Climate change and ports

Impacts and adaptation strategies

March 2021

The risks to port operations and infrastructure from climate change are increasing. This paper explores some of the impacts for the UK ports sector and looks at adaptation strategies to counter them.

In February 2014, a section of the sea wall collapsed at Dawlish Warren, amounting to an estimated £1.2 billion in direct and indirect costs.

This paper is presented by HR Wallingford in partnership with the British Ports Association through the Port Futures thought leadership programme.

The Port Futures Programme was launched by the British Ports Association in 2018 to examine global emerging trends in ports and shipping. This rolling programme of activity address key issues for ports over the next 50 years, including technology, infrastructure and skills, as well as potential opportunities and challenges that these issues present. The British Ports Association (BPA) represents over 100 port members and over 80 associate members. Our port members own and operate over 400 ports, port facilities and terminals of all sizes across the UK, facilitating more than 86% of the UK's maritime trade, 95% of which is carried by sea.

Climate change is a top priority for ports; it presents significant regulatory challenges but, as this report makes clear, the industry is also on the frontline when it comes to impacts – with clear operational challenges from more extreme weather, rising sea levels and more. This will require action to adapt as well as action to decarbonise both port operations and shipping, helping the UK meet our net zero ambitions.

Executive summary

- The consequences of climate change for UK ports could be far-reaching. Whilst the overall direction is clear, there are many uncertainties on the scale and timing of impacts for UK ports.
- Sea level will rise in the UK and have the most significant impact for many ports. It will occur for all the modelled climate change scenarios, all around the UK.
- Increased intensity of extreme rainfall also tends to cause increased risk of flooding.
- Other changes may include average and extreme winds and waves, tide range and tidal streams, pressure on water supplies and risks to health from hotter summers. These will affect navigation, port operations and land transport.
- The UK Government's 2018 climate change projections notably include higher sea level rise compared to the 2009 projections.
- Tools and methodologies now exist that can be adopted by port managers to analyse the multiple hazards and impacts. The results allow port managers to identify and prioritise adaptation strategies.
- Adaptation to climate change needs to take account of the likely lifetime of the port infrastructure, the operability of the port, resilience under extreme conditions, and building future adaptability into present day port investments.
- Future adaptation strategies include: building in allowances for sea level rise when constructing port infrastructure; investing in assets that will make it easier to raise breakwaters and sea walls in the future; and advance planning of how to replace structures when needed, embracing the 'build back better' philosophy.

Introduction – the possible impact of climate change on ports and changing projections

As ports are located in coastal zones, low-lying areas and deltas, they are especially exposed to the risk of climate change impacts. Operations and infrastructure at UK ports are liable to be affected by rising sea levels, floods, storm surges and strong winds, so it's imperative that they are prepared to withstand the impacts of climate change.

With a changing marine and coastal climate, the extreme sea conditions previously used for designing existing port infrastructure are more likely be exceeded. This leads to a higher probability of port infrastructure being flooded and port operations being disrupted. Some ports have already drawn up climate change adaptation plans, but these should be regularly reviewed. For example, in 2018 when the UK Government revised its projections for climate change, it raised its projections for sea level rise from its 2009 projections.

Exceeding the original design conditions increases the likelihood of the structural failure of port infrastructure, including breakwaters. Such failures are expensive. In February 2014, the sea wall in Dawlish in Devon collapsed, closing the main railway line from London to Cornwall for two months. The direct cost of reinstating the railway line was £50 million, but the related business disruption of this key transport link cost the UK's economy £1.2 billion. The message is clear: the costs of effective, preventative adaptation can be a fraction of the avoided, post-failure expense.

Under future climate change scenarios, it is also likely that extreme marine and coastal events will become more frequent. Ports need to provide safe access and safe berths for ships, and ports typically have defined operating limits for ship movements and for cargo handling operations. Increases in port closure arising from a rise in extreme events are a potential concern that would have a financial impact.

To ensure ships can safely access ports in stormy conditions, the layout can be tested as physical models in laboratories – as pictured above at HR Wallingford.

How can ports respond?

Ports can respond to climate change in two ways: **adaptation** and **mitigation**. Adaptation includes upgrading existing infrastructure and designing new infrastructure to withstand the main impacts of climate change, such as sea level rise and floods. Appropriate adaptation measures depend on the extent and timing of future climate change and its impacts.

Mitigation is about reducing greenhouse gas emissions to contribute to reducing future climate change. Ports are involved with many mitigation initiatives, and the International Maritime Organization (IMO) is leading efforts to reduce emissions from shipping. Mitigation is not discussed further here.

In this paper we focus on the adaptation measures that ports can consider.

Climate change projections for UK ports

The UK Climate Projections 2018 (UKCP18 [1]) provide the most up-to-date assessment of how the climate of the UK may change over the 21st century. They were prepared for the UK Government to enable planning for climate change and are based on the latest developments in climate science. They were subject to an independent peer review to assess the science.

UKCP18 contains various reports with large amounts of data on many aspects of climate change. Sea level rise, extreme water levels, wave climate, storm surge and tides are covered in the Marine Report. Summaries of the forecasts are included in a number of factsheets, including ones covering sea level rise and storm surge and wind.

More technical users can access a user interface to interrogate aspects of the UKCP18 data and tailor the outputs to their needs, for example choosing to look at a particular region. The reports provide area specific projections that will be valuable for UK ports when assessing the resilience of their existing infrastructure in future conditions, and also when designing new infrastructure.

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[1] https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/index . **Note:** Except where indicated otherwise, the source of all data included in this paper is the UK Climate Projections 2018 (UKCP18) published by UK Met Office in November 2018. This data is used under the conditions of the Open Government Licence v3.0 for public sector information, but it must be noted that this paper is a summary and readers must refer to the original publications and data on the UKCP18 website.

What does the guidance say?

UKCP18 says there is no doubt that mean sea level has been rising for hundreds of years and will continue to rise. The global mean sea level is expected to rise by between 0.3 m and 1.1 m during the 21st century, and to continue to rise, possibly at an accelerating rate, for at least two more centuries.

Whilst the overall trends are not in doubt, there are many uncertainties when it comes to how each part of our coastal system will respond as an integrated whole. Many variables contribute to the coastal climate, and these respond differently to climate change, as well as varying around the UK coastline. Some of the many issues are discussed further below.

Sea level rise

Sea level rise is undoubtedly the most important issue for UK ports. It is not a question of whether sea levels will rise, but rather a question of how much and by when? In recognition of this uncertainty, mean sea level rise information is presented as a series of scenarios. These scenarios are defined in UKCP18 in terms of representative concentration pathways (RCPs), relating to assumed greenhouse gas concentration trajectories that are associated with different plausible climate futures, and examples are given below.

UKCP18 Projections for sea level change at key locations

	Sea level change at 2100 (m) relative to 1981 – 2000 average		
Location	**RCP 2.6**	**RCP4.5**	**RCP8.5**
London	0.29 - 0.70	0.37 - 0.83	0.53 – 1.15
Cardiff	0.27 - 0.69	0.35 - 0.81	0.51 – 1.13
Edinburgh	0.08 - 0.49	0.15 - 0.61	0.30 – 0.90
Belfast	0.11 - 0.52	0.18 - 0.64	0.33 – 0.94

Source: UKCP18 Marine Report, November 2018

These 5th and 95th percentile projections vary across the UK because of allowances for slow land movement owing to the release of pressure since the last ice age, after the ice that had covered large parts of northern Britain melted. The north-western part of the country is slowly rising and the south-eastern part is slowly sinking. In addition there is a High++ (H++) estimate, that forms part of the Government guidance on sea level rise, representing the upper plausible limit of climate change within the time period considered, and intended for testing options under more extreme climate change and exceedence events. The H++ allowance for the UK for total sea level rise by 2100 is 1.9 m (unchanged since UKCP09 in 2009)[2].

Clearly the scenario assumed for port planning purposes has an important bearing on the design levels adopted. It is important therefore to understand the background to these scenarios and make a judgement on which one to adopt.

[2] https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances

The scenarios range from a world that implements substantial reductions in emissions of greenhouse gases to one in which global greenhouse gas emissions continue to rise. The substantial temperature increases associated with the latter are much higher than the those with the former (RCP2.6).

It is important to note, for ports relying on older planning documents, that UKCP18 sea level rise is projected to be higher than in UKCP09. Due to the new treatment of land ice contribution to sea level rise, the upper end of the range of sea level rise in UKCP18, for the high emission scenario for London, is around 25 cm higher than in UKCP09 at 2100. This has already been factored into UK adaptation planning for flood risk, for example [3].

Storm surges

Storm surges are temporary increases of water level above the level of the tide, owing to variations in atmospheric pressure and winds. They can have catastrophic results. One of the worst natural disasters of modern times in the UK is considered to be the North Sea storm surge of 1953, although in 2013-14 there were larger storm surges at some locations on the east coast of England.

UKCP18 concludes that a zero upward trend is the best estimate for storm surges during the 21st century, although the Marine Report [4] includes illustrations of possible more extreme trends. Nevertheless, the report reiterates that the dominant source of increase and uncertainty in extreme still water levels is expected to be mean sea level.

Coastal damage caused by the 1953 storm surges at Sutton on Sea, Lincolnshire (inspected by HR Wallingford).

[3] https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances

[4] https://www.metoffice.gov.uk/pub/data/weather/uk/ukcp18/science-reports/UKCP18-Marine-report.pdf

Wave heights and directions

UKCP18 suggests there will be changes of the order of 10 to 20% in average wave height in the 21st century and a general tendency towards lower wave heights. Changes in extreme waves are also projected to be around 10 to 20%, but there is little agreement in the sign of change among the model projections. High resolution wave simulations suggest that the changes in wave climate over the 21st century on exposed coasts will be dominated by the large-scale response to climate change. However, more sheltered coastal regions are likely to remain dominated by local weather variability.

It is also of note that the Environment Agency guidance for flood and coastal risk projects includes a recommendation for climate change allowances of 10% for increased offshore waves and winds[5].

Where wave heights are locally limited by water depth, extreme wave heights may change because of increased water depths resulting from climate change.

In its laboratories, HR Wallingford tested the proposed new wall at Dawlish in many different combinations of the design elements under a variety of predicted wave conditions.

Potential changes in storm tracks, in response to climate change, can have significant spatial variability in terms of the relative change to the marine climate at different ports. This can include subtle changes in wave direction which can potentially adversely influence operations. As well as changes in the magnitude of the sea conditions, it is therefore also important for port planners to consider directional changes. The alignment of breakwaters and jetties is based on the historical wave climate and even subtle changes in the direction of the predominant wave conditions can lead to increased wave penetration into harbours and changes in the levels and positions of sand and mud banks.

Although the overall conclusion of UKCP18 does give a clear direction of change, the variability means that localised, port-specific analysis is needed to support operations. This approach will ensure the unique features of each port are appropriately captured within the adaptation options.

[5] https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances

Sedimentation

Sedimentation and the associated requirement for maintenance dredging are a significant part of the operational planning and cost at many UK ports. For most ports, history has shown that there is variation in the actual rates and locations of sedimentation from year to year. This leads to changes in the annual requirements for maintenance dredging in the port and access channels.

Much of this variation from one year to the next can be accounted for by the patterns of storminess, river discharge and wave direction. An underlying trend associated with climate change in any one of these factors could have a knock-on effect on the requirements for maintenance dredging at a particular port. Observing changes in patterns of sedimentation, channel and bank movements and relating these to the factors influencing sedimentation at a port will assist in adaptation and planning for future port operations. An increased risk of episodic infill causing rapid loss of depth in a berth or access channel represents a significant risk to operations.

Precipitation and localised flooding of port facilities

Rainfall patterns are expected to change, with more intense rainfall events as well as changes to monthly average rainfall. These will affect all types of infrastructure including ports. Climate change allowances, including data, are published by the Environment Agency [6].

Water supply

Conversely, the effects of climate change upon water availability to support port operations also need to be taken into account. With a few exceptions, water companies expect that the changing UK climate will result in a general reduction in available water resources. Resilient infrastructure will be needed to cope with, and recover from, supply disruption, and to anticipate trends and variability in order to maintain services for people and to protect the natural environment now and in the future.

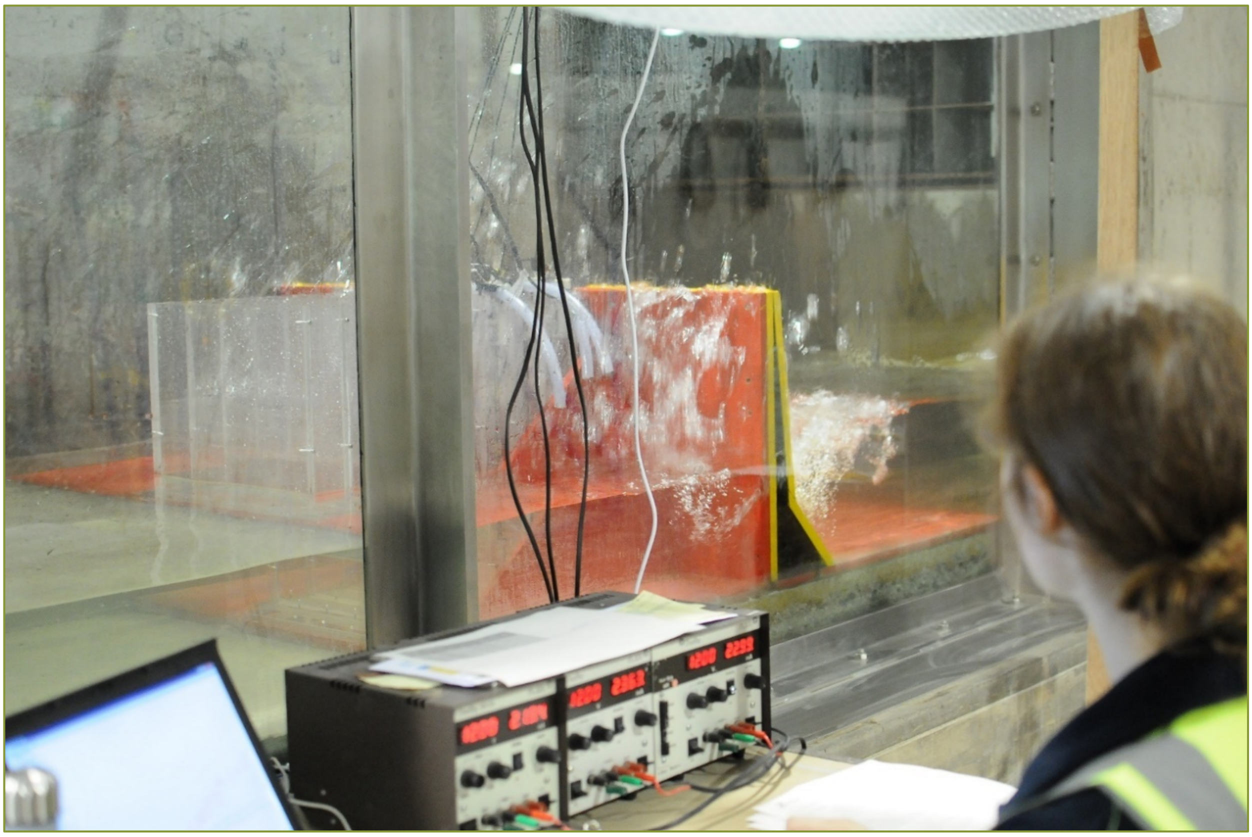
[6] https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances

Sea surface temperature

Sea surface temperatures are not included in UKCP18, although there is some information in UKCP09. Sea temperatures are likely to increase, as will air temperatures, but this is unlikely to have a major impact on ports. There may, however, be changes to the rate of biofouling of ships and marine structures and the risk of spread of invasive marine species.

Winds

In the UKCP18 projections, marine winds to a large extent are reflected by changes in waves. It states that wind speeds are dominated by annual variability. No substantial long-term trend in mean wind speeds is evident up to 2100, although an increase in the frequency of winter storms for the second half of the 21st century is suggested.

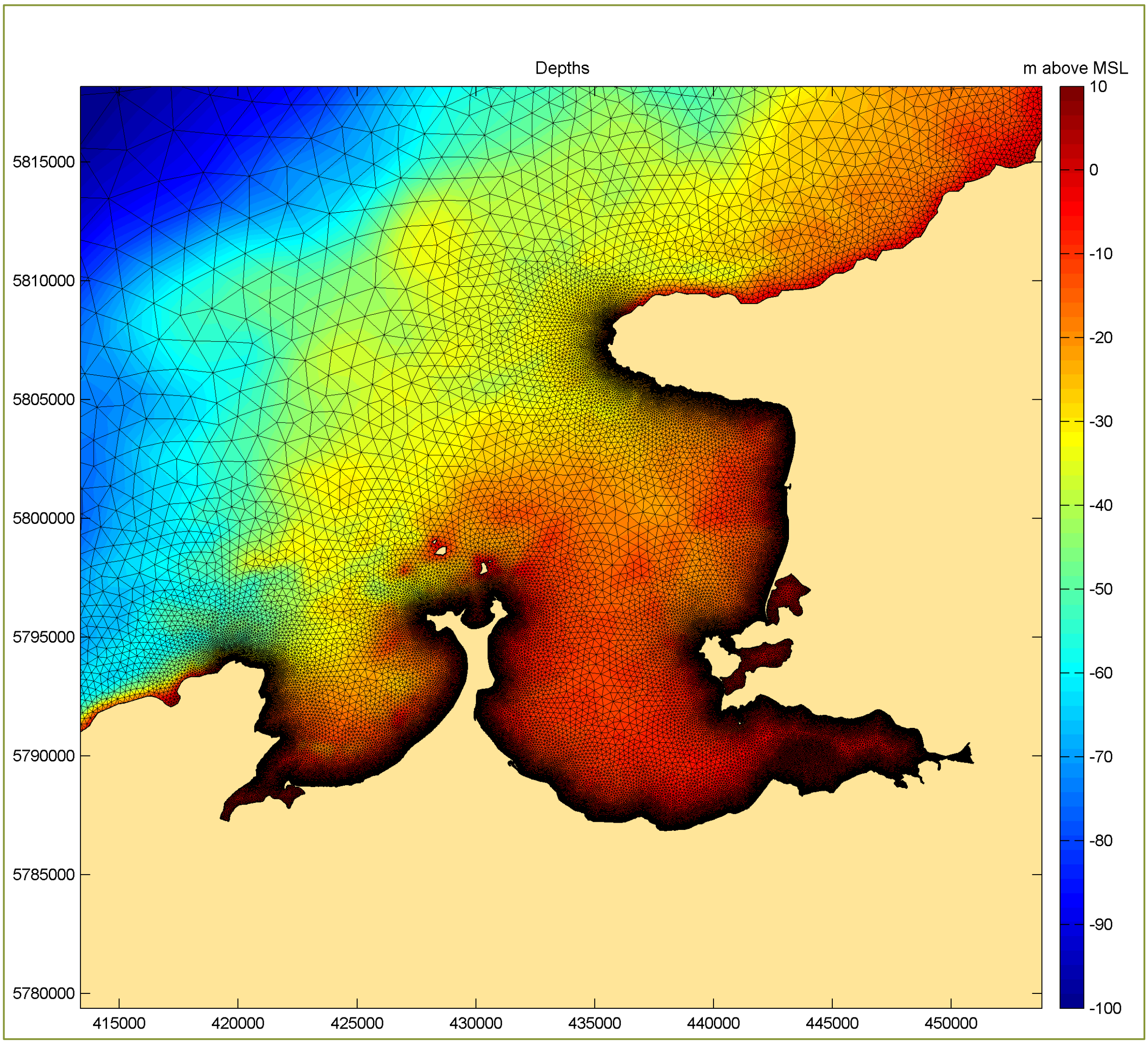


A multi-segmented collection tank measuring the effect of wind on wave overtopping was developed for the WindWave project. HR Wallingford, which was part of the National Environment Research Council (NERC)-funded research consortium, tested different wind speeds using the flumes in its modelling hall.

Potential changes in tide and surge characteristics

Mean sea level rise will cause a direct increase in both low and high waters. However, since the propagation of tide and surge is dependent on water depth, there is also a potential for mean sea level change to have a more complex effect on local tidal range and the extent of storm surges above the high tide.

Port planners need to be mindful of the sensitivity of their projects to long-term changes to tides that may be driven by changes in sea level.



Images generated of Tralee and adjacent bays in south-west Ireland by HR Wallingford using a calibrated tide, surge and wave forecast system, which could be used an indicator of potential coastal flooding.

Conditions beyond 2100

UKCP18 includes exploratory mean sea level projections that extend to 2300. These have been designed to be used alongside the 21st century projections. UKCP18 emphasises the inherent uncertainty in projections on these time horizons and that higher values associated with, for example, the potential for accelerated ice mass loss from West Antarctica, cannot be ruled out.

How can port planners adapt to climate change related risks in the context of uncertainty?

It is evident that uncertainty regarding climate change and its influence on the marine and coastal climate is significant. This poses challenging questions in relation to the refurbishment and maintenance of existing ports, as well as the design of new ones. Traditional engineering allows for uncertainties by taking conservative approaches. If, however, the works to be undertaken are based on assumed worst case scenarios for all aspects, this can lead to an escalation in costs and potentially over-designed and unaffordable interventions being proposed.

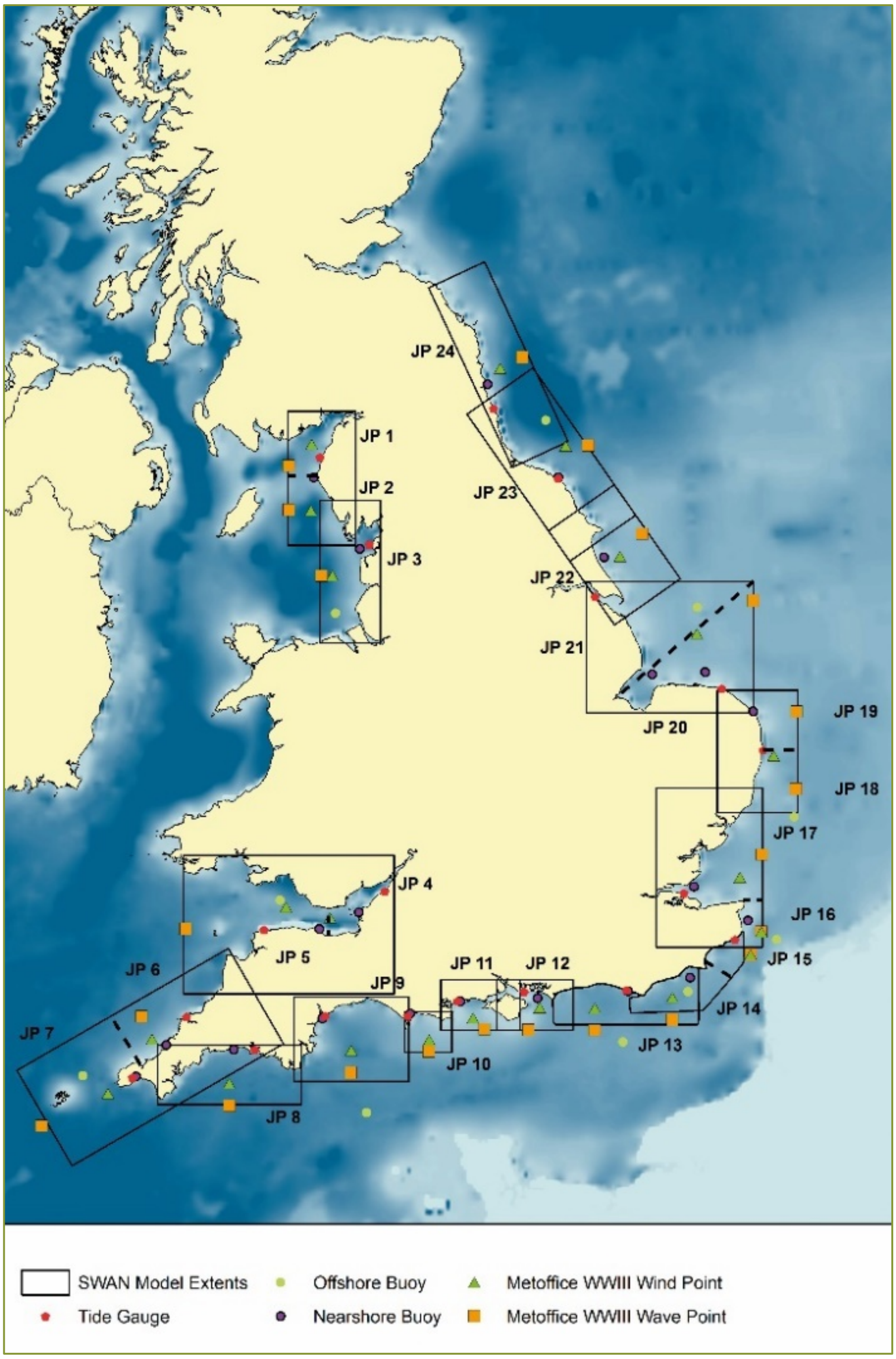
These challenges are not unique to ports, and the sector may be able to gain useful insights from others. For example, the Office for Nuclear Regulation (ONR) has recently published guidance that actively supports a managed adaptive approach [7]. This acknowledges uncertainty and encourages appropriately managed flexible and adaptable designs. In the case of ports, a prudent investment may well include assessment of the potential risks at an early stage, leading to an appropriately developed, port-specific approach to managing these risks by capturing uncertainty and building in both resilience and flexibility.

After the UK's 2013/2014 flood, The Environment Agency (EA) appointed HR Wallingford to conduct a National Risk Flood Assessment (NaFRA) to improve its coastal flood risk data around the coastline. The project delivered improvements to the EA's flood risk model and underpinning data, generating a more accurate picture. It also produced: a new coastal extreme event data set; a new module that enables waves and overtopping models to be built and run using the new coastal event data; and a new web-based approach for early review and providing feedback on flood model results.

For the modelling, uncertainly was present throughout the chain from the deep sea to the place at risk of flooding – with overtopping considered the most challenging of these uncertainties. Efforts therefore focused on improving the offshore analysis to consider all the important variables: waves (height, period and direction), winds (speed and direction) and water levels, in a multivariate joint probability calculation to feed overtopping models. HR Wallingford developed 24 SWAN 2D wave transformation models around England to transfer multivariate joint probability analysis from offshore through to nearshore, before being further transformed to the defences.

[7] http://www.onr.org.uk/documents/2017/principles-for-flood-and-coastal-erosion-risk-management.pdf

Data from the Met Office (Wave Watch III hindcast), Environment Agency (Coastal Flood Boundaries, surf zone bathymetry, tide gauge data, defence data), Seazone (TruDepth offshore bathymetry), CEFAS and Channel Coast Observatory (wave buoy data) have been used in the analysis.



Mapping of offshore to nearshore data conducted by HR Wallingford for the National Flood Risk Assessment (NaFRA).

Implications of climate change for adaptive port investment strategies

The anticipated life of port assets has a big impact on the extent to which climate change needs to be considered. Port investments often fall into two broad categories: those such as crane systems which will probably only have a life of the order of a generation (i.e. around 30 years or less) and those such as breakwaters and quay structures which are anticipated to last (in some form) for a number of generations (at least 100 years).

For investment in single generation assets, it is likely that investment decisions will primarily be influenced by factors other than climate change, such as ship capacity/dwt, required speed of turnaround, storage and transhipment.

For investment in multi-generational assets, their ability to be adapted for climate change should become a much bigger consideration, as this affects the delivery of 24/7 operations, survival of extreme events and post extreme event adaptation.

Issues with 24/7 operations caused by climate change may include:

- the viability of quayside operations as mean sea levels raise risk of flooding and operability of mooring systems;
- increases in loading/unloading downtime at quay structures due to increases in wave action;
- delays in ship movements in and out of harbours due to greater incidence of unsafe navigational conditions.

Extreme events may lead to issues such as:

- increases in overtopping of breakwaters (due to a combination of sea level rise and increased storminess);
- potential for more frequent damage to breakwaters and other exposed structures as the magnitude and/or frequency of extreme events increases;
- potential for episodic infill of dredged areas such as berths and approach channels.

Options for adaptation investment strategies

Future adaptation options for the above may be one or more of the following:

- Ensuring appropriate levels of robustness for a range of future conditions, including building in allowances for increases at the time of construction/installation.
- Investments in tangible assets such as provisions to facilitate future raising or upgrading of
  - the crest of breakwaters
  - the operating level of quay walls and
  - berthing/mooring facilities at quay walls.
- Advance planning for replacement structures in the event of damage/failure. The philosophy of the Sendai disaster recovery framework (Build Back Better)[8] applies here and requires advance planning to avoid a knee-jerk reaction to replace structures on a like-for-like basis.

A mix of measures is therefore needed to adapt to climate change in ports, according to the nature of port operations, assets and their risk exposure. PIANC (the World Association for Waterborne Transport Infrastructure) provides international guidance [9] on such a portfolio, which lists a wide range of options for adapting or strengthening the resilience of navigation infrastructure assets, operations and systems. The diagram by HR Wallingford's Chief Technical Director for Resilience Jonathan Simm on the following page shows how managing assets for resilience needs to reflect a spectrum of requirements.

Methodologies are increasingly being adopted for conducting climate change risk assessment in existing ports[10] [11]. These use quantitative evaluation of multiple hazards and impacts to provide port managers with essential information to identify and prioritise adaptation strategies. For instance, HR Wallingford investigated the climate change risks and the use of climate science for decision-making to support the scoping phase of Future Climate for Africa programme for the ports sector.

Clearly the uncertainty discussed in the previous section needs to be addressed in all these decisions, but it is possible to develop a map of potential decision pathways in advance that can be implemented as and when the direction of change becomes clearer.

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[8] https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030

[9] https://www.pianc.org/climate-change-adaptation-portfolio-of-measures

[10] https://www.tandfonline.com/doi/full/10.1080/03088839.2020.1725673?scroll=top&needAccess=true

[11] https://www.researchgate.net/publication/335834309_Future_Climate_Change_for_Africa_-_The_use_of_climate_services_for_decision_making_in_the_port_sector/link/5d7f3d47a6fdcc2f0f7146b2/download

Everydayness	Survivability	Recoverability
Assets need to function to deliver their everyday requirements in the face of market and climate changes (including sea level rise), whilst recognising that some port assets such as breakwaters and coastal defences have importance for the wider community surrounding the port and need to work for them. Communities will also be concerned that green solutions are considered which enable natural processes as far as possible (including sustaining necessary longshore coastal sediment movement and encouraging habitats).	In addition, assets need to survive extreme events, with risk of failure and/or downtime appropriately managed. Given the uncertainty of future events, the idea of 'designing for exceedance' becomes important (rather than being fixated on a single design event), knowing how performance will be affected and any reductions managed. It is likely that any green solutions will need to be backed up by substantial conventional engineering measures (grey).	If damage or disruption does occur as a result of extreme events, then minimising downtime and ensuring rapid recovery becomes essential. However, damaged infrastructure should be replaced with solutions that reflect long-term changes in climate, avoiding the presumption of replacing like for like and embracing opportunities for transformation in approach.

Infrastructure resilience mix priorities for flood and coastal erosion risk management

Summary: impact of climate change on ports and coasts

UK coastal flood risk is expected to increase throughout the 21st century and beyond under all emission scenarios considered. This means that increases in both the frequency and magnitude of extreme water levels around the UK coastline are likely. This increased future flood risk will be dominated by the effects of mean sea level rise, rather than changes in atmospheric storminess associated with extreme coastal sea level events. There may also be changes in tidal characteristics.

Ports will need to plan and implement adaptation measures to increase the resiliency of infrastructure and to reduce its vulnerability to the effects of climate change. Adaptation measures required at a particular location will need to be designed using site-specific assessments taking into account local and regional characteristics.

As part of the scoping phase of the Future Climate for Africa programme, HR Wallingford investigated climate change risk, and the use of climate science for decision-making to support it.

Author information

HR Wallingford Chief Technical Director of Flood Risk, **Ben Gouldby**, has over 20 years' experience in the development and application of a wide range of flood risk analysis models, and in the production of flood hazard and risk maps from a range of different flood sources. He has led the technical development of the method which has been used to underpin the national flood risk assessment of England and Wales since 2004.

Peter Hunter has over 35 years' experience of port, harbour, coastal and river engineering, including barrages and storm surge barriers such as those at Cardiff Bay and St Petersburg. Peter has taken part in drafting various standards and technical guidelines, including various PIANC guidelines and BS6349-3 covering shipyards and navigation locks. He is the UK representative on the PIANC Maritime Commission (the World Association for Waterborne Transport Infrastructure) and has been a member of their Permanent Task Group on Climate Change.

About HR Wallingford

HR Wallingford has extensive experience in providing design and engineering advice to the ports sector, and in giving advice on how to respond to climate change and implement practical steps to improve resilience. Its experts works closely with policy makers, planners and other stakeholders to understand the scope for adaptation action to reduce current risks and plan for future climate change.

The organisation's high-resolution site-specific marine and coastal forecasts help clients plan for safe working conditions, understand the risk of storm surges, wave overtopping or structural damage and improve the efficiency of their marine operations.

HR Wallingford has considerable experience of mapping and modelling floods and their consequences. Its experts understand how to apply different computational models and systems to address a wide range of flood risk issues. They have developed many of these tools which means they are well placed to offer bespoke solutions to clients.

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