Lessons learned from the coastal flooding of process industry sites on Teesside and Humberside by the storm surge on 5-6 December 2013

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Abstract: On 5-6 December 2013 there was a storm surge in the North Sea that caused flooding along the east coast of England. 2,800 homes were flooded, but there were no fatalities. The effect on the process industry was significant, with sites flooded on Teesside and Humberside. Coastal water levels were the highest recorded since January 1953 and the highest tide ever was recorded on the Humber.

On 1st December the Flood Forecasting Centre warned of a storm surge in the North Sea on Thursday 5th December. The Environment Agency issued 71 severe flood warnings and 18,000 people were evacuated. Industrial sites along the coast shut down operations and withdrew personnel from low lying areas.

Inter Terminals, Riverside Terminal on the north bank of the River Tees is a top-tier COMAH site storing liquid chemicals in above ground tanks. Several empty tanks floated when the whole site became flooded and electrical and control systems were damaged but there were no injuries and no loss of containment. The damaged flood defence embankment was repaired within a few days and portable generators were installed to enable limited manual operation to resume within 2 weeks.

Inter Terminals, Immingham Terminal on the south bank of the Humber Estuary is a top-tier COMAH site storing liquid chemicals in above ground tanks. The storm surge overtopped and opened the dock gate of Immingham docks flooding the whole site. Electrical and control systems were damaged but there were no injuries and no loss of containment. The site resumed restricted production after 2 weeks and full production after 12 weeks.

SABIC operates a top-tier COMAH site on the Tees estuary storing liquid and gaseous petrochemicals in underground salt cavities. The storm surge washed away part of a flood defence embankment, flooding the site and damaging electrical and control systems, but there were no injuries and no loss of containment. The Environment Agency built a temporary roadway to provide access for heavy machinery and closed a 50m breach within 12 days. SABIC personnel repaired and tested damaged equipment, returning the first storage cavity to service in February and restoring normal site operations by April 2014.

CEMEX operates a cement works at South Ferriby on the Humber estuary. The whole site was catastrophically flooded by the storm surge which damaged the kiln and destroyed the electrical and control systems. There were no injuries and no loss of containment – largely due to decisive actions taken shortly before the site was flooded. The site did not restart production until December 2014, a year after it was flooded.

Background 1953 – 2013

East coast floods January 1953 and consequential improvements to flood risk management

On 31st January 1953, a combination of high spring tides, a deep depression and northerly gales caused a storm surge in the southern North Sea that affected the coast of England from Lincolnshire to Kent. There was no flood warning system at the time and the surge struck at night, drowning many occupants of single storey beach chalets in their bedrooms. In total 307 people died, 24,500 houses were damaged and 32,000 people were evacuated. It was the worst peacetime disaster ever to strike Britain.

As a consequence flood defence banks were built along the coastline, a comprehensive flood-warning scheme was introduced and the Thames Barrier was built to protect London.

Flooding incidents 1998 - 2012 and consequential improvements to flood risk management

The first major flooding of recent years occurred during Easter 1998, when more than 60 mm of rain fell across parts of central England in 48 hours. Five people lost their lives, 4,500 properties were flooded and the cost of damages was estimated at £350M. The worst affected town was Northampton where most of the residents were unaware that they lived in a floodplain and were caught completely by surprise. A fuel terminal operated by BP Oil in Northampton was flooded, though there was no loss of containment that might have caused pollution of the River Nene. The following year this site became a lower-tier establishment under the Control of Major Accident Hazards (COMAH) Regulations 1999. Following the floods, the Environment Agency (EA) commissioned an independent and wide-ranging review of its flood defence activities (Bye, 1998) and made the following improvements:

- Publicity campaigns to increase public awareness and to encourage at-risk homeowners to develop a flood plan

- Publication of indicative flood plain maps on the internet
- Upgrading river flow telemetry systems
- New computer models to be used for flood forecasting
- Better communications with the Met Office and the emergency services
- More understandable flood warnings codes
- The use of automated telephone messaging to disseminate flood warnings

Autumn 2000 was the wettest for 250 years and the prolonged heavy rainfall caused significant river and groundwater flooding in many places, with North Yorkshire, the Severn Valley, and parts of Kent and Sussex particularly badly affected. Two people lost their lives and 10,000 properties were flooded, though flood defences protected 280,000 properties. The total cost of damages was estimated at £1bn. The improved flood warning arrangements introduced by the Environment Agency following the Easter 1998 floods undoubtedly reduced the loss of life and assisted the work of the emergency services.

The Autumn 2000 floods affected several COMAH sites, most notably a top-tier waste treatment and storage site operated by Cleansing Services Group (CSG) on the banks of the River Severn near Gloucester. The site was destroyed during a storm by a fire which consumed 180 tonnes of waste chemicals and the emergency services had to evacuate 60 people from their homes. The site flooded a few days later and the local residents were evacuated a second time.

Following the 1998 and 2000 floods the Environment Agency carried out an internal review of flood risks at the major hazards sites that it regulated (Whitfield, 2003). The key findings were:

- Many major hazards sites are located on an indicative flood plain and are therefore susceptible to either river or coastal flooding. (These locations were usually chosen deliberately because they provided level building land, access to good transport links, a supply of cooling water and a discharge route for liquid effluents).
- Many sites were built during the 1950s and 60s and the flood defences provided at the time might not be adequate to protect against the anticipated effects of sea-level rise and climate change.
- Many sites had never experienced flooding so flood risk might not have been properly addressed as part of the on-site and off-site emergency plans.
- Flooding of major hazards sites could lead to the loss of containment of dangerous substances and have a significant effect upon the environment. Pollution could affect the water courses themselves, adjacent sensitive habitats or necessitate the closure of drinking water intakes with consequent disruption to public water supplies.
- Flooding could also have significant financial and operational implications for the site concerned. In some cases it might lead to an operator going out of business, impacting the economy and leaving the Environment Agency and Local Authorities to deal with land contamination and clean-up issues.

In May 2002, the Environment Agency introduced a new policy "Management of Flood Risks at Major Installations" which provided a structure for assessing flood risks on COMAH sites and those now regulated under the Environmental Permitting Regulations 2010 (EPR). Sites at high risk of flooding were identified using Geographical Information Systems (GIS) overlays of site locations and indicative flood plains. These sites were then inspected to ensure they had carried out flood risk assessments and incorporated flooding into their on-site and off-site emergency plans.

In January 2005 prolonged heavy rain in north-west England flooded 2,700 homes. In Carlisle 3 people lost their lives and 1,800 properties were flooded. The cost of the flooding was estimated at over £400 million.

Summer 2007 was the wettest in England for 250 years. In total 13 people lost their lives, 55,000 properties were flooded and around 7,000 people were rescued by the emergency services. There was the largest loss of essential services since World War II, with almost half a million people without water and electricity. Transport networks failed, a dam breach was narrowly averted and emergency facilities were put out of action. The insurance industry estimated the cost £3bn. The Government commissioned a review of the lessons to be learned (Pitt, 2008) which resulted in significant improvements to flood risk management, including:

- In 2009 the Flood Forecasting Centre (FFC) was established as a joint venture between the Environment Agency and the Met office to provide improved flood risk guidance for England and Wales. The FFC is based in the Operations Centre at the Met Office headquarters in Exeter and is jointly staffed from both organizations.

- In March 2011, the UK held Exercise Watermark, its largest ever flood defence exercise (Defra, 2011). It cost £1.8M and involved around 10,000 people, 10 government departments, emergency services, utility companies and communities. It was primarily a desk top exercise, though there were practical aspects including the evacuation of a primary school and the use of RAF helicopters to airlift people from rooftops and flooded caravan parks. Although all the incidents in the preceding 13 years had involved river flooding caused by heavy rainfall, half of the exercise was devoted to a coastal flooding scenario caused by a storm surge. This demonstrated that the Environment Agency and the Government had not forgotten the lessons learned from the east coast floods of 1953.

In March 2011 a tsunami on the east coast of Japan flooded the Fukishima Nuclear power plant and causing a major nuclear accident. The Office for Nuclear Regulation carried out a flood risk assessment of nuclear power stations soon after the Fukishima accident. The UK stations are designed to withstand a 1 in 10,000 (0.01%) annual chance of flooding, which is much more severe than the 1953 floods. Most stations were found to be resilient to their design specification, though a few were slightly less resilient and had to make improvements. The December 2013 storm surge was comparable to the 1953 surge and none of the 4 nuclear power stations along the North Sea coast were affected.

In January 2013 the Environment Agency marked the 50th anniversary of the 1953 flood with a number of publications and events. These were intended to maintain awareness of flood risk in the local populations along the North Sea coast.

The COMAH 1999 regulations implement the requirements of 1996 European directive on the control of major accident hazards involving dangerous substances (known as the Seveso II directive). This has recently been revised as the Seveso III directive which specifically requires operators to assess "natural causes, for example earthquakes and floods" for their potential to cause major accidents (European Union, 2012). Seveso III requirements will be implemented in Great Britain by the COMAH 2015 regulations. The reference to earthquakes and floods reflects a growing awareness across Europe of the risks associated with Natural Hazard Triggered Technological Accidents (Natechs). The Major Accident Hazard Bureau of the European Commission has published a Natech database to provide a source of lessons learned (MAHB, 2015).

East coast storm surge 5-6 December 2013

Flood warnings and preparation

On Sunday 1st December 2013 the Flood Forecasting Centre identified that a low pressure system, northerly winds and a high tide might combine to cause a significant surge along the North Sea coast on Thursday 5th. The Environment Agency immediately started making preparations; opening Incident Control rooms and setting up shift rosters for staff. The forecasts issued on Monday and Tuesday were for a low risk of flooding – with water levels predicted to be below the height of most of the coastal defences. On Wednesday the forecast was upgraded to medium risk and on the morning of Thursday 5th it was upgraded to high risk – with water levels expected to exceed the height of the flood defences at multiple locations. The Environment Agency issued 71 severe flood warnings which were sent automatically to 160,000 homes and businesses and 18,000 people were evacuated from their homes (mainly in Great Yarmouth and Kings Lynn). This was by far the largest number of severe flood warnings (indicating "Severe flooding Danger to life") that had been issued at the same time.

Incident management and recovery

The surge hit Teesside in the late afternoon and travelled southwards along the coast during the evening, exceeding the level of the January 1953 surge in several places. Fortunately no lives were lost, but 1,400 homes were flooded, while 800,000 properties were protected by flood defences. Process industry sites were flooded on Teesside and Humberside. The Thames barrier was raised to protect London and recorded the highest tide since it started operating in 1984. On Friday morning the Environment Agency received situation reports from each Area and flew a coastal survey aircraft along the entire east coast, taking thousands of aerial photographs. This information was collated to assess the damage caused to flood defences and prioritise repair work to protect properties and businesses from flooding during subsequent high tides.

On Teesside, the flood defences at Port Clarence had been overtopped causing flooding to 30 properties but the defences remained intact. The flood defences at Inter Terminals Riverside Terminal had also been overtopped and damaged with 2 short breaches. Inter terminals was responsible for the maintenance of these defences and they successfully completed the repairs within a couple of days, with some assistance from the Port Authority. At the SABIC Brinefields storage area a 50m length of the flood defence embankment had been completely washed away so flood water was flowing into and out of the site with every tide, widening the breach as it did so. The Environment Agency made the repair of this breach their top priority on Teesside because of the potential safety and environmental consequences if there was a loss of containment and the importance of the site to the operations of SABIC and the wider Teesside chemical industry. The repair work, which took 16 days and cost about £1.5M, included:

- Calling in a military Chinook helicopter for 3 days to drop big bags containing rocks into the breach. It soon become clear that this was insufficient to close the breach but it did protect the ends of the embankment and prevent the breach from growing with each tide.
- Closing the A178 to through traffic so that it could be used solely to provide access to the breach.
- Using a remote controlled survey boat to measure the depth of the scour hole at the breach so the amount of material need to close the breach could be calculated.
- Employing contractors to build a 150m temporary access road along the back of the embankment then close the breach using rocks topped with clay.

Flooding at Inter Terminals, Teesside

Site description

Inter Terminals, Riverside Terminal, is a top-tier COMAH site located on the north bank of the River Tees. The site provides bulk liquid chemical storage in above ground storage tanks with facilities to import and export by ship, road and pipeline. The site is substantially automated with remote valve operation via a Supervisory Control and Data Acquisition (SCADA) computer control system. It also has an EPR permit. (Note: At the time of the incident Inter Terminals was trading as Simon Storage).

Preparations for flooding

The Terminal is in a flood zone 3 so a flood risk assessment had been carried out and site plans with topographical information were available (Flood zone 3 means that, if there were no flood defences, the area could be flooded from the sea by a flood that has a 0.5 per cent (1 in 200) chance of being exceeded in any year). Emergency response plans and evacuation plans were in place and some employees were registered with the Environment Agency flood warning system. The river defence protection level was 4.15 MAOD (Metres Above Ordnance Datum), but lower areas existed along the Billingham Beck around the south side of the site.

During the run up to the 5th December, several flood warnings were received from the Environment Agency with predicted increased tide levels. Terminal operations including shipping, road loading and pipeline transfers continued during the week. Since the site is located several miles upstream of the east coast, the potential impact was not fully realised until the 5th December when operations were shut down and electrical power isolated.

The flooding on 5-6 December 2013

The surge caused a rise in the river level to 4.3 MAOD which over topped the defences along the river frontage and Billingham Beck and erosion of the bank created 2 short breaches, lowering the effective protection level. The huge volume of water entering the site from the river and the beck flooded the whole site to a depth of 1.8m

Site personnel sought safe refuge in the site control room on the upper floor of the main office building. Most of the tank bund walls were overtopped and several tanks with low inventory were floated from their bases, damaging pipework and supports. Mobile plant was also floated and swept along with the inrush of flood water causing impact damage when it collided with other stationary infrastructure. There were no injuries and no loss of containment of any product.

Short term site recovery

The low level of the site meant that the flood water was unable to flow back to the river. After receiving authorisation from the Environment Agency, flood water was pumped back into the river to allow access to key plant. Mobile generators were brought in to provide essential utility power and the terminal remained inoperable during this immediate recovery period.

Long term site recovery

The main electrical switchgear and process control systems were rendered inoperable and substantial work to replace the equipment was undertaken. Key systems such as level alarms and tank gauges were prioritised and transfer operations which were previously automatic SCADA controlled were managed manually. Emergency procedures were put in place to cover these operations.

Primary containment systems were inspected from an asset integrity perspective and remedial works were identified including the repositioning of storage tanks, pipeline replacement and repair and electrical equipment replacement and testing. A post flood review was undertaken to agree and record the lessons learned.

The river defence embankment is being raised to 4.85 MAOD and work to protect the rest of the site boundary to the same level is also planned. The final protection of the site will be 1 in 1000 (0.1 %) annual chance of flooding in any year.

Figure 1. Inter Terminals, Riverside Terminal. Water overtopping the flood defences – as seen from a ship at the terminal.

Figure 2. Inter Terminals, Riverside Terminal. Damaged flood defence embankment showing the temporary repair.

Flooding at Inter Terminals, Humberside

Site description

Inter Terminals, Immingham Terminal is a top tier COMAH site located on the south bank of the Humber estuary. The site provides bulk liquid oil and chemical storage in above ground storage tanks with facilities to import and export by ship, road and pipeline. It also has several environmental permits. (Note: At the time of the incident Inter Terminals was trading as Simon Storage).

Preparations for flooding

The terminal is in a flood zone 3 location so a flood risk assessment had been carried out and site plans with topographical information were available. Emergency response plans and evacuation plans were in place and some employees were registered with the Environment Agency flood warning system. The river defence protection level was approximately 6.0 MAOD, but the dock door crest level was only 4.7 MAOD. All the flood defences along the frontage of the port are owned, maintained and operated by Associated British Ports (ABP).

During the run up to the 5th December, several flood warnings were received from the Environment Agency, with predicted tide levels. Terminal operations including shipping, road loading and pipeline transfers continued during the week.

Just prior to the flood, precautions were taken to protect as much key equipment as possible and to restrict transfer operations. Hours before the flood, the Teesside terminals reported that they had been badly hit by the surge which was heading southward. The site landlord ABP was also issuing their own alerts based on different information, with confusion between Chart, AOD and tide tables data. All operations were shut down and soon afterwards ABP isolated all electrical power. All systems were made safe and non-essential staff evacuated. A safe refuge was identified in the upper floor of the operations office for remaining staff.

The flooding on 5-6 December 2013

The surge caused a rise in the river level to 5.3 MAOD which overtopped the dock entrance gates, filling the dock until it overflowed into the dock estate, flooding the terminals up to 1m deep. The embankment protection itself failed in several places causing a further flow into the terminal.

None of the tank bund walls were overtopped and the bunds remained dry throughout the flood. Although mobile plant was floated there was little mechanical damage to infrastructure. All ABP and site switchrooms were flooded and the waste water treatment was rendered inoperable, but there was no loss of containment of any product.

Short term site recovery

The levels of the site allowed most of the flood water to recede into the river and dock. After receiving authorisation from the Environment Agency, residual flood water was pumped back into the river. Electrical power remained off in the short term with mobile generators brought in to provide essential utility power. The terminal remained substantially inoperable during this immediate recovery period.

Long term site recovery

Priority systems were eventually restored after extensive remedial work to key mechanical and electrical infrastructure but temporary power remained in place for some time. The site was surveyed for damage to any primary containment systems. A post flood review was undertaken to agree and record the lessons learned. Eventually, after each switchroom had been overhauled and tested, full power was regained after 12 weeks.

The main offices which saw the maximum flood depth were also overhauled and brought back into service.

As the site landlord, ABP is responsible for the flood defences at Immingham Docks. ABP, Inter Terminals and other dock users have agreed to fund a major project which includes raising the outer dock entrance gates to gain a protection level of 6.5 MAOD and an equivalent flood risk of 1 in 1000 (0.1%) annual chance of flooding. The Environment Agency provided advice to ABP on the dock gate levels and on other flood defence improvements that were included in this project.

Flooding at SABIC, Teesside

Site description

SABIC UK Petrochemicals Limited is part of the SABIC Group, with the ultimate parent company being Saudi Basic Industries Corporation based in Riyadh, Saudi Arabia. It manufactures bulk petrochemical products (Ethylene, Propylene, Butadiene, Cyclohexane, and Benzene) at a number of plants on the Tees Estuary and is highly integrated with other operating sites on Teesside and the United Kingdom. It is a top-tier COMAH site holding large inventories of hydrocarbons as well as an EPR permit.

Preparations for flooding

SABIC participated in the 2011 Exercise 'Watermark' and lessons learnt were incorporated into the emergency response protocols, which were further tested as part of the COMAH 'Live Play' exercises in subsequent years. When flood warnings were received during the first week of December SABIC implemented standard operating practices to prepare for the storm surge. These preparations included; emptying the effluent treatment facilities, isolation of all non-essential electrical equipment; sandbagging of vulnerable areas such as switch houses and the removal of all containers that could float, so the site was well prepared for the storm surge.

The flooding on 5-6 December 2013

When the high tide occurred on the late afternoon of 5th December 2013, monitoring of river levels was focused on the banks of the river Tees where SABIC has a processing plant and jetty facilities. Whilst there was some localised flooding it was considered to be manageable, so by early evening the site was moving into clean-up mode and returning to normal operation. What happened next was unprecedented and not planned for in any flood damage assessment or COMAH major accident scenario.

At approximately 8pm whilst undertaking a routine tour of the Brinefields and Cavities area a process technician heard a large crashing sound and observed a "tsunami like" wall of water coming from Greatham Creek into the area which stores hydrocarbons in underground salt cavities. Fortunately the technician was in a safe location away from the incoming water.

The Site Alarm was raised immediately and the cavities placed into a safe operating condition by closing the Remote Operated Shut-Off Valves. A full damage assessment could not be made in the darkness so the decision was taken to cease all hydrocarbon movements to and from the area. This decision not only affected operations within SABIC but had immediate consequences for other local businesses that have infrastructure and product storage within the area.

SABIC has a Crisis Management protocol that is brought into action following incidents that have the potential to cause significant societal or business impact and on the early morning of the 6th December the Crisis Management Team convened. It was clear from the initial damage assessments that a number of COMAH Major Incident Scenarios were feasible and that SABIC would need to be directly involved with the broader flooding incident management that was being co-ordinated by government agencies. Contact with the Emergency Control Centre was established and recovery operations commenced.

Site recovery

From SABIC's perspective the major emergency response had two main objectives:

1. To maintain safe containment of the hydrocarbon inventories whilst the flood defences were being repaired.
2. To return the area to normal operation as soon as practicable without endangering people or the environment.

Within 3 days SABIC was able to establish an inspection routine during low tide. This enabled integrity assurance of the operating area and a limited amount of damage assessment to be made. It soon became apparent that the pressure containment envelope was secure and there had been only limited damage to the cavity wellheads and piping infrastructure. The major damage sustained was to the electrical distribution, instrumentation and control systems including all telemetry networks. Operations in the storage area were restored after 5 months of intense electrical and instrumentation repair and replacement work. The SABIC insurance loss assessment was in excess of £10 million (including both asset replacement and business losses). Discussions are ongoing with government agencies regarding the ongoing integrity of the established flood defences in the Teesport Area.

Figure 3. SABIC Brinefields and Cavities storage area showing the flood defence breach.

Figure 4. SABIC - Chinook helicopter dropping big bags into the breach.

Figure 5. SABIC – note flood level mark half way up the control room wall.

Figure 6. SABIC - flood damage to electrical equipment.

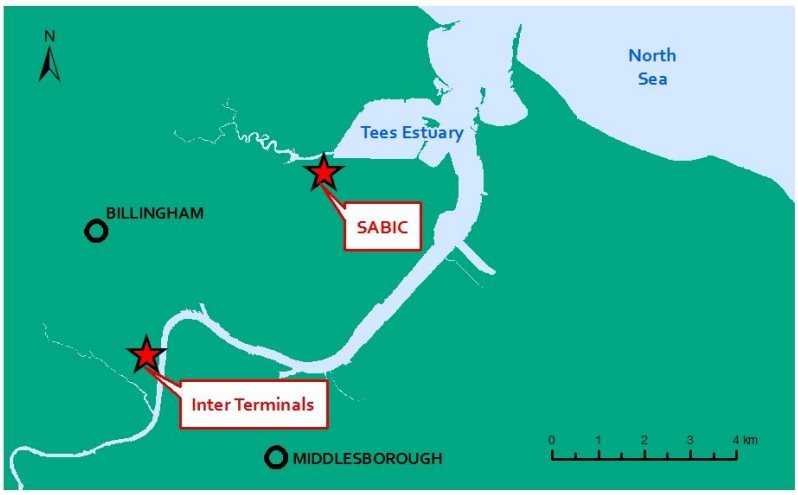

Figure 7. Map of Teesside showing flooded sites.

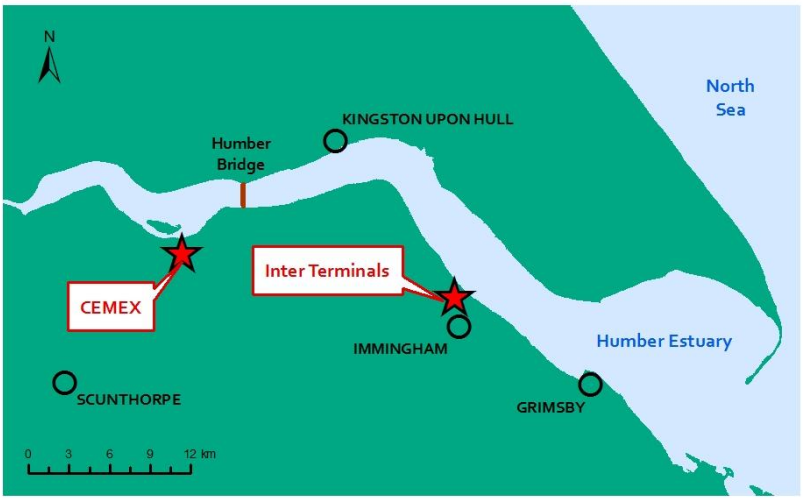

Figure 8. Map of Humberside showing flooded sites

Flooding at CEMEX, Humberside

Site description

CEMEX South Ferriby cement works is located west of the village of South Ferriby on the south bank of the Humber estuary and is one of three cement producing sites making up CEMEX UK Cement. The plant capacity is approximately 700,000 tonnes of cement per annum and it directly employs 122 people, many of whom live in the surrounding area.

The site is operated under an EPR permit and Greenhouse Gas permit, both issued by the Environment Agency.

Preparations for flooding

During the week before, the cement works was prepared for a minor flood, using sandbags etc., although flooding at that time was considered unlikely because the predicted surge levels were lower than the flood defences. However on the morning of Thursday 5th December flood warnings were issued by the Environment Agency indicating that flooding was expected – there was a high risk of flood defences being overtopped along the Humber. The local internal incident management team and UK rapid response team were established and flood contingency plans were put in place.

As the top priority is health and safety, all non-essential employees were sent home, shift times altered and those on site remained in safe positions. Mobile machinery and plant was moved to higher ground where possible. Power was cut to operations when it became clear that sub-stations would be threatened and shutdown of the cement kiln was initiated.

Containment of oils and waste fuels was implemented to minimise potential loss. All contingency plans worked and CEMEX were able to support the local village in evacuating and making preparations.

The flooding on 5-6 December 2013

At 18:44 hours on 5th December, the flood defences on the Humber Estuary were overtopped and the site was inundated with flood water from two directions. Fortunately, all employees were safe with the final three employees being rescued from site by the emergency services. The flooding was much greater than expected and the entire site was submerged with flood waters up to 3 metres deep in places. The site lost all power and communication links.

The flood water and silt caused catastrophic and irreparable damage to control systems, the power supply network, compressed air systems, buildings and the cement kiln which was still operational due to insufficient cooling time. High and low voltage systems were destroyed by water tracking into the terminated ends of the cables and all production ceased. Damage could have been worse had it not been for decisive action taken by the Plant Director, that minimised impact to both plant and equipment and ensured the welfare of employees.

All normal communication channels were lost so CEMEX used social media to provide direct and reliable communications to all employees. Temporary offices were installed in a cabin at the unaffected nearby quarry and most of the workforce was kept off site for up to three weeks whilst the site was professionally cleaned, decontaminated and made safe.

Site recovery

Site recovery work has been extensive, initially involving cleaning and removal of unsafe structures along with implementing plans to ensure customers could be supplied with cement from the other CEMEX UK Cement sites.

Repairs involved significant time and investment with up to 400 contractors on site at any one time. The work included the installation of new primary sub-stations, a new compressor building, a new control room, 6.4 km of new high voltage cables, (with none of the original high voltage system being reusable), along with low voltage and control cabling and 22 metres of new kiln shells. 86 skips of electrical equipment alone were removed from site. Wherever possible, new cables and plant have been elevated to 2 metres above ground level.

Cement works such as South Ferriby are very capital intensive, with new sites costing several hundred million pounds and having operational lives typically in excess of 40 years. South Ferriby has been operational since the 1970's and as such, much of the equipment that was damaged in the flood was no longer directly replaceable. Recovery costs to bring the site back into operation have been very high - tens of millions pounds. Re-commissioning of cement production commenced early in December 2014, a year after the flooding occurred. Environment Agency managed flood defences have been repaired along the Humber with discussions ongoing to implement further defences for the cement works and the village of South Ferriby.

Figure 9. CEMEX, South Ferriby and the Humber estuary.

Figure 10. CEMEX - Employees awaiting rescue.

Figure 11. CEMEX – wall collapsed due to pressure of floodwater.

Figure12. CEMEX – a new compressor building raised on 2m concrete plinths.

Lessons identified from the east coast storm surge December 2013

1. Flood defence structures can fail completely during a flooding incident; walls and embankments might be over-topped or collapse under the weight of water or flap valves and sluice gates might not close properly.
2. The site emergency plan should include a Layers of Protection Analysis (LOPA) which considers flood defence structures to be simply one layer of protection. If a flood defence structure fails, other layers of protection should be capable of preventing a COMAH major accident and avoiding a major business impact.
3. Flood risk assessment and emergency plans should be reviewed on a regular basis to ensure they are up to date. (For example some sites that had registered to receive Environment Agency flood warnings did not receive an automatic warning because they had not told the Environment Agency that staff had moved into new roles or that site telephone numbers had changed. In some cases the warning was sent to the wrong location because the operator had provided the telephone number for their head office rather than the site that was at risk of flooding).
4. The site flooding emergency plan should use the Environment Agency flood warnings as trigger points to initiate the different stages of the plan. The plan should allow for the actual weather experienced at a site to be worse than was forecast - weather forecasting is not an exact science.
5. Emergency exercises have a vital role to play in ensuring an effective response to a flooding incident. For example Exercise Watermark in 2011 had involved liaison between the emergency services, the Environment Agency and the military including the use of helicopters. This training was put into practice when military Chinook helicopters were called in to stabilise the breach in the flood defences at SABIC on Teesside.
6. Sites should consider the need to relocate existing safety critical equipment and to install new build above the maximum flood level.
7. One of the biggest difficulties faced by the sites during the initial recovery phase was the lack of an electricity supply. This was a particular problem in December and January when there were only 8 hours of daylight. Fortunately there were enough emergency generators available, but there might not have been if flooding had been more widespread.

8. Storage tanks containing a small inventory should be partially filled to prevent them from floating when surrounded by flood water.
9. Floating objects can cause significant damage when they are swept along by flood water and collide with other fixed infrastructure. Any objects that can float should be secured or removed from site as part of flooding preparations. (For example, one site had a floating van and another site had a floating skip).
10. The Environment Agency had to extract some COMAH site information from paper files which created extra work for incident management staff during the first few days after the surge. [Improvements have been made by putting the COMAH site boundaries and site entrances data onto the Environment Agency incident management mapping system in 2015].
11. The Environment Agency guidance note on preparing for flooding at EPR and COMAH sites should be revised to include all the lessons from the 2013 storm surge. The original guidance was produced in 2012 by the Chemical and Downstream Oil Industries Forum (CDOIF) a joint collaboration of the COMAH regulators, trades unions and industrial trade associations and published by the Environment Agency. [This action was completed by November 2014. (Environment Agency, 2015)].

Conclusions

The east coast flooding of January 1953 was the worst peacetime disaster to affect the UK and it resulted in significant improvements to flood warning systems and flood defences, including building the Thames Barrier. Since 1998 there have been several major inland flooding incidents which have resulted in the Environment Agency updating its warning systems and incident management procedures. The Environment Agency has also used its role as a regulator of major hazard industries to ensure that operators have made improvements to flood resilience on their own sites. This has been particularly important for the 124 COMAH sites located on the North Sea coastline, most of which have been built since 1953.

The east coast storm surge of December 2013 was similar in magnitude to the 1953 event but the outcome was very different – see Table 1. The emergency planning done by the regulators and industry ensured that there were no major accidents or pollution incidents but there is no room for complacency – there are always lessons to be learned and improvements to be implemented. The predicted effects of climate change include an increase in the number and intensity of winter storms so defences that currently provide a 1 in 100 annual chance of being exceeded in any year may only provide 1 in 10 annual chance of being exceeded in any year by the end of the century. This means the next east coast storm surge may be significantly higher than the levels of 1953 and 2013.

	East coast floods, January 1953	East coast storm surge, December 2013
Breaches of flood defences	1200	6
Properties affected	24,000 flooded	2,800 flooded (and 800,000 protected by flood defences)
Deaths	307	2 (not flood related)
Agricultural Land inundated	65,000 ha	6,800 ha
People evacuated	32,000	18,000
Infrastructure and industrial damage	2 Power Stations	No significant loss of utilities due to flooding, though 370,000 homes were without electricity due to the storm. Significant impact on the operation of 2 industrial sites on Teesside, 1 on Humberside and most of Immingham Port
Flood Warnings	No warnings issued because there was no flood warning system	71 severe flood warnings issued. More than 160, 000 warning messages sent directly to homes and businesses using an automated telephone system

Table 1. Comparison of the effects of the east coast storm surges of 1953 and 2013.

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