coulthard *et al.*, 2007a, b) OFWAT (2008) concluded that this division from one controlling agency to three led to difficulties in the design, management and operation of Hull's drainage system. At a national level, similar conclusions were drawn by Pitt (2008). In particular, there was no 'lead agency', with each organisation rarely looking beyond the limits of their responsibilities, and rarely consulting with each other. For example, there are several sections of sewer/culvert that change 'ownership' between Yorkshire Water, the EA and Hull City Council several times (back and forth). This led to separate management and maintenance practices. Up until September 2007, there was not even a unified map of the land drain, sewer and river network configuration. In Hull, this is particularly important due to the pumped drainage system and the input at the periphery of the sewer network of open land drains and culverts.

By not having a lead agency, there was no incentive for these organisations to work together, nor penalty if they failed to do so. This also led to issues concerning which organisation(s) should fund work that would clearly affect the other agencies. The responsibility for the management, prediction and warning from surface water flooding, especially in urban areas, was not clear. For example, the water companies are required to prevent sewage spillages, but sewer surcharging and subsequent surface water flooding are not as tightly regulated. The water authorities are closely regulated by a government-appointed regulator (OFWAT) in terms of quality of water provision, quality of service and price. But within OFWAT's regulatory framework, there is comparatively little scope to assess the quality of flood protection. Conversely, the EAs remit (pre-2007) was more closely aligned with flood risk from water courses and open bodies of water, not sewers. The disaggregation of the governance and management of drainage led to an unclear or a nonexistent chain of responsibility for surface water flooding in urban areas.

Acting upon these shortcomings, the UK government has enacted the Flood and Water Management Act (2010). One facet of this legislation is that the EA will have overall responsibility for all flooding (including surface water flooding), with the local authority taking control (under the EA's auspices) of regional surface water drainage. This will be carried out through the generation of Surface Water Management Plans (SWMPs). The SWMPs will be carried out by the Local Authority to establish which areas are likely to be at risk from surface water flooding and what action can be taken to reduce this risk. Once approved by the EA, the Local Authority may then have the powers to instigate changes to the local water companies' drainage system. At present, there are five trial SWMPs being carried out across the United Kingdom and Hull is one of these trial areas.

A final issue following the 2007 floods was that there was little or no warning system for pluvial flood events. The United Kingdom has an established and well-organised system of warning from fluvial flooding through the EA as a result of investment following extensive flooding in 2000. There are country-wide maps of fluvial flood risk and a multitiered warning system. However, this does not account for the impact of pluvial flooding or flash flooding that is not linked to fluvial systems. There are difficulties in modelling rainfall-related flooding, largely due to the widespread temporal and spatial variation in rainfall intensity and volume. But there are existing modelling packages that can simulate the impacts and that might be used as the basis for a warning system; however, it would appear that before 2007, this was not seen as a priority. In response to this, the UK government has set up a new National Flood Warning centre.

It is important, however, to note that while policy changes and investments in infrastructure will take years to come into effect, changes to personal and social resilience have already occurred. For example, if Hull were to be struck by a similar-size event before physical improvements have been made, the physical impacts would largely be the same. However, the actual impact would be far less, as the local population, council, agency and emergency services would be much better prepared to cope with the situation. Social resilience can be increased and local vulnerabilities can be reduced very rapidly and cost effectively through education, networks and planning with significant impact.

Conclusions

The June 2007 floods came from an unexpected source: surface water flooding. This revealed a major weakness in UK flood defence strategy, which has no capability for forecasting or warning from pluvial flooding. Furthermore, the design levels of urban drainage need to consider the vulnerability of the site. This is especially important for low-lying areas with no natural gravity-driven drainage such as Hull. Finally, the way in which the UK water industry is presently structured, postprivatisation, means that there is no lead agency for urban surface water flood management, although the recently enacted Flood and Water Management Act provides a new framework for responding to urban flood risk.

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