Enabling Resilient UK Energy Infrastructure:
Natural Hazard Characterisation Technical Volumes and Case Studies

Case Study 5:

Cottam

LC 0064_18CS5

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This document forms part of the Energy Technologies Institute (ETI) project 'Low Carbon Electricity Generation Technologies: Review of Natural Hazards', funded by the ETI and led in delivery by the EDF Energy R&D UK Centre. The aim of the project has been to develop a consistent methodology for the characterisation of natural hazards, and to produce a high-quality peer-reviewed set of documents suitable for use across the energy industry to better understand the impact that natural hazards may have on new and existing infrastructure. This work is seen as vital given the drive to build new energy infrastructure and extend the life of current assets against the backdrop of increased exposure to a variety of natural hazards and the potential impact that climate change may have on the magnitude and frequency of these hazards.

The first edition of *Enabling Resilient UK Energy Infrastructure: Natural Hazard Characterisation Technical Volumes and Case Studies* has been funded by the ETI and authored by EDF Energy R&D UK Centre, with the Met Office and Mott MacDonald Limited. The ETI was active from 2007 to 2019, but to make the project outputs available to industry, organisations and individuals, the ETI has provided a licence to the Institution of Mechanical Engineers and Institution of Chemical Engineers to exploit the intellectual property. This enables these organisations to make these documents available and also update them as deemed appropriate.

The technical volumes outline the latest science in the field of natural hazard characterisation and are supported by case studies that illustrate how these approaches can be used to better understand the risks posed to UK infrastructure projects. The documents presented are split into a set of eleven technical volumes and five case studies.

Each technical volume aims to provide an overview of the latest science available to characterise the natural hazard under consideration within the specific volume. This includes a description of the phenomena related to a natural hazard, the data and methodologies that can be used to characterise the hazard, the regulatory context and emerging trends. These documents are aimed at the technical end-user with some prior knowledge of natural hazards and their potential impacts on infrastructure, who wishes to know more about the natural hazards and the methods that lie behind the values that are often quoted in guideline and standards documents. The volumes are not intended to be exhaustive and it is acknowledged that other approaches may be available to characterise a hazard. It has also not been the intention of the project to produce a set of standard engineering 'guidelines' (i.e. a step-by-step 'how to' guide for each hazard) since the specific hazards and levels of interest will vary widely depending on the infrastructure being built and where it is being built. For any energy-related projects affected by natural hazards, it is recommended that additional site- and infrastructure-specific analyses be undertaken by professionals. However, the approaches outlined aim to provide a summary of methods available for each hazard across the energy industry. General advice on regulation and emerging trends are provided for each hazard as context, but again it is advised that end-users investigate in further detail for the latest developments relating to the hazard, technology, project and site of interest.

The case studies aim to illustrate how the approaches outlined in the technical volumes could be applied at a site to characterise a specific set of natural hazards. These documents are aimed at the less technical end-user who wants an illustration of the factors that need to be accounted for when characterising natural hazards at a site where there is new or existing infrastructure. The case studies have been chosen to illustrate several different locations around the UK with different types of site (e.g. offshore, onshore coastal site, onshore river site, etc.). Each of the natural hazards developed in the volumes has been illustrated for at least one of the case study locations. For the sake of expediency, only a small subset of all hazards has been illustrated at each site. However, it is noted that each case study site would require additional analysis for other natural hazards. Each case study should be seen as illustrative of the methods outlined in the technical volumes and the values derived at any site should not be directly used to provide site-specific values for any type of safety analysis. It is a project recommendation that detailed site-specific analysis should be undertaken by professionals when analysing the safety and operational performance of new or existing infrastructure. The case studies seek only to provide engineers and end-users with a better understanding of this type of analysis.

Whilst the requirements of specific legislation for a sub-sector of energy industry (e.g. nuclear, offshore) will take precedence, as outlined above, a more rounded understanding of hazard characterisation can be achieved by looking at the information provided in the technical volumes and case studies together. For the less technical end-user this may involve starting with a case study and then moving to the technical volume for additional detail, whereas the more technical end-user may jump straight to the volume and then cross-reference with the case study for an illustration of how to apply these methodologies at a specific site. The documents have been designed to fit together in either way and the choice is up to the end-user.

The documents should be referenced in the following way (examples given for a technical volume and case study):

ETI. 2018. *Enabling Resilient UK Energy Infrastructure: Natural Hazard Characterisation Technical Volumes and Case Studies,* Volume 1 – Introduction to the Technical Volumes and Case Studies. IMechE, IChemE.

ETI. 2018. *Enabling Resilient UK Energy Infrastructure: Natural Hazard Characterisation Technical Volumes and Case Studies,* Case Study 1 – Trawsfynydd. IMechE, IChemE.

1. Introduction

This case study illustrates the appropriate use of the methodology from the technical volumes for Cottam, England. Cottam is located in the East Midlands region of England. The site was chosen as representative of an inland river environment. This case study provides an assessment for the river flooding hazard. The aim of this case study is to assess flood risk, mainly from fluvial and tidal sources; risk of flooding from other sources, such as surface water and ground water flooding, have also been considered. All relevant key data associated with flooding, such as river water levels, sea levels and river discharges, have also been presented. For more information on this particular hazard, see Volume 5 — River Flooding.

1.1 Infrastructure at Cottam

The Cottam power station, owned by EDF Energy, is situated at the eastern edge of Nottinghamshire on the west bank of the River Trent at Cottam village near Retford (*Figure 1*). The site extends over 620 acres of mainly arable land. The station was commissioned in 1969 by the Central Electricity Generating Board. Another power station at West Burton on the west bank of the River Trent is 5.6 km downstream of Cottam. The decommissioned High Marnham power station on the west bank of the River Trent was 9.7 km upstream of Cottam. The power station site is centred on National Grid Reference E481286, N379231. The surrounding land and floodplain is protected by Environment Agency (EA) flood defences along the River Trent (*EA, 2009*). The flood defences are maintained by EA. Information provided by EA has confirmed the crest level of these defences which can provide protection against combined fluvial and tidal flooding for up to a 1% annual exceedance probability (AEP) event.

The power station site at Cottam is located in Flood Zone 3a (high likelihood flooding area) and benefits from the flood defences maintained by EA. The land surrounding the power station is classified as less vulnerable in terms of flood risk in accordance with the National Planning Policy Framework (*MHCLG, 2018*).

Figure 1. Location of Cottam power station in Retford in Nottinghamshire. (Sources: © 2017 Google LLC, used with permission. Google and the Google logo are registered trademarks of Google LLC. Ordnance Survey data Crown copyright database right © 2018)

1.2 Hydro-meteorological characteristics of Cottam

The stretch of the River Trent from Cromwell Weir to its confluence with the Humber Estuary is tidally influenced (*JBA, 2017*). Cromwell Lock is located approximately 24 km upstream of Cottam. Therefore, Cottam is within the tidally influenced reach of the Trent.

The tidal River Trent is navigable at the location of the power station. There are numerous water level gauging stations on the Trent, as illustrated in *Figure 2*. The nearest flow gauging station to Cottam is at Muskham on the Trent which is about 30 km upstream of Cottam. There are no streams/rivers joining the Trent between Muskham and Torksey, adjacent to Cottam. *Table 1* provides some key flow parameters of the River Trent at Muskham.

EDF Energy has no recorded incidents of flooding on the power station site, but historical records suggest that the River Trent has a history of flooding. More details are provided in *Section 1.3*.

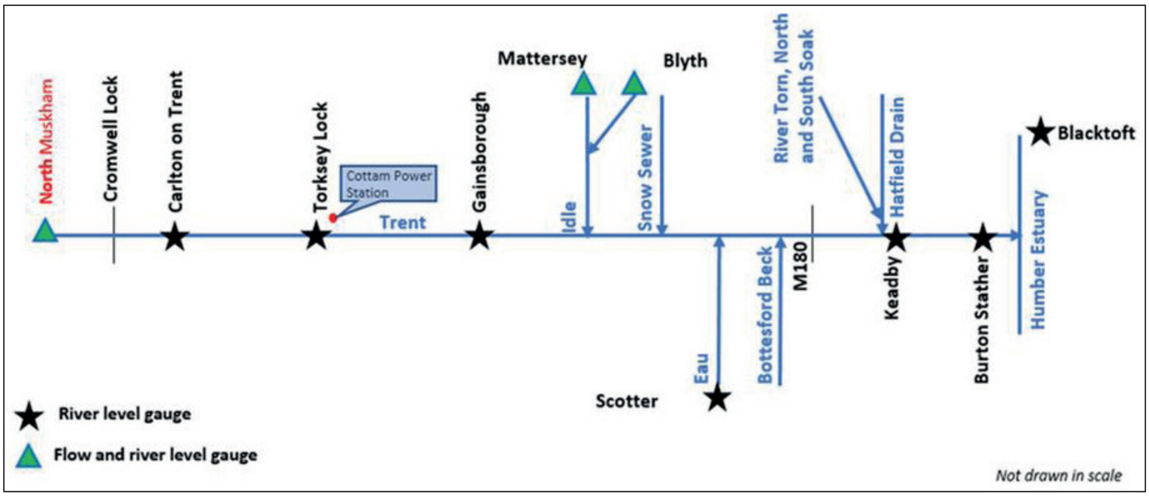

Figure 2. Flow and water level gauge network on the River Trent and tributaries of the Trent (Cottam is adjacent to Torksey Lock) (Source: Mott MacDonald)

Table 1. Flow characteristics of the River Trent at North Muskham (Station Number: 28022), about 30 km upstream of Cottam. (Source: Mott MacDonald (2013); Marsh and Hannaford (2008) for QMED)

Observed and estimated flows	Flow (m^3/s)
Mean annual maxima flood (*QMED**)	438.07
Highest recorded flow	1002.2 (27th February 1977)
20% AEP	589
10% AEP	673
5% AEP	794
2% AEP	1020
1.33% AEP	1136
1% AEP	1215
0.5% AEP	1433
0.1% AEP	2124
Note: Design peak flows of different AEP events are obtained from Mott MacDonald 2013 Modelling Study of Tidal Trent	

1.3 History of flooding in the River Trent

There are records of many historic flooding events, both fluvial and tidal, in the tidal stretch of the Trent around Cottam. In February 1795, significant river flooding occurred at Burton due to breaching of the River Trent embankments with flood water propagating up to Lincoln. In March

*All technical terms marked in blue can be found in the Glossary section.

1947, the flood embankment along the Trent was breached, inundating 50,000 acres of land in Gainsborough with approximately 2000 properties affected (*RMS, 2007*). In December 1965, flooding was widespread with water over 2 m deep. In the winter of 2000 flooding occurred in Girton. The most severe tidal flooding took place in October and November 1954 because of a series of tidal surges breaching defences. Other large events were understood to have occurred in October 1875 and March 1932.

The Flood Map data provided by EA, and reproduced in *Figure 3*, show the site's flood extent for four historical events. The flood information provided by EA for these four events is summarised in *Table 2*. It indicates that the cause of flooding in these four events was primarily insufficient channel capacity of the River Trent. There is no information on the depth or duration of this flooding.

Table 2. Environment Agency historical flood information (Source: EA)

Map reference	Flood vent code	Name	Start date	End date	Source of flooding	Cause of flooding
2000	EA034_ FEG_4030_12_ NOV_2000	Lower Trent 12 Nov 2000	12/11/2000	12/11/2000	Main river	Channel capacity exceeded (no raised defences)
1977	EA034_ FEG_4030_1977	Tidal Trent 1977	01/02/1977	01/02/1977	Main river	Channel capacity exceeded (no raised defences)
1932	EA034_ FEG_4030_1932	Tidal Trent 1932	01/01/1932	01/01/1932	Main river	Channel capacity exceeded (no raised defences)
1947	EA034_ FEG_4030_1947	Tidal Trent 1947	01/03/1947	01/03/1947	Unknown	Channel capacity exceeded (no raised defences)

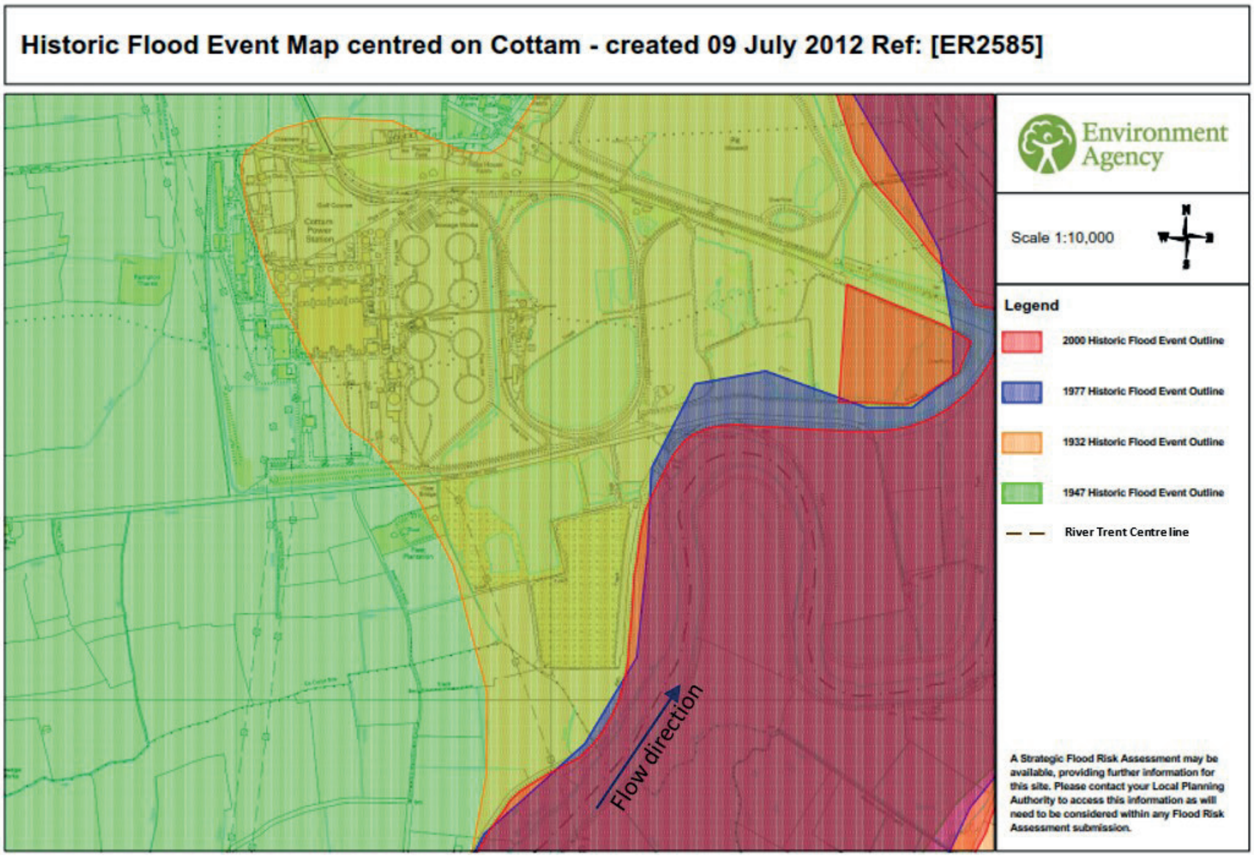

Figure 3. Map showing spatial outlines of historical flood events near Cottam. (Source: EA (contains Ordnance Survey data Crown copyright database right © 2018))

To better characterise the river flooding hazard and to achieve a good understanding of the risk associated with a site, it is important to consider a wide range of factors that could contribute to the risk to the subject site. Broadly, these considerations can be split into three broad categories: site characteristics (e.g. topography, geology); different sources of flood risk (e.g. fluvial sources, groundwater); other factors that may affect flood risk (e.g. climate change and interdependencies). The rest of this section outlines how to assess these broad categories at the Cottam site.

2.1 Site characteristics

2.1.1 Topography

Cottam power station is in the East Midlands region of England and in the River Trent catchment. It is approximately 1.2 km south-west of the village of Cottam and 1.2 km east of the village of Rampton. A location plan with key local features is provided in *Figure 4*.

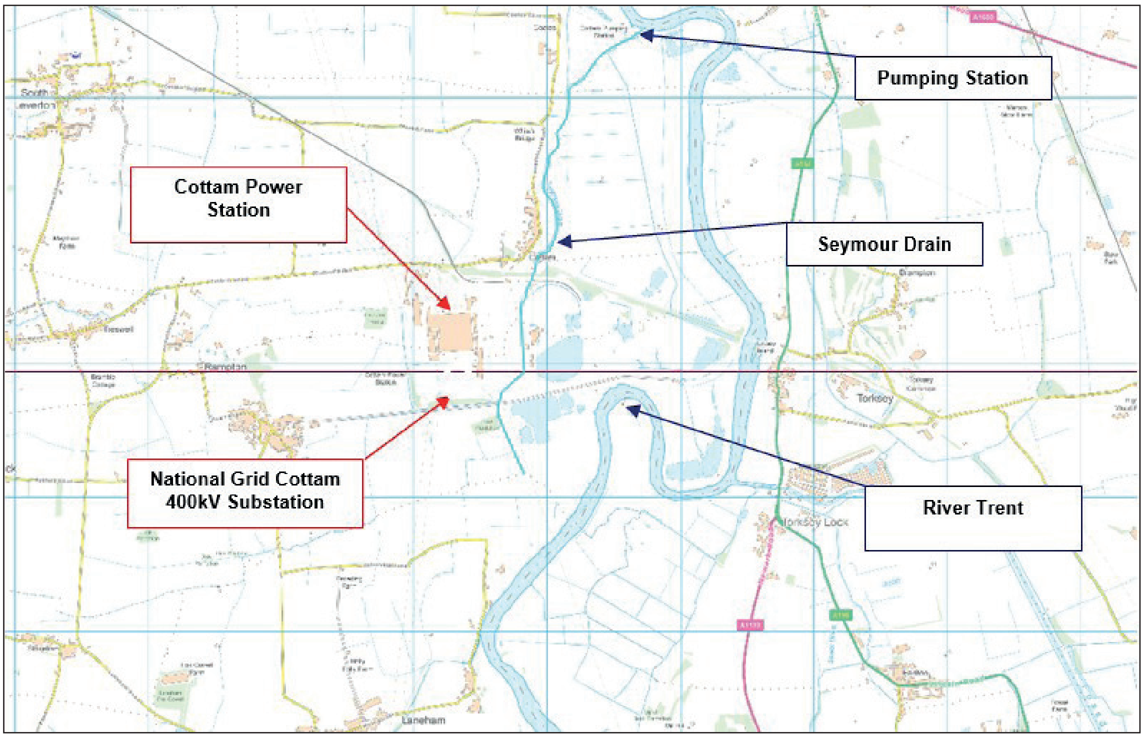

Figure 4. Cottam power station — map of the local area with key local features. (Source: Mott MacDonald, contains Ordnance Survey data Crown copyright database right © 2018)

Light Detection and Ranging (LIDAR) ground elevation data with 1 m and 2 m resolutions (i.e. in 1 m x 1 m and 2 m x 2 m cells or pixels), as surveyed in July 2011, is available for most of the area on the floodplain of the River Trent and for the power station site (*Figure 5*). The vertical accuracy of the LIDAR data was typically ± 0.15 m.

The topographic survey data covering the power station site show that the ground elevation is typically between 6.0 and 8.0 metres above ordnance datum (mAOD). The power station on the east and south side has a relatively high embankment/defence (which encircles the station). On the west side, the elevation is relatively low, between 4.8 and 5.6 mAOD along the boundary of the site, and thus, flow spilling to the left bank floodplain will inundate this area.

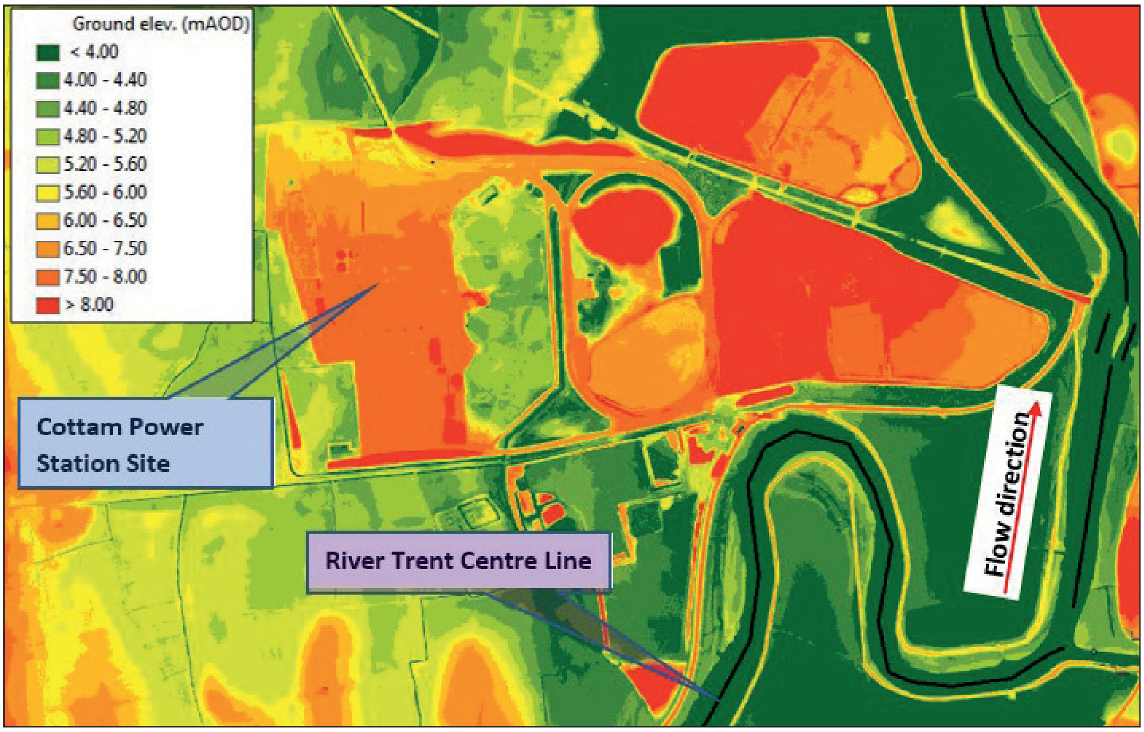

Figure 5. Ground elevation from LIDAR (2011) at Cottam power station site and on the left bank floodplain of the River Trent. (Source: EA)

2.1.2 Geology and hydrogeology

The British Geological Survey's 'Geology of Britain viewer' (*BGS, 2018*) suggests the area near Cottam power station is underlain by a bedrock of Mercia Mudstone with superficial deposits of sand, gravel and some clays (River deposits, Quaternary).

2.1.3 Hydrology and drainage

The River Trent (an *EA main river*) is located approximately 1 km south-east of the site. It flows in a northerly direction but encounters a sharp meander that changes the flow direction to the south for a short distance, before turning north again.

Seymour Drain, maintained by the Inland Drainage Board (IDB), drains the water north through the power station-owned land. It joins the River Trent approximately 3 km north of Cottam. The flow into the Trent from the Seymour Drain is controlled by a pumping station located adjacent to the Trent (*Figure 4*). An unnamed drain flows east adjacent to Torksey Ferry Road, and joins Seymour Drain approximately 200 m south-east of the site.

Several open bodies of water are close to the site, and are used by the power station as storage ponds for pulverised fuel ash (PFA), a by-product of coal burning. Approximately 1.5 km south-east of the site, on the inside bend of the meander of the Trent, there are two large wetland lakes used as habitat for wetland birds.

There is a flow gauging station on the River Trent at North Muskham approximately 30 km upstream of the Cottam power station, with flow data available from the early 1960s. Other local gauging stations can be found at *HM Government (2018)*. The annual maximum flow (AMAX) is shown in *Figure 6* together with mean annual maxima flood (QMED).

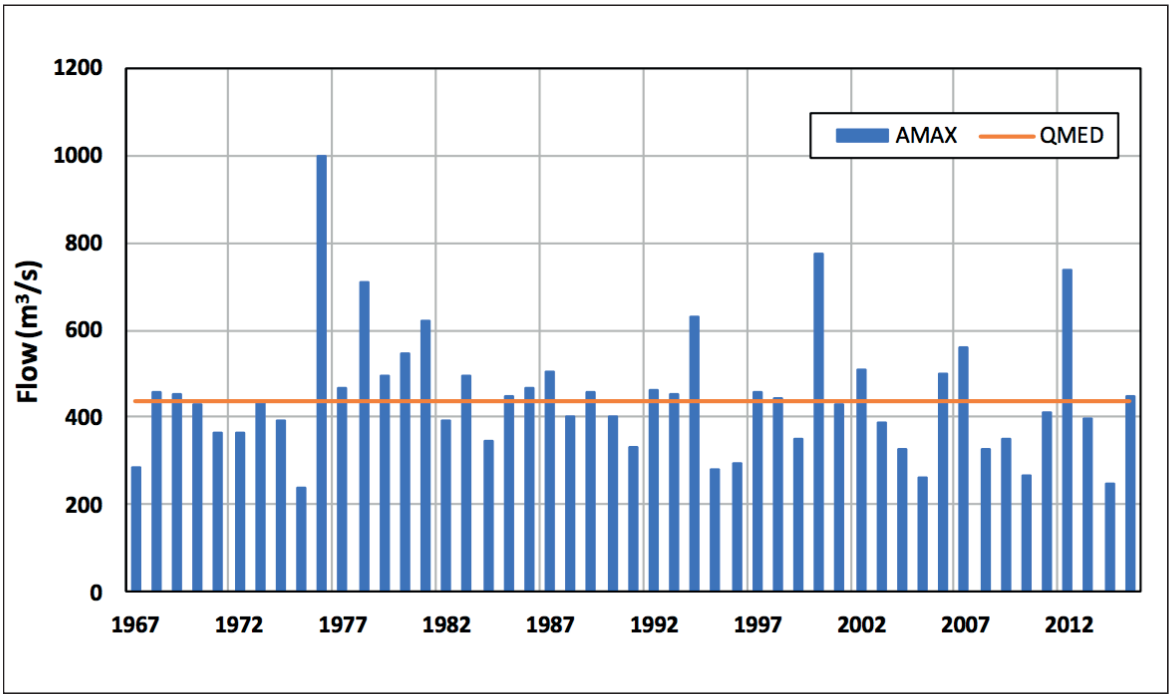

Figure 6. Annual maximum flow (AMAX) and mean annual maxima flood (QMED) in the River Trent at North Muskham (approximately 30 km upstream of Cottam). (Source: NRFA (2018))

2.1.4 Existing flood defences

Formal flood defences exist along the Trent close to Cottam power station. They are maintained by EA (*Figure 7*) and are classified as 'soft defences' (here being earth embankments). They offer up to a 1% AEP Standard of Protection (SoP) according to the EA data. EA's flood defence database, also called the Asset Information Management System (AIMS), records the defences as having a crest level of 7.9 mAOD at the closest point to Cottam power station. However, AIMS has less detail than LIDAR as it only contains single crest levels for long sections of defence. In the same area, EA's 2 m LIDAR indicates that the crest level varies between 7.6 and 8.7 mAOD.

Although the existing flood defences maintained by EA provide a certain level of protection, future funding for the maintenance of these defences is not certain. As the funding requirements to continue maintaining and building assets are expected to increase in the future, EA has recognised that there will be areas where flood risk is likely to increase, and the risk from flood defences being breached remains a reality. Therefore, it would not be an unfair assumption that areas on both banks along the tidal stretch of the Trent will remain vulnerable to flood risk; most of the historic floods in the tidal Trent were triggered by breaching of flood defences. As such, risk of flooding at Cottam power station from joint fluvial and tidal events remains a possibility, and very likely in a future climate change scenario, where sea level is predicted to rise by 1.21 m in the Humber Estuary over the next 100 years (see *Section 2.4* and *Table 8*), and both rainfall and river flows are predicted to increase over the next century.

Different infrastructure and assets will have different design lives. When assessing an existing asset, it is necessary both to consider the flood risk at the current time, and also to the end of the asset's design life and beyond. Similarly, when building a new asset, it is very important to consider the flood risk throughout its whole design life. For infrastructure such as nuclear power plants, it is also vitally important to understanding the flood risk during the decommissioning stage, to ensure that the most sustainable solution is in place to effectively manage the risk. For these reasons, the anticipated design life should be taken into account when deciding the level of protection for an asset and characterising the natural hazard under consideration.

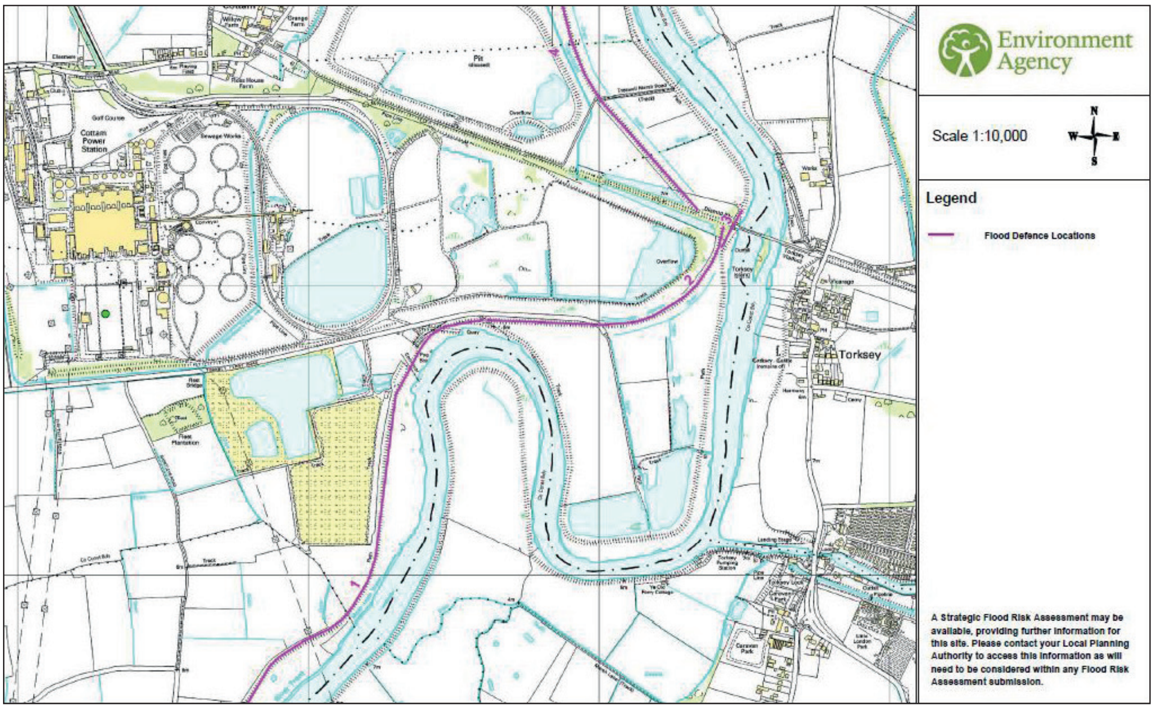

Figure 7. Existing EA defences near Cottam power station (only shows defences on the left bank). (Source: EA (contains Ordnance Survey data Crown copyright database right © 2018))

2.2 Sources of flood risk

2.2.1 Fluvial flooding

Flood zones (Zone 1, 2 and 3) are geographic areas that have been defined according to varying levels of flood risk. These zones are depicted on flood risk maps published by EA. Each zone reflects the severity or type of flooding in the area. The definitions of the flood zones used by the Government are provided in *Table 3*.

Table 3. Definition of flood zones as provided by EA.

Flood zone	Definition
Zone 1 Low Probability	Land having a less than 0.1% AEP of river or sea flooding. (Shown as 'clear' on the Flood Map — all land outside Zones 2 and 3)
Zone 2 Medium Probability	Land having between a 1% AEP and 0.1% AEP of river flooding; or land having between a 0.5% AEP and 0.1% AEP of sea flooding. (Land shown in light blue on the Flood Map)
Zone 3a High Probability	Land having a 1% or greater AEP of river flooding; or land having a 0.5% or greater AEP of sea flooding. (Land shown in dark blue on the Flood Map)
Zone 3b The Functional Floodplain	This zone comprises land where water has to flow or be stored in times of flood. Local planning authorities should identify in their Strategic Flood Risk Assessments areas of functional floodplain and their boundaries accordingly, in agreement with the Environment Agency. (Not separately distinguished from Zone 3a on the Flood Map)
Note: these flood zones refer to the probability of rivers and sea flooding, ignoring the presence of defences.	

The current EA Flood Maps (*Figures 8* and *9*) indicate that Cottam power station is in Flood Zone 2 and also partly in Flood Zone 3, i.e. in medium and high probability zones in terms of flooding.

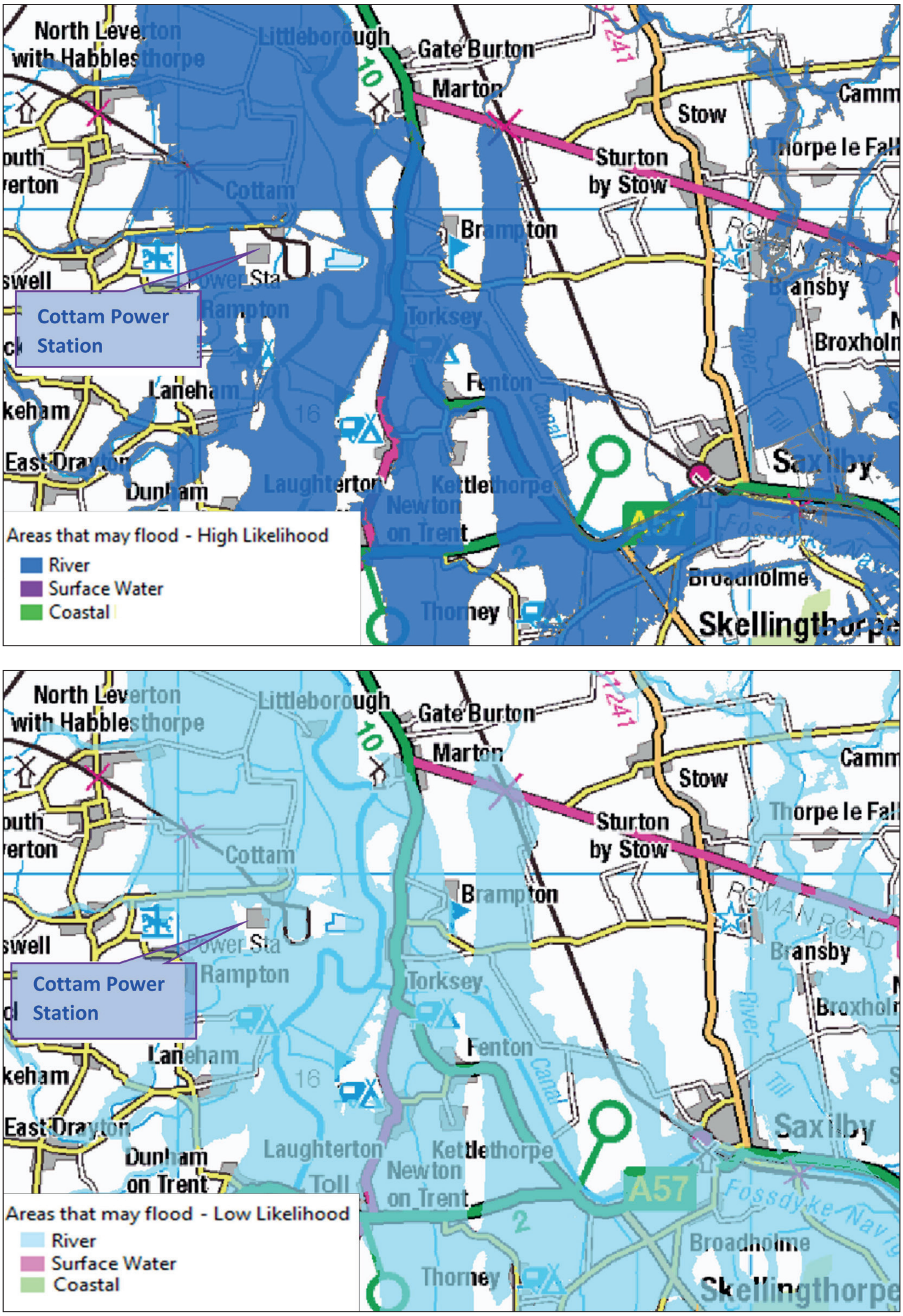

Figure 8. Zone 3 (high likelihood, upper plate) and Zone 2 (low likelihood, bottom plate) river flood outlines at Cottam. (Source: EA (contains Ordnance Survey data Crown copyright database right © 2018))

Figure 9. Zone 3 (high likelihood) and Zone 2 (low likelihood) river flood outlines at Cottam power station site. (Source: EA (contains Ordnance Survey data Crown copyright database right © 2018))

Although EA's Catchment Flood Management Plan (CFMP) study reported that no flooding in the floodplain is expected in the defended scenario for a 1% AEP event, assuming the flood defence is in excellent condition and would not be breached during a 1% AEP event. It is advisable to consult EA on the flood outline from flood events more severe than a 1% AEP flood, and flood levels associated with climate change scenarios.

2.2.2 Tidal influence and extreme sea level

The River Trent flows into the Humber estuary near Faxfleet. *Figure 10* shows the location of the Trent confluence with the Humber as well as the key river gauging stations on the Humber and the Trent.

Figure 10. Map showing the location of the Trent confluence with the Humber and key gauging locations. (Source: EA (contains Ordnance Survey data Crown copyright database right © 2018))

Tides heavily influence the water level in the Humber estuary, including the water level at the location where the Trent joins the Humber. As a result the tidal Trent is under the daily influence of the tide in the sea. The tidal influence from the Humber extends further upstream of the Trent for over 80 km; the tidal limit is at the Cromwell Lock/Cromwell Weir (for location, see *Figure 2*). Cromwell Weir is over 20 km upstream of Cottam on the Trent. Thus, the Cottam area is well within the tidal influence zone. Therefore, when assessing the flood risk at Cottam power station, the influence from the Humber, especially under extreme sea level conditions, also needs to be considered.

Practical guidance for design with consideration of extreme sea levels along the UK coast was published in 2011 by EA (*EA, 2011a*). It provides Coastal Flood Boundary (CFB) data for the

UK mainland and islands. The CFB data at Immingham on the Humber are shown in *Table 4*. The key outputs from that project include:

- a consistent set of extreme peak sea levels of different AEP, ranging from 100% AEP to 0.01% AEP events;
- extreme peak sea levels available for a total of 16 AEP events (this dataset does not generally cover the estuary);
- peak sea level values along the coastline at a spacing of about two kilometres. This enables rapid selection of appropriate levels and reduces the need for long distance interpolation;
- advice on generating an appropriate total storm tide curve for use with extreme sea levels. Standard surge tide shapes are given for each part of the coast.

For Cottam power station, the nearest CFB data point (chainage 3886 km, i.e. the distance from Newlyn) is shown in *Figure 11*. The extreme levels range between 4.16 and 5.72 mAOD for the 100% AEP and 0.01% AEP; the lower bound level is 4.06 and 5.22 mAOD and the upper bound level is 4.26 and 6.22 mAOD respectively. It should be noted that these extreme values do not include allowance for sea level rise due to climate change.

Figure 11. Location of nearest CFB data points for Cottam in the Humber Estuary at CFB chainage 3886 km. (Source: EA (contains Ordnance Survey data Crown copyright database right © 2018))

Table 4. Extreme sea level at Immingham: CFB data from the nearest data point (chainage 3886 km). (Source: CFB data (EA, 2011b), base year 2008.)

AEP (%)	Return period (year)	Extreme sea level (mAOD)	Confidence Interval[1]	Lower and upper bound levels (mAOD)	
				Lower bound	Upper bound
100	1	4.16	0.1	4.06	4.26
50	2	4.26	0.1	4.16	4.36
20	5	4.4	0.1	4.3	4.5
10	10	4.51	0.1	4.41	4.61
5	20	4.62	0.1	4.52	4.72
4	25	4.66	0.1	4.56	4.76
2	50	4.77	0.1	4.67	4.87
1.33	75	4.83	0.2	4.63	5.03
1	100	4.87	0.2	4.67	5.07
0.67	150	4.95	0.2	4.75	5.15
0.5	200	5	0.2	4.8	5.2
0.4	250	5.02	0.2	4.82	5.22
0.33	300	5.06	0.2	4.86	5.26
0.2	500	5.15	0.3	4.85	5.45
0.1	1000	5.28	0.3	4.98	5.58
0.01	10,000	5.72	0.5	5.22	6.22

[1]A location of interest 50 km outside the influence of the raw SSJPM analysis site may require further additions to the Confidence Interval (EA, 2011a).

2.2.3 Astronomical tide

Cottam power station is adjacent to the Trent and is about 58 km upstream of the tidal Trent's confluence with the Humber. The tidal influence from the Humber on the water levels in the Trent near Cottam is evident from historical records. *Figure 10* shows the locations of several gauging stations, i.e. the tidal gauge at Immingham on the Humber, and the water level gauges at Torksey, Gainsborough and Keadby on the River Trent.

Tidal levels based on observed tidal records are available at Immingham from 1959 to 2017. Yearly extreme tidal values (yearly maximum) are also available at Immingham from 1959 to 2017; both datasets can be downloaded from the online British Oceanographic Data Centre (BODC) database (*BODC, 2018*).

Examples of spring and neap tides from Immingham, together with CFB extreme sea levels, are shown in *Figure 12*. Yearly maximum tidal levels from 1990 to 2017 are shown in *Figures 13* and *14* along with CFB data.

River levels for the last five days, and the highest recorded levels for the river gauges at Torksey, Gainsborough and Keadby can be viewed online (*HM Government, 2018*). The five-day water levels for a period in February 2018 at these three gauges, along with highest recorded water levels, are shown in *Figures 15*, *16* and *17*. The full set of historical data may be obtained from EA upon request. Data availabilities are (as of 2018): Torksey: 1972 to date; Gainsborough: 1993 to date; Keadby: 1993 to date.

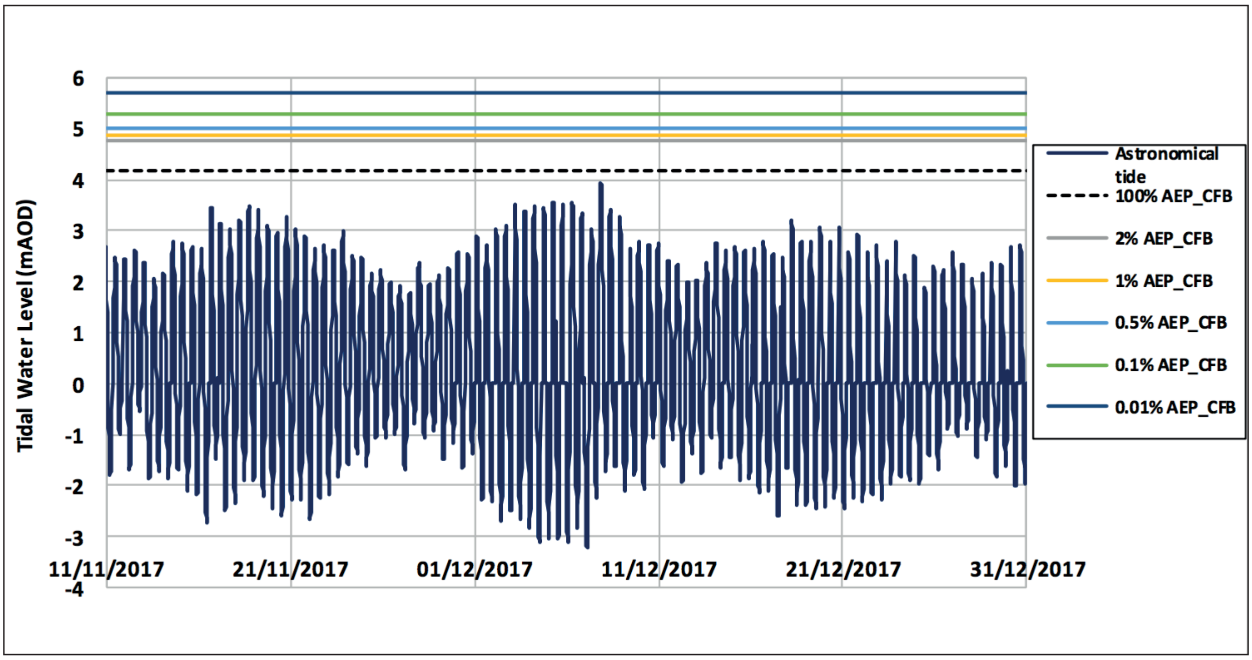

Figure 12. Tidal gauge data at Immingham on the Humber (BODC tide gauge) and nearest CFB data (at chainage 3886 km) from different AEP events; tidal data shown for a selected period (full year's data and historical data are also available on BODC site). (Source: EA)

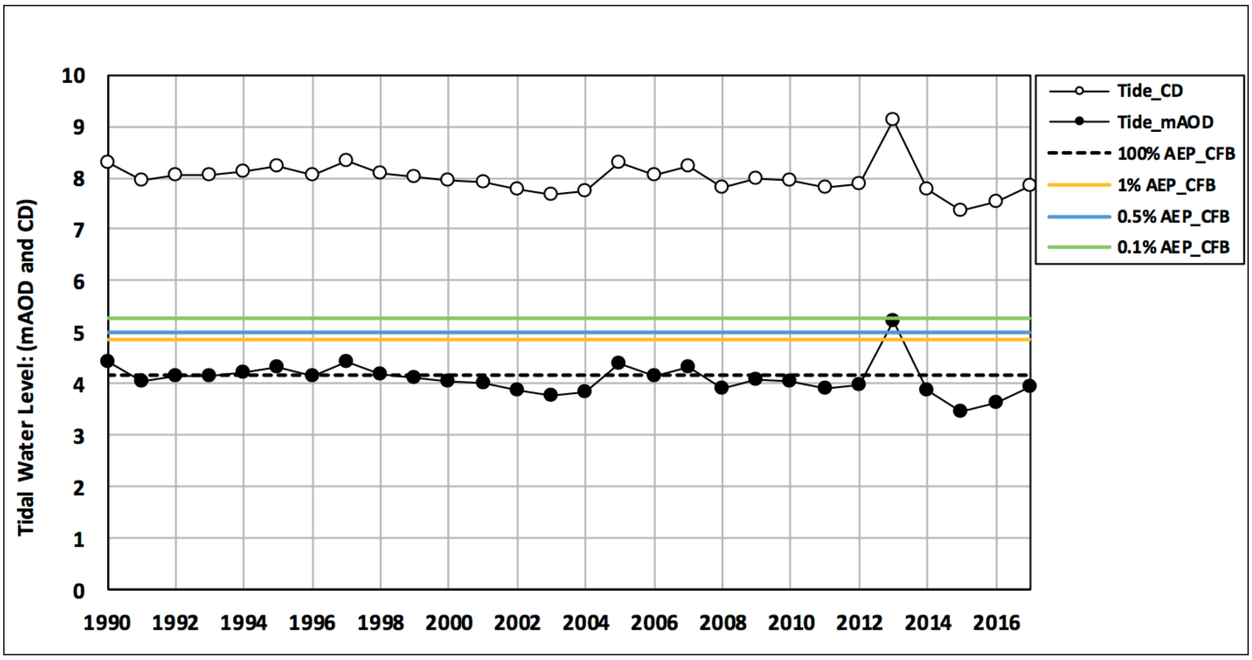

Figure 13. Extreme yearly tidal value (yearly maximum) at Immingham on the Humber (BODC tide gauge) and nearest CFB data (at chainage 3886 km) from different AEP events. (Source: EA)

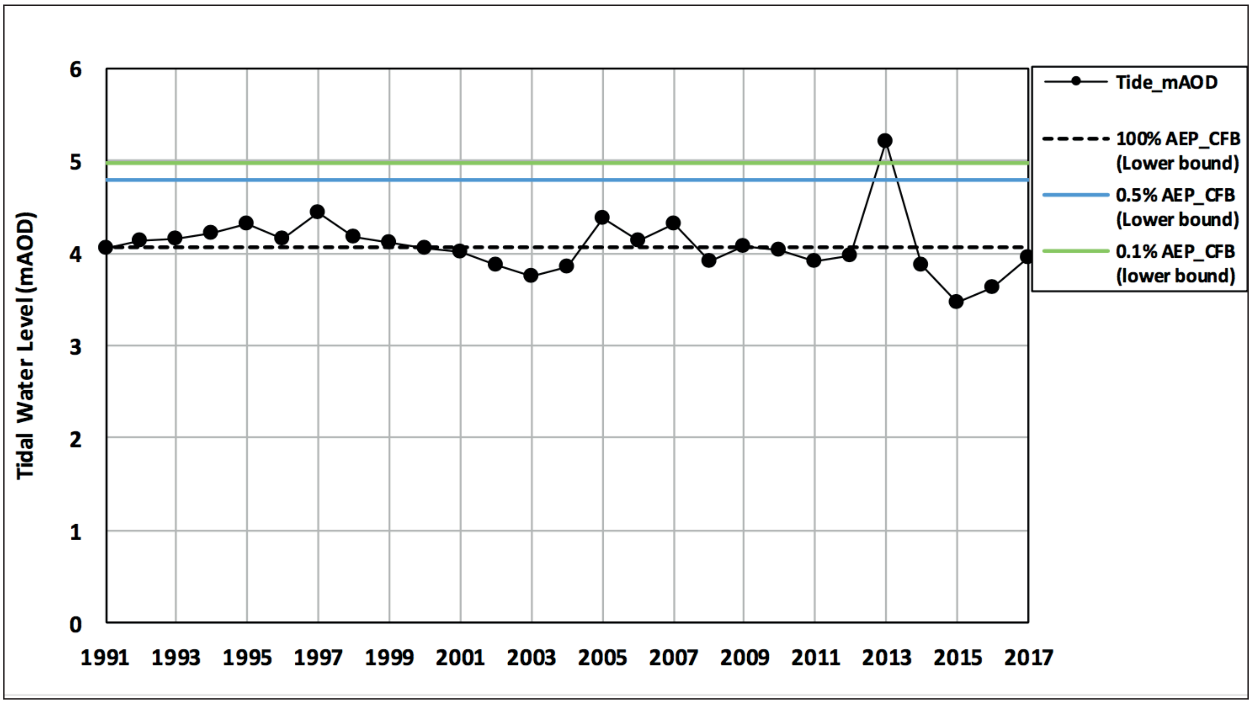

Figure 14. Extreme yearly tidal value (yearly maximum) at Immingham on the Humber (BODC tide gauge) and nearest CFB data (at chainage 3886 km) from different AEP events at lower bound of confidence interval. (Source: EA)

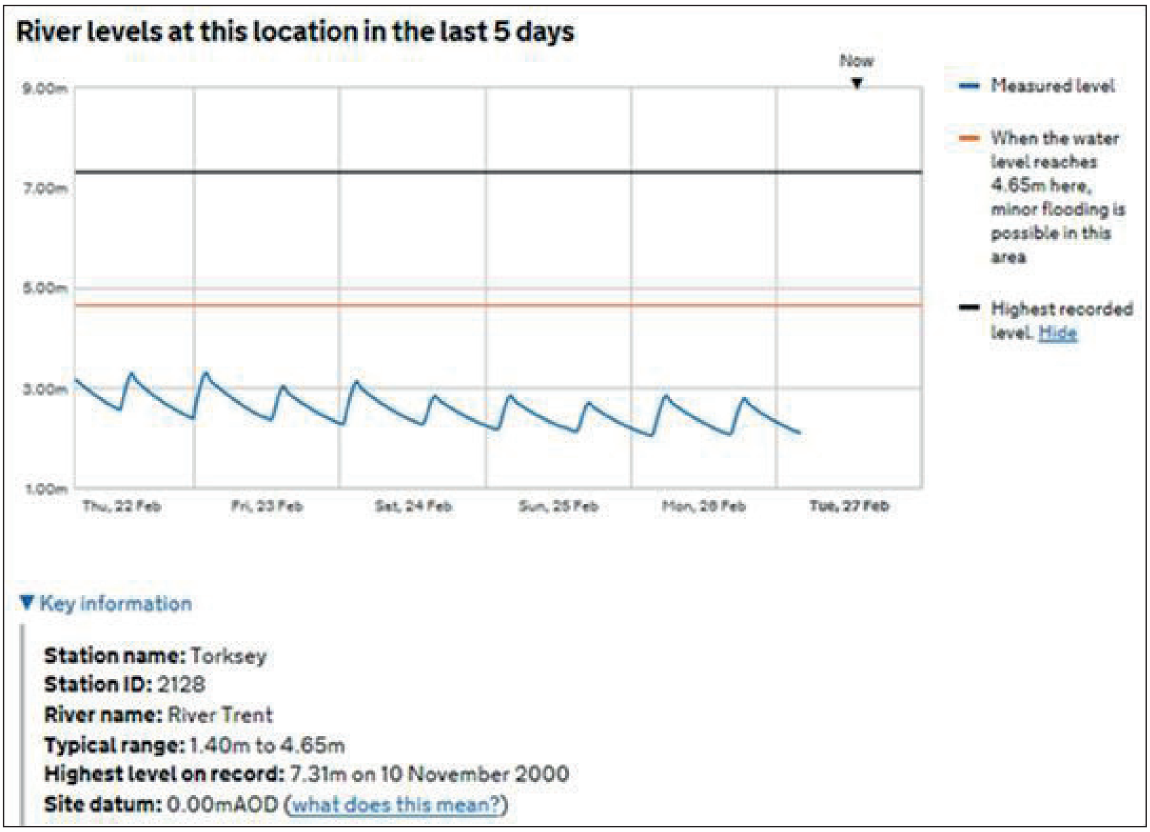

Figure 15. Water level data at Torksey gauge (adjacent to Cottam) on the River Trent. (Source: EA)

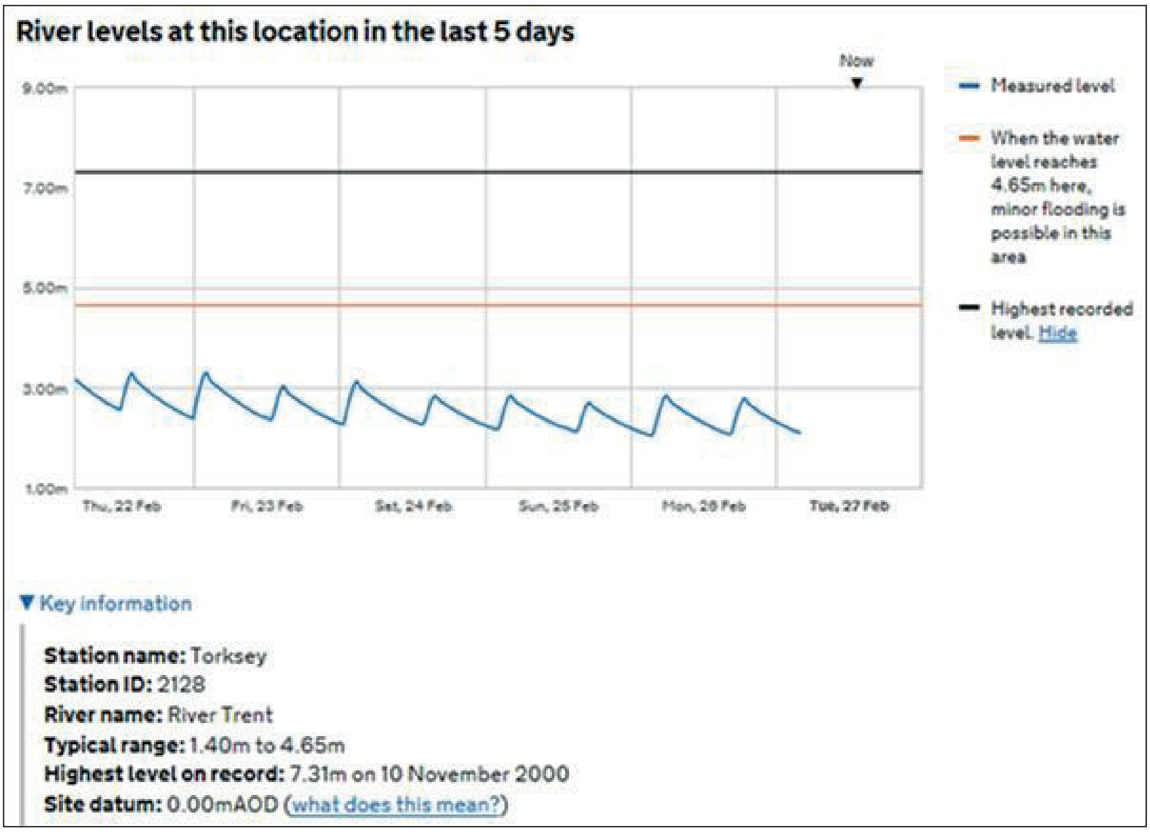

Figure 16. Water level data at Gainsborough gauge on the River Trent. (Source: EA)

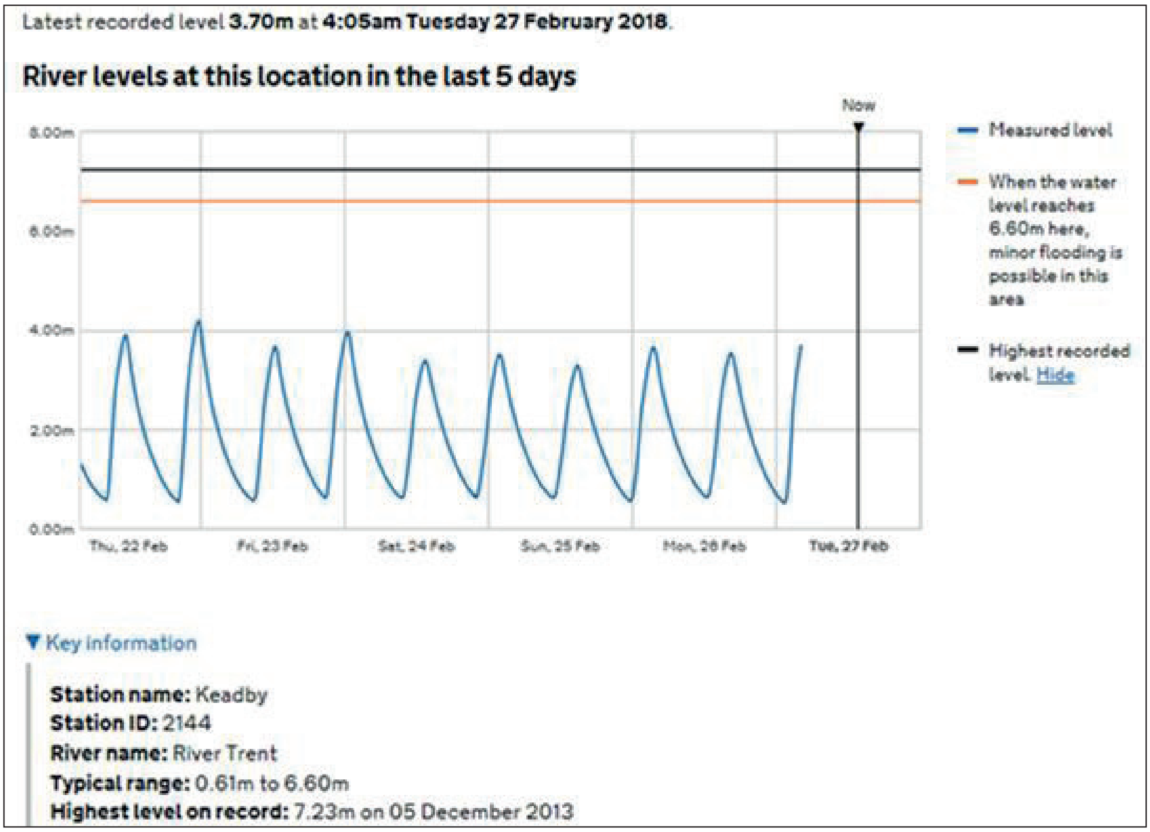

Figure 17. Water level data at Keadby gauge on the River Trent. (Source: EA)

2.2.4 Wave

Wave data for the Humber Estuary and North Sea can be extracted from WaveNet, Cefas's strategic wave monitoring network for the United Kingdom (*Cefas, 2018*). There is one current monitoring deployment at Amethyst and two historic deployments at Spurn Head and at Donna Nook by Acoustic Wave and Current Profiler (AWAC).

The wave effect in the Humber estuary is one of the key factors for consideration when assessing flood risk along the Humber. However, at the confluence of the tidal Trent with the Humber, which is about 60 km from the mouth of the Humber Estuary (Spurn Point), the wave effect is less significant with an estimated significant wave height of less than 0.5 m. The wave effect diminishes moving upstream of the Trent. Cottam is located nearly 58 km further upstream of the Trent confluence with the Humber; the wave effect in the Trent near Cottam power station is negligible and has no discernible effect on the water level.

2.2.5 Groundwater flooding

High groundwater levels were encountered in 2000 at National Grid's site next to Cottam power station, with varying depths between 0.2 m and 4.2 m below ground level (*Mott MacDonald, 2013*). The 2013 report provides a generalised assessment of the susceptibility of the area around the Cottam 400 kV substation to groundwater flooding and suggests that the site is at a relatively high risk (*Figure 18*).

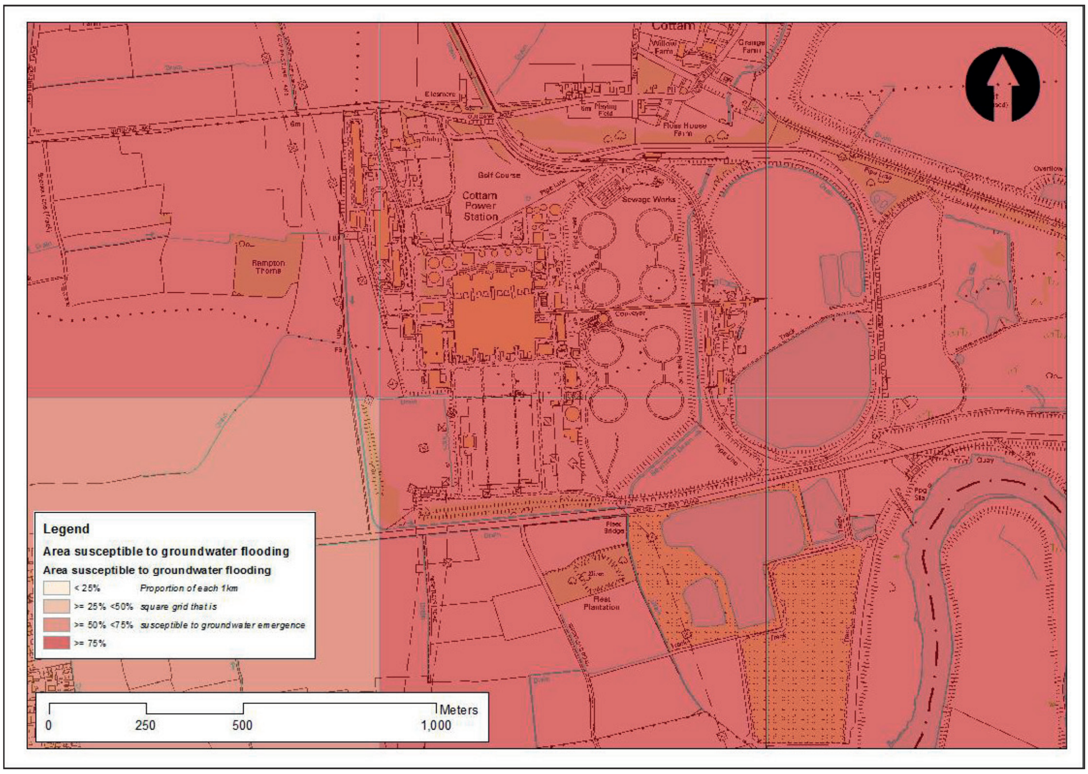

Figure 18. Environment Agency Groundwater Flooding Susceptibility Map — Cottam power station area. (Source: EA, contains EA information © 2018 EA and database right. Contains Ordnance Survey Data © Crown Copyright Ordnance Survey — National Grid EL 100024241)

2.2.6 Artificial sources of flooding

Cottam power station is located approximately 350 m north-west of a storage pond used by the power station to store PFA. Another PFA storage pond exists approximately 600 m to the east of the site. A review of the EA reservoir flooding map indicates that part of the site is at risk of flooding from the PFA storage ponds (*Figure 19*). The EA flood map shows the area that might be flooded if a reservoir (pond) were to fail and release the water it holds.

Given the very low likelihood of reservoir failure, the flood risk to Cottam power station from reservoirs is considered to be a secondary source. It is not expected to be significant compared to the risk from fluvial flooding, provided that the reservoir is properly maintained and regularly inspected.

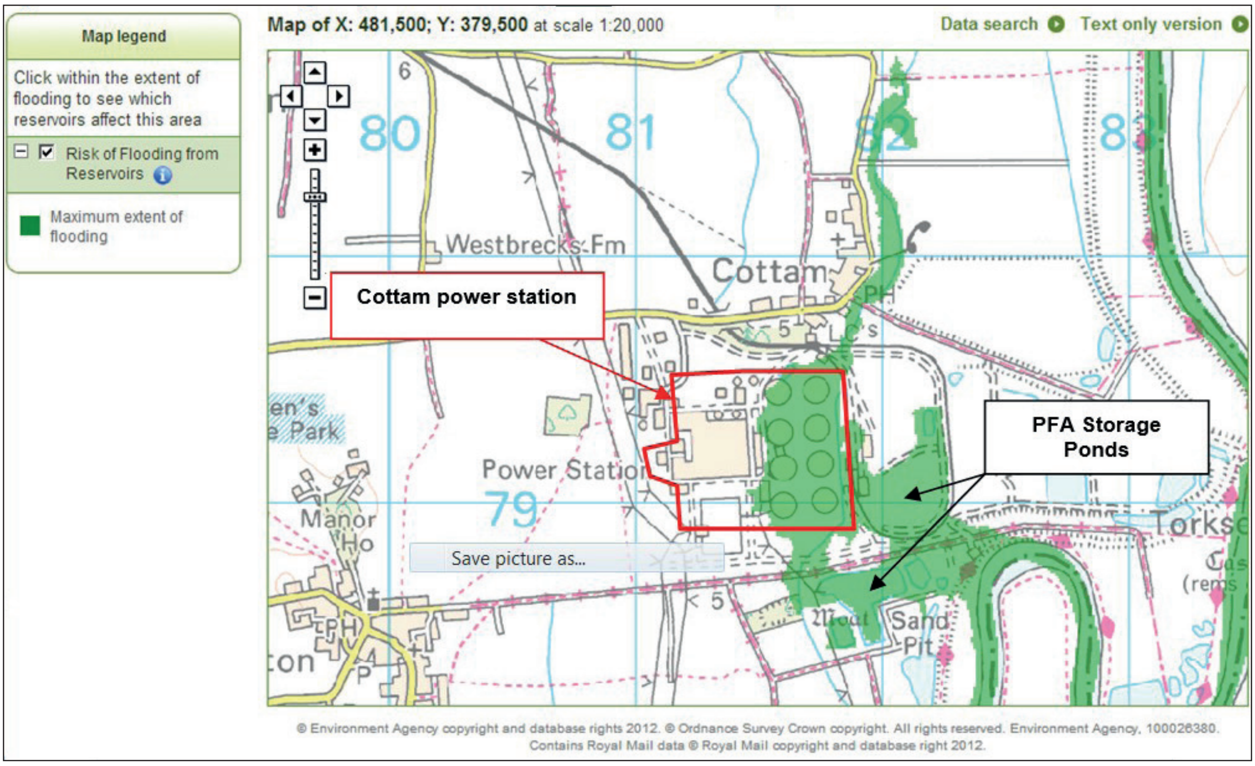

Figure 19. Environment Agency map of the risk of flooding from reservoirs at Cottam.
(Source: EA (contains Ordnance Survey data Crown copyright database right © 2018))

2.3 Other factors

2.3.1 Joint probability

The primary source of potential flooding at Cottam is associated with both fluvial and tidal sources. Therefore, a multivariate joint probability analysis (river flow and sea level) should be considered for assessing flooding at Cottam power station. The flood risks from other sources (surface water, groundwater and artificial sources) are regarded as secondary sources. They should also be considered when designing site drainage systems. A full analysis is outside the scope of this case study; for more information about the methodologies behind this type of analysis see Volume 5 — River Flooding.

2.3.2 Climate change allowance

Making an allowance for climate change in flood risk assessment will help to minimise vulnerability and provides resilience to flooding and coastal change in the future. The guidance on Flood Risk Assessment, with consideration of the latest climate change projections, can be found through the Government website (*EA, 2017*)

To assess how fluvial and coastal flood risk may change in the future, it is necessary to consider climate change allowances for:

- peak river flow by river basin;
- peak rainfall intensity;
- sea level rise;
- offshore wind speed and extreme wave height.

These allowances are based on climate change projections and different scenarios of carbon dioxide (CO_2) emissions to the atmosphere. There are different allowances for different epochs or periods of time over the next century. EA will use these allowances as benchmarks when providing advice on flood risk assessments and strategic flood risk assessments.

When assessing tidal flood risk, in addition to considering the increases in fluvial flow and rainfall intensity due to climate change, it is especially important to consider the sea level rise alongside increases in offshore wind speeds and extreme wave heights. A summary of different allowances for climate change is provided in *Table 5*.

Table 5. Humber River basin district peak river flow allowances due to climate change (Source: EA (2017))

Allowance category	Total potential change anticipated for the '2020s' (2015 to 2039)	Total potential change anticipated for the '2050s' (2040 to 2069)	Total potential change anticipated for the '2080s' (2070 to 2115)
Upper End	20%	30%	50%
Higher Central	15%	20%	30%
Central	10%	15%	20%

Sea level allowance

Table 6 provides the sea level allowance values across the coast of England (Cottam power station is in the East Midlands). Thus, for Cottam power station, the climate change allowance values for this area should be applied to assess the impact on flooding of projected future sea level rise. The power station, though an inland site, is well inside the zone of regular tidal influence, and thus, future sea level rise would have a considerable impact on flooding at this site.

These allowances account for slow land movement due to 'glacial isostatic adjustment' resulting from the release of pressure after ice that covered large parts of northern Britain melted at the end of the last ice age. Practically, this means that the northern part of the country is slowly rising and the southern part is slowly sinking. Therefore, net sea level rise is less for the North West and North East than the rest of the country.

Table 6. Sea level allowance for each epoch in millimetres (mm) per year with cumulative sea level rise for each epoch in parentheses (baseline year of 1990). (Source: EA (2017))

Region of England	1990 to 2025 (mm)	2026 to 2055 (mm)	2056 to 2085 (mm)	2086 to 2115 (mm)	Cumulative rise 1990 to 2115 (m)
East, East Midlands, London, South East	4 (140)	8.5 (255)	12 (360)	15 (450)	1.21
South West	3.5 (122.5)	8 (240)	11.5 (345)	14.5 (435)	1.14
North West, North East	2.5 (87.5)	7 (210)	10 (300)	13 (390)	0.99

Wind and wave height allowance

Table 7 provides offshore wind speed and extreme wave height allowance set by EA for the UK coast. They apply to the Humber estuary (into which the River Trent flows).

Table 7. Offshore wind speed and extreme wave height allowance (baseline year of 1990). (Source: EA (2017))

Applies around all of the UK coast	1990 to 2055	2056 to 2115
Offshore wind speed allowance	+5%	+10%
Offshore wind speed sensitivity test	+10%	+10%
Extreme wave height allowance	+5%	+10%
Extreme wave height sensitivity test	+10%	+10%

Considering potential climate change impact, the extreme sea level could rise from 6.22 mAOD (value taken from the upper bound of the confidence interval in *Table 4*) to 7.35 mAOD in 0.01% AEP tidal event by 2115 (sea level rise of 1.133 m is added corresponding to the 2008 to 2115 horizon; note again that base year for the CFB data is 2008), which is only 0.5 m below the current defence crest (just within the freeboard). Such extreme sea levels, combined with very small fluvial events, may compromise the defence height.

2.3.3 Interdependency risk

The electricity generated by Cottam power station joins the National Grid to provide power to a wide community and businesses. When assessing the level of resilience to flooding of any infrastructure such as the Cottam power station, in addition to examining the asset itself it is also important to assess the interdependency between different assets, to understand the cascade effect of the asset failure in the interdependency chain, and develop necessary resilience measures and solutions to ensure the system as a whole is resilient to flooding.

2.4 Summary of key contributing factors to flood risk at Cottam

Sections 2.1 to *2.3* illustrate the key contributing factors to the flood risk at Cottam. *Table 8* provides a summary of key flood defence and flow parameters of the tidal Trent at Torksey (near Cottam), as well as the key tidal parameters in the sea at the mouth of the Humber for both present-day and future climate change conditions. The values presented in *Table 8* give an overview of the indicative flood risk at Cottam from the key influential factors.

Table 8. Key characteristic parameters of the tidal Trent at Torksey (at Cottam), at North Muskham (30 km upstream of Cottam) and at Immingham in the Humber Estuary. (Source: Mott MacDonald 2018)

Data	Unit	Value	Comment
Flood defence crest on Trent's bank at Cottam	mAOD	7.6 to 7.90	AMIS and LIDAR
Highest recorded water level at Torksey	mAOD	7.31	Occurred on 10/11/2000 AMAX on 09/11/2000 at North Muskham was 774.31
Highest recorded water level at Immingham	mAOD	5.13	Immingham is in Humber Estuary
AMAX flow at same day of highest water level recorded at Torksey	m^3/s	774.31	Highest water level at Torksey occurred on 10/11/2000
Maximum of AMAX at North Muskham	m^3/s	1000	North Muskham (30 km upstream of Cottam)
QMED at North Muskham	m^3/s	438.00	North Muskham (30 km upstream of Cottam)
CFB at Humber Estuary	mAOD	5.72 (0.01% AEP)	Median confidence value
	mAOD	6.22 (0.01% AEP)	Upper confidence bound value
CFB + sea level rise	mAOD	6.85 (0.01% AEP)	Median confidence value + sea level rise by 2115
	mAOD	7.35 (0.01% AEP)	Upper confidence bound value + sea level rise by 2115
Wave height	m	3.5 to 5.0	In Humber Estuary and North Sea

Flood risk to the Cottam power station site has been assessed in this report based on the data, information and study reports available online and in published scientific literature. Flooding from all probable sources (e.g. ground and surface water, fluvial and tidal, and combined fluvial-tidal events, and waves and surges) have been considered in the assessment.

The power station site at Cottam is situated in Flood Zone 3a, i.e. in a high likelihood flooding area. The land surrounding the power station is protected by EA flood defences against combined fluvial and tidal flooding up to a 1% AEP. EDF Energy has no recorded incidents of flooding at Cottam power station. However, many historic flood events have occurred in the stretch of the tidal Trent, e.g. in 1795, 1875, 1932, 1947, 1954 and 2000; most or all of them were tidal flooding and occurred due to either breaching or over-topping of the flood embankments along the Trent.

The site is free from fluvial and tidal flooding due to the presence of the flood defences along the Trent maintained by EA. Surface water flooding was observed in the neighbourhood of the power station. Groundwater flooding was also noted at the site; based on EA's groundwater flooding map, the site has a relatively high risk of groundwater flooding.

The tidal Trent is under daily influence of tide from the sea through the Humber estuary; the highest recorded water level at the Torksey river gauge (near Cottam power station) was 7.31 mAOD on 10th November 2000. The extreme sea levels presented in CFB datasets suggest that the water level in the Humber Estuary near Immingham varies between 4.16 mAOD and 5.72 mAOD for 100% AEP and 0.01% AEP flood events respectively. Wave data from Cefas's WaveNet recorded wave height above 3.5 m within the Humber Estuary, and above 5.5 m in the North Sea near the mouth of the Humber Estuary. However, the wave effect at Cottam is considered to be negligible because of the distance from the sea.

Flood outlines at Cottam power station published by EA are available online in an Environmental Systems Research Institute (ESRI) shape file and MapInfo TAB file for Flood Zone 2 and Zone 3. However, detailed flood maps for different ***design flood*** events between 50% AEP and 0.1% AEP could be obtained from site-specific Strategic Flood Risk Management (SFRM) and Flood Risk Management (FRM) studies conducted by EA, local councils and other development partners.

Climate change allowances for flows and sea level should be considered when assessing future flood risk to Cottam, for example up to 2115:

- an increase in fluvial flow by: 20%, 30% and 50% respectively for Central, Higher Central and Upper End allowance category;
- an increase in sea level of 1.21 m with respect to the baseline year 1990.

The joint probability of a fluvial event and a tidal event should also be considered when assessing the flood risk for Cottam power station. Apart from considering the resilience to flooding for an individual asset, it is also vitally important to understand the interdependencies between different assets to ensure the system is resilient. As ever, it is important to consider the flood risk during the design life of the infrastructure and also beyond to its decommissioning stage when deciding the level of river flooding to protect against.

3.1 Recommendations

To determine design conditions for any new development work and obtain planning permission, a site-specific Flood Risk Assessment (FRA) study must be carried out. It is also necessary to meet the requirements of NPPF in England (*MHCLG, 2018*) (equivalent policies exist in Wales, Scotland and Northern Ireland) and local planning policy. Local plans should apply a sequential, risk-based approach to the location of development, where possible to avoid flood risk to people and property and effectively manage any residual risk. There is also a need to take account of the potential impacts of climate change; this can be done by applying the *Sequential Test* and, if necessary, the *Exception Test*.

The power station site is located in Flood Zone 3a. As land surrounding the site is classified as less vulnerable in accordance with the NPPF, the development is permitted by the NPPF without the need for the Exception Test. In carrying out site-specific FRA, a hydraulic model should be used or updated if there is an existing model available (there are existing hydraulic models for this site, e.g. *Mott MacDonald, 2013* and *EDF Energy, 2014*). Flows used for modelling should be derived following Flood Estimation Handbook (FEH) methodology for different magnitudes of events, such as 50%, 20%, 10%, 4%, 3.33%, 2%, 1.33% and 1% AEP events, and should also consider climate change and extreme flood events, such as 0.5% and 0.1% AEP events. Flood risk should be assessed using the most up-to-date data, hydrology and updated hydraulic model as necessary. Any protection work and new development, resilient to flooding, should comply with the Government's development and adaptation plan (*HM Government, 2016*).

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RMS. 2007. *1947 UK River Floods: 60-Year Retrospective.* Available at: *http://forms2.rms.com/rs/729-DJX-565/images/fl_1947_uk_river_floods.pdf* (accessed on 10th May 2018).

Design flood

Flood of a given flow used in fluvial designs (e.g. height of an embankment or size of a bridge or culvert) is known as design flood. It is usual to express how often floods could be larger than the design flood, which is known as flood frequency, often expressed as a return period. Flood frequency can alternatively be expressed in terms of an AEP, which is the inverse of the return period.

EA main river

The Environment Agency classifies large rivers and streams as 'main rivers'; other rivers are called ordinary watercourses. See more functional definitions at *EA (2018)*.

Exception Test

A method of managing flood risk while still allowing necessary development to occur; this test is only appropriate for use when there are large areas in Flood Zones 2 and 3, where the Sequential Test alone cannot deliver acceptable sites, but where some continuing development is necessary for wider sustainable development reasons.

QMED

The mean annual maxima flood; QMED has an annual exceedance probability of 50% AEP.

Sequential Test

A flood risk assessment approach for ensuring new development in areas with the lowest probability of flooding, i.e. in Flood Zone 1; a sequential approach should be used in areas known to be at risk from any form of flooding.

Abbreviations

AEP	Annual exceedance probability
AIMS	Asset Information Management System
AMAX	Annual maximum flow
AOD	Above Ordinance Datum
AWAC	Acoustic Wave and Current Profiler
BGS	British Geological Survey
BODC	British Oceanographic Data Centre
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CFB	Coastal Flood Boundary
CFMP	Catchment Flood Management Plan
CO_2	Carbon dioxide
EA	Environment Agency
ESRI	Environmental Systems Research Institute
FEH	Flood Estimation Handbook
FRA	Flood Risk Assessment
FRM	Flood Risk Management
IDB	Inland Drainage Board
JBA	Jeremy Benn Associates
LIDAR	Light Detection and Ranging
mAOD	Metre Above Ordinance Datum
MHCLG	Ministry of Housing, Communities and Local Government
NPPF	National Planning Policy Framework
NRFA	National River Flow Archives
QMED	Mean annual maxima flood
PFA	Pulverised fuel ash
RMS	Risk Management Solutions
SFRM	Strategic Flood Risk Management
SoP	Standard of Protection

Appendix: Assumptions and limitations

The analyses in this case study are subject to a number of assumptions and limitations which are listed below:

- Flood outlines presented in this case study are taken from EA's online maps. They are based on SFRM, FRM or broad scale mapping studies, and should only be used as a first source of information for planning purposes. Site-specific flood risk management studies should be carried out to obtain planning permission for any development work.

- Cottam site is located in Flood Zone 3a; however, such qualification may change in the future based on updates and/or improvements of flood outlines by EA; the recommendation is to obtain EA's up-to-date flood outlines.

- EA's flood maps suggest that the Cottam site is benefitting from existing flood defences along the Trent for up to for 1% AEP event, assuming those defences are in excellent condition. As such, it is advisable to consult EA on the flood outline from events more severe than 1% AEP flood, and for flood levels associated with climate change scenarios.

- Hydrological design peak flows presented in this case study on the Trent at North Muskham are based on a 2013 modelling study. As such, hydrological flow estimates and flood outlines may change in the future as more data become available.

- Flood defence height is based on topographical survey data captured prior to 2013. As such, these values should be used with caution, and should be validated through new field survey and latest LIDAR data.

- All model-predicted flood outlines are based on fixed river bed condition with bed elevation data derived from historical topographical surveys; whereas the tidal Trent is morphologically active, and thus, physical changes in the river bed could influence the channel capacity and the flood outlines. It is recommended that the model-predicted flood levels and outlines should be used with caution.

- Sea levels, i.e. those taken from the CFB dataset and presented in this case study, were published in 2011. EA is currently updating this dataset and thus future flood risk assessment should be based on the updated CFB data, once they become available.

- Sea level rise prediction has considerable uncertainties, and the upper and lower bound values could vary more than ±0.5 m around the median values. As such, predicted flood outlines due to sea level rise should be used with caution, and if required (for purpose of design), sensitivity analysis should be carried out using modelling techniques and using upper and lower bound values.

- As Cottam power station is more than 100 km away from the North Sea along the waterway through the Humber, the use or the effect of CFB extreme sea levels and extreme tidal levels at the power station should be inferred through regional models or correlation analysis, rather than direct extrapolation or interpolation of the sea levels.

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