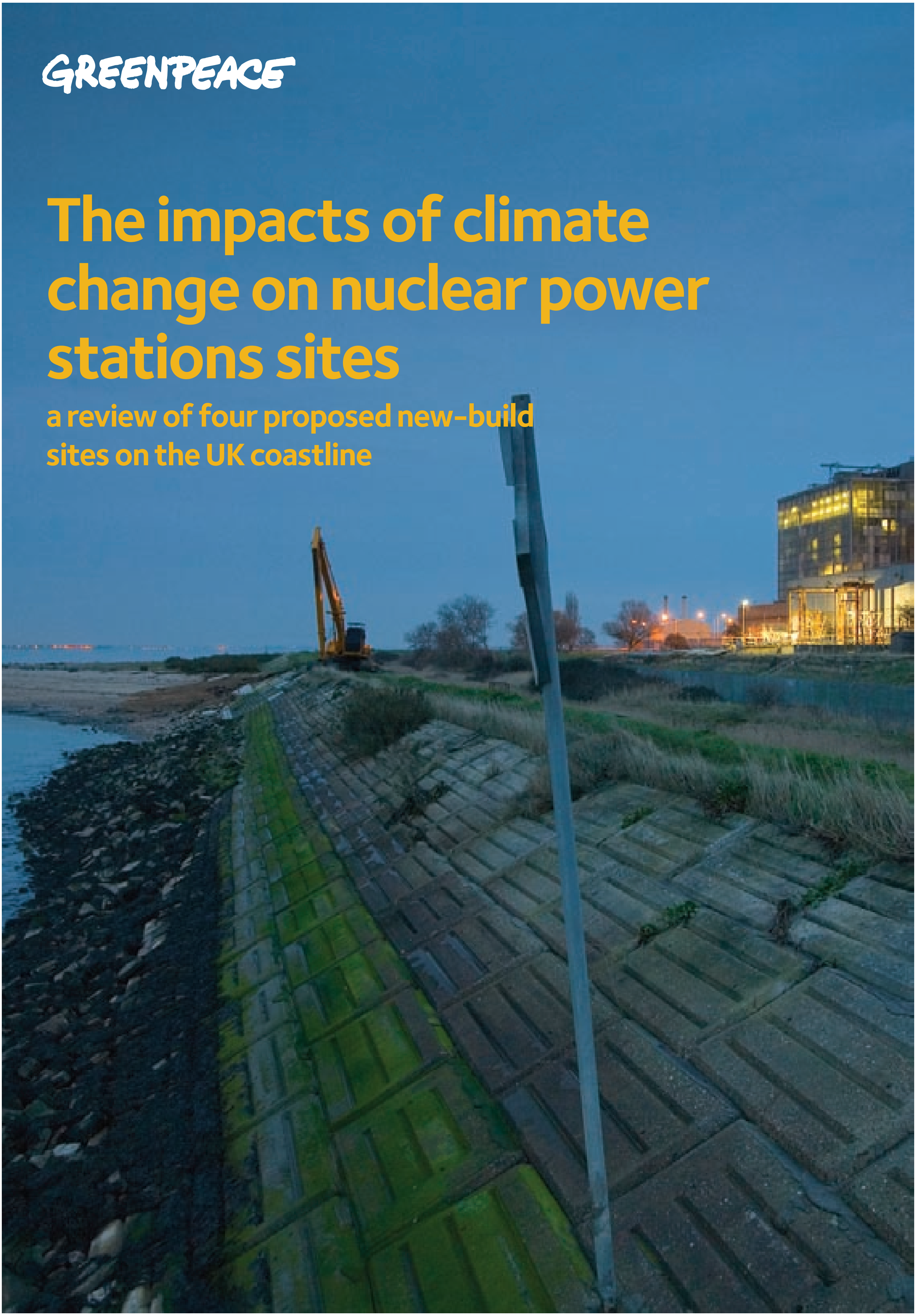
The impacts of climate change on nuclear power stations sites

a review of four proposed new-build sites on the UK coastline



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Foreword

By Dr Doug Parr, Chief scientist, Greenpeace UK

The findings of the UK Government's recent Energy Review present nuclear power as the best cure for climate change – an affordable source of large amounts clean energy. In so doing, they flout the history which shows that investment in nuclear energy is hugely expensive in the long-term and represents an unjustifiable drain on the country's exchequer, and even more importantly a massive risk to its long-term safety.

At the same time as sweeping aside the issues of safety and cost which have long put a brake on any nuclear new-build, this shift in energy policy ignores nuclear power's limited potential in tackling climate change within the critical next few decades, because of the long lead-time required to plan and construct new plants. As such, the proposal to build new nuclear plants is a dangerous distraction which could cost valuable time, money and effort better spent delivering real, sustainable solutions.

Greenpeace believes that nuclear power has no role in a future energy scenario and that, in broader terms, our reliance on remote power stations whose energy output must be wastefully transmitted over long distances poses a threat to our future climate and energy security. Practically, new nuclear plants could only provide a limited proportion of the nation's energy, and their construction would require massive investment in maintaining and upgrading the national transmission and distribution grids. This would lock the UK into a long-term reliance on the grid model and force it to remain dependent for much of its power on large, remote nuclear and fossil-fuel power stations. These stations currently waste up to two-thirds of their input energy in dissipated heat – heat which could be captured and put to use if in an energy model based on widespread use of local combined heat and power generation.

Ironically, while climate change is the Government's ostensible reason for building new nuclear power stations, the predicted impacts of climate change on our seas represent a further compelling – and so far mostly overlooked – reason why those plants should not be built; at least in the industry's preferred locations adjacent to existing coastal sites. Because of the need for an isolated site with a plentiful supply of cooling water, all of the UK's nuclear power stations are located on coastal sites, often at very low elevations, and are consequently highly vulnerable to rising sea levels. An increase in global sea level is generally acknowledged to be one of the likeliest outcomes of global warming, as a result of the expansion of warmer water and the melting of mountain glaciers.

This review looks at the impacts that this phenomenon will have on the coastal environment around a selection of power station sites, over the lifetime of both existing and proposed nuclear reactors, and examines the risks to which they would be exposed by rising tide levels, coastal erosion and storm surges. It also highlights the even more disastrous consequences that would ensue upon the loss of a significant area of land-based ice such as the Greenland ice shelf, which could result in a catastrophic global sea level rise.

These findings challenge the irresponsible political bravado which argues that 'tough choices' have to be made in favour of nuclear power. They make it clear – even for those who still believe that nuclear power is clean, safe and the answer to our energy problems – that building new nuclear power stations at existing sites, or at similar coastal locations, would be an act of folly. It will be increasingly difficult and expensive – and eventually perhaps impossible – to maintain the presence of power stations on these sites. To build new reactors in these locations would thus be to deliver an appalling legacy to future generations.

If we are serious about tackling climate change, we should not be distracted by the false promises of a nuclear future. There are much safer, more reliable, and significantly cheaper alternatives to tackling climate change, such as increased energy efficiency, renewable power technologies and decentralising our energy infrastructure. Notwithstanding the findings of the Government's Energy Review, it is to these sustainable alternatives that we must look if we are to achieve a clean energy future and halt the rising tide of global warming.

Introduction

The coast is a dynamic system, subject to change over short-, medium- and long-term timescales. The coast's ability to change in response to external pressures (such as climate change or human influence) is also critical to the continued provision of its various physical and socio-economic functions (McFadden *et al.*, 2006)[1]. Change at the coast is both natural and essential.

As a result, adding a structure to the coast which requires fixing the position of the shoreline, either in the short or long term, may well be detrimental to the physical sustainability of the surrounding region. However, building a significant structure with a very long lifespan, such as a nuclear power station, on a highly dynamic stretch of coast could not only harm the integrity of the physical system but result in wide-spread consequences from flooding of the nuclear plant. Yet, given that nuclear power stations require water for cooling, proximity to the national grid as well as a remote setting; coastal zones have been the preferred site. The fact that the coast may be dynamic over the life-time of the site has not seemed to influence the choice of location. Construction of nuclear plants in such coastal areas, then, requires action to fix the coastline, entailing an ongoing battle with a dynamic physical environment that would normally be undergoing constant change.

The coast is a complex system where many different elements interact on a range of both temporal and spatial scales. Given the vulnerability of nuclear power stations and their potential for disastrous failure, the likely effects of climate change on any individual site must therefore be viewed in the context of the behaviour of the surrounding coastal system as a whole – it is not enough to consider only the site itself.

It is with an awareness of the need to address this wider context that this brief review has been conducted. It considers the likely impacts of climate change on four existing nuclear power station sites around the UK coastline, which have also been proposed as sites for new reactors: Dungeness, Hinkley Point, Bradwell and Sizewell. It summarises potential impacts of climate change across an estimated timeline encompassing the construction, useful life and decommissioning (including waste disposal) of these proposed nuclear power stations. It works from an analysis of current behaviour of coastal systems in the vicinity of the plants through to predictions as to the longer-term evolution of the relevant coastlines (approximately to 2200).

The earliest estimated date for new reactors to come on line is put at 2018[2]/2020[3]for the first plants to 2035[4] for the last reactor in a series of 10 AP1000s or 6 EPRs (a replacement programme). All of these dates are subject to slippage and it is possible that dates for reactors opening and final shut down could be much later. The figure for the operational lifetime of the reactors, expected to be up to 60 years[5], comes from the nuclear industry. The timelines also take into account reactor dismantling, waste removal/disposal and final site-clearance.[6]. Based on current assessments could cover a period from 2018 -2195.

As indicated above, this review is not a product of exhaustive field research and consultation and should not be seen as such. Rather, our predictions are based on desk analysis using established but up-to-date sources of data on likely sea level rise, backed up by geomorphological field observations at each power station. A simple analysis of the facts, even under the constraints mentioned, is sufficient to show the vulnerabilities of both the current and future environment at the sites.

Climate change and the UK coast – predictions and assumptions

Knowledge of the nature of climate change at a global level and at national and regional scales has advanced considerably over the past few decades. Such knowledge largely accumulates progressively, with gradual refinement of complex models describing climatic behaviour.

Most climate change science has focused on identifying trends to enable short- to long-term projections of the directions and magnitudes of change. However, more recently, a research focus has emerged around the realisation that an additional concern for the 22nd century is the possibility of 'climate surprises' – sudden, dramatic climate change which are much harder to model and predict. In attempting to predict the likely impacts of climate change on such vulnerable and dangerous installations as nuclear power stations, especially when located in such an unstable environment as the coast, it is vital that consideration be given to both progressive trends and 'climate surprises'.

There follows a summary of the climate change and sea level assumptions on which our analysis is based.

Climate trends

This review uses values for shorter-term UK climate change trends from the regional climate predictions developed by the UK Climate Impacts Programme (UKCIP) (Hulme *et al.*, 2002)[7]. Each climate change trend assumes a different greenhouse gas scenario and the trends are labelled accordingly e.g. low emissions and high emissions. The range of emissions scenarios chosen by UKCIP reflect the range of global scenarios published by the Intergovernmental Panel on Climate Change (IPCC) in the Third Assessment Report on climate change. These were derived from emissions scenarios approved by the IPCC and contained in the Special Report on Emissions Scenarios (SRES) report.

The review concentrates on two climate change trends which are of particular relevance to coastal settings: average sea level rise and storm surges. Rising sea levels are an important consequence of rising global temperature, mainly as a result of thermal expansion of ocean water, with the melting of mountain glaciers and the Greenland ice-sheet contributing smaller amounts. Table 1 outlines projected net sea level change to 2080 for the regions relevant to this study, given low- and high-emission scenarios. The estimates of sea-level reflect the on-going adjustment of the land to the de-glaciation that followed the last ice-age (i.e. isostatic adjustment). As a result of this the average level of the sea to land will not be the same across the UK with the south-east of England predicted to experience the greatest levels of relative sea level rise.

While the century-scale rise in average sea level may exert a significant threat to low-lying unprotected coastal areas, it is extremes of sea level that occur as storm surges which will be likely to cause the most damage. Future changes in extreme sea levels are therefore very important, although the uncertainties in modelling such changes remain very large. Estimates of increases in the once-in-50-years maximum storm surge level for the east, south-east and west of England by 2080 are given in Table 2. These predictions, for three different global emission scenarios take account of changes in storminess, in addition to the predicted global sea level rises and vertical land movements. The largest increase in surge height, up to 1.4m for the high-emissions scenario, occurs along the south-east coast of England, which experiences both the largest change in surge height due to increases in storminess, and also one of the highest isostatic subsidence rates.

Predictions for trends in sea-level rise over the longer term, even over the 22nd century, involve very high degrees of uncertainty. The first estimates of global sea level rise beyond 2100, developed at the Hadley Centre, assume stabilisation of greenhouse gas concentrations in 2100. Estimates of sea-level rise for 2150 and 2200 based on a low and a high emissions scenario are given in Table 3. The results indicate that even if greenhouse gas concentrations are stabilised at the end of the century sea levels continue to rise significantly in the long-term.

Climate surprises

The danger of relatively sudden, low-probability and high-impact changes in the climate system (climate surprises) is increasingly invoked as an additional justification for stringent greenhouse gas emission reduction. An example of such an event includes the potentially highly serious impact of a shutdown of the oceanic thermohaline circulation: the term for the global temperature and salinity-driven circulation of the oceans which includes currents such as the Gulf Stream and which play a critical role in current climate. Another is the release into the atmosphere of methane hydrates from the deep ocean, a far more potent greenhouse gas than CO_2; or the collapse of the West Antarctic Ice Sheet (WAIS), which would trigger an abrupt and extreme rise in sea level, estimated at 5-6m (Oppenheimer and Alley, 2004)[8]. There are widely divergent opinions on the likelihood of this extreme sea-level rise; however this includes the view that WAIS collapse may begin in the 21st century. Given that the collapse of the ice sheet would have the most immediate effect on sea levels, it has been taken as the basis for the worse case scenario used in this review.

TABLE 1: PROJECTED NET SEA-LEVEL CHANGE TO 2080 FOR LOW AND HIGH EMISSION SCENARIOS[9]

	Low emissions	High emissions
East England	0.22m	0.82m
South–east England	0.19m	0.79m
South–west England	0.16m	0.76m

TABLE 2: ESTIMATED VALUES OF THE PREDICTED INCREASE IN 50-YEAR SURGE HEIGHT BY 2080[9]

Emission scenario	East England	South–east England	South–west England
Low	0.6-1m	0.2-0.4m	0
Medium-High	1.3m	0.6-0.8m	0.2-0.3m
High	1m	1.4m	0.7-0.8m

TABLE 3: ESTIMATES OF GLOBAL SEA-LEVEL RISE BASED ON IPCC SRES SCENARIOS OF EMISSIONS AND CONCENTRATION OF GREENHOUSES GASES, WITH STABILISATION AFTER 2100[9]

	SRES B1 - low emissions and concentration	SRES A1B – high emissions and concentration
2150	**0.7-0.8m**	**0.9-1m**
2200	**0.9-1m**	**1.2-1.3m**

Impacts on nuclear power station sites

Dungeness

Dungeness is located on Dungeness Foreland on the south-east coast of Kent, a huge expanse of shingle that has been deposited by the sea over the past 10,000 years, and has been shaped by a series of natural (e.g. deposition from rivers) and human (land reclamation) processes. The foreland has an active shingle ridge face (ie one that is currently subject to the action of the sea and is being changed by processes of erosion and deposition), with a series of relict (no longer active) shingle ridges to the landward side that appear to have accreted progressively on a sandy foundation. There are two power stations on the site (A and B), situated side by side immediately inland from the active shingle ridge (see maps).

The morphological response of the foreland to sea-level rise is related to a number of broad-scale factors that determine the behaviour of the physical system as a whole. The nose (the tip of the foreland) at Dungeness is migrating in a north-easterly direction at approximately 10m per year (DEFRA, 2002)[10]. The shoreline at the power station receives very little natural sediment, even though there is some limited input of sand into the system from eroding cliffs to the west (Beachy Head to Cliff End). In summary, this shingle moves eastwards along the Pett Levels frontage; however, since the construction of the Rye Harbour terminal groyne (1920), the sediment accumulates on the western side of the River Rother and therefore does not replenish the current ridge at the power station site. Furthermore, shingle on the active ridge moves eastwards from the south-facing shore of Dungeness, around the nose to be deposited on the east-facing shore, thus further depleting the south-facing shore.

In response to the reduction of sediment supply from the west, the south-facing shore is attempting to shift its orientation parallel to the prevailing incident wave fronts as this would reduce longshore drift (the tendency for material to be moved along a shoreline by wave action) and develop a potentially more stable form. However, since 1965 around 60,000m^3 per year of shingle has been artificially moved from the eastern-facing side to the southern-facing side of Dungeness to maintain a fixed plan position of the shoreline and prevent this reorientation. Approximately half of this volume is used in front of the nuclear power station sites to maintain safety risk levels, while the other half is used further east by the Environment Agency to maintain the beach face for Ministry of Defence purposes. Without this continuous management, the reorientation of the south-facing shore would continue and erosion of the presently active foreshore shingle with potential breaching of the ridge and subsequent flooding within the site. The mean high water at spring tides (MHWS) at Dover tidal gauge (Appendix 1) is 2.99m above ordnance datum Newlyn (AODN), with a value for the highest tide of 3.56m AODN.

The approximate elevation of the Dungeness power station site ranges from 2m to 5m AODN. Even a simple review of the elevations across the site suggests that without the protection afforded by the artificial dumping of shingle, the area may have already experienced significant flooding.

The predicted high-emission scenario 0.79m increase in sea level for the south-east by 2080 (Table 1), with a possible global increase of sea level of 1.3m by 2200 (Table 3), would exert significant additional stress on the system. Even a low sea-level rise estimate of 0.19 cm would have implications for sustainability of current practices at this low-lying and sediment starved coastline. The south-facing shore is already highly susceptible to longshore drift and erosion and this vulnerability will increase with sea level rise, further increasing dependence on continual artificial recycling of shingle. Predicted increases in storm surge (Table 2) will be of great significance to the site. Current artificial re-shaping of the ridge at the nose of the foreland (Photo 1) increases the height of the structure and attempts to limit the migration of the nose in order to safeguard the power stations. With increasing storm surge heights, such artificial profiling may result in its over-steepening, increasing its susceptibility to over-washing during storm events and the breakdown and breaching of the ridge.

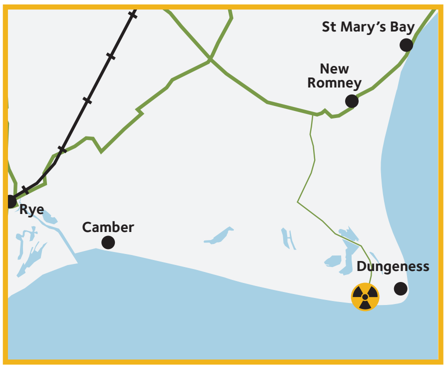
Adding the increase forecast under the high-emission scenario to the current value highest predicted tide (Appendix 1) suggests that by 2080 high tides could be around 4.35m. Given that the approximate maximum elevation of the power station site is 5m, breaching of the barrier under such conditions would result in widespread flooding of the site. The active ridge is currently very close to the boundaries of the power station (Photo 2). This means that there is very limited potential for the ridge to move inland as current shoreline becomes inundated with rising sea-levels (and the shoreline migrates landwards). There is limited, if any, natural resilience within the system i.e. room to let nature take its course.

A sea level rise of the sort that would be caused by loss of the WAIS could thus be expected to have a devastating impact on the nuclear site, with potential total loss not only of the power station site but a significant portion of the surrounding area through erosion and flooding. In terms of the siting of any new reactor, the east-facing shore is relatively more suitable given the natural accretional tendency of this section. However, while the impacts of erosion on the station would be reduced by this choice of location, the current average spot-heights of 6m for this area suggest that the site would likely remain under threat from flooding.

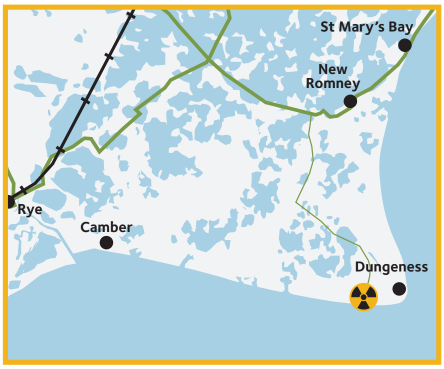
Photo 1. Profiling of the gravel ridge at the nose of the foreland attempts to safeguard the power stations. However, with increasing storm surge heights, re-profiling may result in over-steepening. This increases the susceptibility to barrier breakdown and breaching, which would result in widespread flooding of the area.

Photo 2. 60,000m3 per year of shingle is recycled from the east-facing to the south-facing side to maintain the fixed plan of the shoreline.

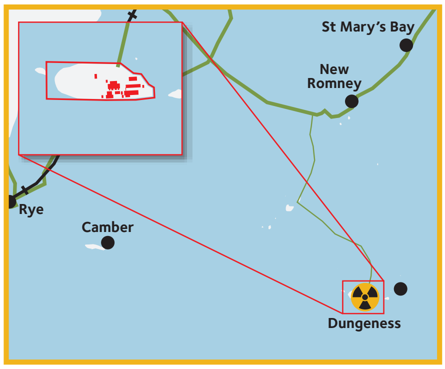
N.B. The graphics used in this report are a simulation of the predicted impacts of climate change, through sea level rise, on the UK coastline.



Present day



Impact of storm surge height of 1.4m, predicted for 2080



Impact of sea level rise of 6m, worst case scenario for end of century

Hinkley Point

The Hinkley Point power stations overlook the Bristol Channel and are located on a rock platform at about 11m AODN with an extensive rock outcrop in front within the intertidal zone. The land rises immediately beyond the site boundary to the west to 25–30m. To the south the land falls to 5m within the Wick Moor area and is subject to tidal inundation.

The behaviour of coastline to the west and east of Hinkley Point may exert significant influence on the impact of climate change on the power station. To the west, the predominantly cliffed coastline is essentially erosional, having been in retreat throughout the last 10,000 years, leaving the wide intertidal platform. The differential erosion of the cliffs and variations in exposure to wave energy has led to the development of indentations along the coastline. To the east of the power station the low-lying coast is composed of estuarine and marine sediments. Between Hinkley Point and Stolford, the backshore (the area above the usual spring high tide line) comprises a gravel storm ridge. Beyond this to Stern Point the backshore is characterised by a complex of low gravel ridges, fronted by recent salt marsh and intertidal mud and sand flats, protecting an extensive low-lying hinterland from flooding.

The power station at Hinkley Point is defended by a sea wall, backed by gabions (i.e. a defence structure consisting of wire baskets filled with cobbles) to protect against erosion from water passing over the top of the seawall (Photo 3). There is an additional length of gabions to the west of the station (Photo 4). The extensive rock platforms contribute to foreshore protection. At 11m AODN the site is above mean high water spring tide and highest predicted tide (Appendix 1). However, the shoreline is subject to strong winds, powerful waves and storm surges: this means that the greatest current risk to the power station comes from inundation from extreme events.

Accelerated sea level rise could have significant impacts on this shoreline. Increased water levels would narrow the wide foreshore (the area between low and high tide marks) and reduce the significant wave attenuation which takes place across the sub-tidal and intertidal areas. This would lead to increased erosion potential and increased threat of inundation at the power station site. Under 'normal' wave conditions, the dominant longshore drift within the region is generally towards the east. The gravel foreshore to the east of Hinkley Point is fed by erosion of the intertidal platform and although the volume of gravel supplied is limited, greater water depths resulting from sea level rise might result in a reduced supply of material and a subsequent reduction in the volume of the foreshore, further increasing erosion potential at the site (see maps).

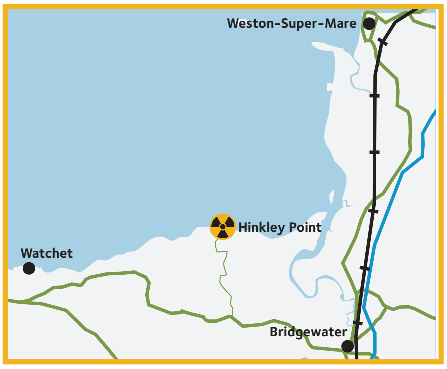
To the west of Hinkley Point, sea-level rise would lead to increased erosion of the soft, low-lying cliffs. A future decision to defend the cliffs in order to reduce erosion could increase gravel starvation to the gravel storm ridge and the complex of low gravel ridges further east, increasing the vulnerability of the eastern flank of the power station site to flooding. Retreat of the gravel ridges and fronting salt marsh would cause landward migration of the shoreline. A potential breach of ridge complex would result in tidal inundation of the extensive low-lying hinterland with the possibility of the creation of a permanent tidal inlet adjacent to the power station. This could in turn cause significant change to the hydrodynamics and patterns of erosion and deposition within the area. While evidence from geomorphological assessments suggests that such a breach is likely over the next 100 years, direct impacts of a breach on the power station site would only be experienced on a longer time-frame. Whilst this does not have relevance to the current power station, such shoreline evolution is significant to a decision on new nuclear build within this area. Over this longer term, the defended frontage of Hinkley point could develop into a more significant promontory, which in turn may have significant implications on the ability to maintain safety risk levels at the plant. This process would be accelerated if the coastline to the west continues to retreat.

Predicted increases in storm surge are likely to have a high impact on erosion and inundation at the site. Current storm events are already overtopping the sea wall so that the gabions are actively defending the power station from erosive impacts. The 0.7–0.8m increase in the 50 year surge height by 2080 predicted in the high emission scenario may add significant additional stress to the defence structure. While the gabions are currently high enough to withstand such an increase, such increased frequency and magnitude of extreme events could weaken the sea wall and undermine the gabion structure. This possibility emphasises the vital importance of maintaining both the gabions and sea wall, and with increased stress on the system this may become more labour- and resource-intensive.

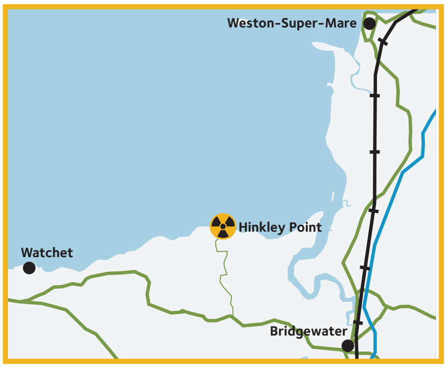
Siting a new nuclear plant to the east of the present stations would not be advisable or indeed feasible under current conditions, let alone with the predicted impacts of climate change. The more highly elevated land to the west of the current site boundary would in general provide a relatively more resistant site. However, given that the cliff line in this area is currently subject to erosion, and that the rate of erosion may increase over the life and decommissioning of a new power station, the reality is that the site is not a feasible option. Building on a new site, would simply transfer the challenges facing the current station along the shoreline and extend them over a longer time frame: postponing but preventing increases in erosion and flood risk.

Photos 3 and 4. Extensive gabions and seawall comprise the defence structure for the power station. Increases in storm surge heights and frequency of storm events could undermine the integrity of this system and result in inundation at the site.

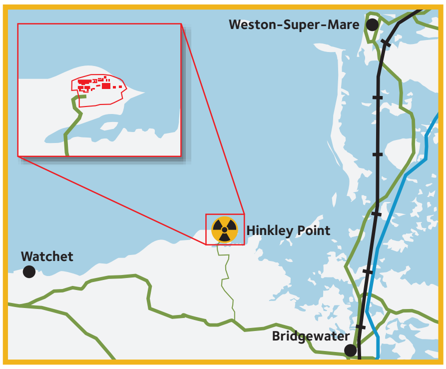
Photo 5. Additional cobble gabions protecting sections of the cliff to the west of the station.



Present day



Impact of storm surge height of 0.8m, predicted for 2080



Impact of sea level rise of 6m, worst case scenario for end of century

Bradwell

Bradwell power station is located on the southern shoreline of the Blackwater estuary in Essex. The power station site is situated at 6m AODN and has been raised above the surrounding land which lies at approximately 2m AODN and which would be regularly flooded without the current flood protection measures.

The Blackwater estuary area has had a long history of reclamation of intertidal salt marshes, drastically changing the coastline and having a pronounced effect on the behaviour of the estuary system, leading to higher water velocities and deepening of the estuary. The embankments used to reclaim the land now defend extensive areas of low-lying backshore from regular tidal inundation. The power station and the low-lying land within its vicinity are currently protected by a 5.1m AODN embankment and the associated drainage network. A jetty provides some protection from wave erosion, dissipating wave energy and allowing the build-up of a series of sand and shell ridges in front of the power station site (see photo 7 and maps).

Whilst the embankments protect from flooding they prevent the supply of fresh sediment from the sea reaching the reclaimed areas. Vertical accretion of sediment continues on the tidal flats and marshes to the seaward of the structure, whilst the landward side is starved of sediment. This has resulted in considerable topographic differences either side of the embankments (Photo 6). The raised elevation of sediment fringing seawards of the embankment increases the potential for over-washing and flooding of the low-lying land which surrounds the power station site. With sea-level rise this potential for over-washing is further increased. The defended area behind the embankments becomes relatively lower than the seaward side and the potential depth to which flooding occurs is increased.

Some sections of the embankment immediately fronting the power station are additionally protected by a sea wall. There is no, or at least very limited sediment seaward of the combined embankment and wall structure, so that it suffers from constant contact with wave energy: there is no natural resilience at the site.

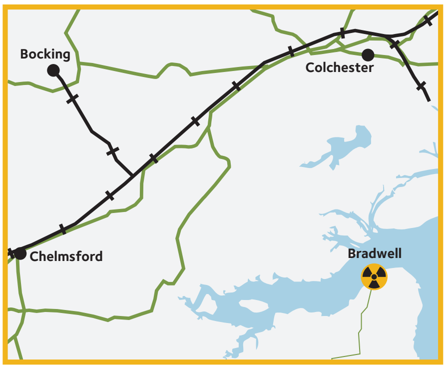
The future risk to the power station is largely associated with maintaining the embankment in the face of rising sea level. The expected natural response of the estuary to sea-level rise would be estuary translation or 'rollover' i.e. as sea-level rises the estuary adjusts to maintain its form and in doing so migrates landwards. The estuary would attempt to maintain its position relative to the tidal frame as the sea-level rose, using marine sediment to build elevation and keep pace with sea-level rise. However, this process is presently thwarted at Bradwell by the coastal protection measures which fix the plan-form of the shoreline and prevent sediment build-up landward of the defence – precisely where it would need to be deposited to enable the estuary to keep pace with sea-level rise. As a result of this, the current loss of stability within the system will increase with sea-level rise, as the landforms of the estuary and its immediate hinterland will become increasingly divorced from natural processes. This will make it harder to maintain the integrity of the current defence system.

If the current policy of holding the defence line was not maintained in the longer-term, a breaching of the embankment would initially lead to the conversion of presently drained agricultural land to mudflats and possibly salt marsh. The power station site could potentially become a defended island: with the low sea-level rise estimates this would result in the low-lying area being inundated with at least every high spring tide. Increased potential magnitude and frequency of storm events would significantly increase the vulnerability of the area. A 1m increase in 50-year surge height as predicted under the high emission scenario 2080 projection (Table 2) would considerably increase the potential for over-washing of the embankment. Over the longer term, given either of the global average sea-level rise predicted for 2200, it may become unsustainable to maintain the current power station site. The risk of flooding of the station site may become an issue; the costs of defending the site would be significantly increased. A WAIS-magnitude increase in sea level would result in total inundation of the nuclear site and surrounding area.

Given this area is extensively low-lying, any new nuclear plant would experience problems similar to those likely to be faced by the current power station.

Photo 6. Considerable topographic differences either side of the embankment significantly increases the vulnerability of the power station to flooding from future climate change.

Photo 7. The development of a series of beach ridges leeward of the jetty is affording some protection to the station. This feature can be seen in the background of photo 6.



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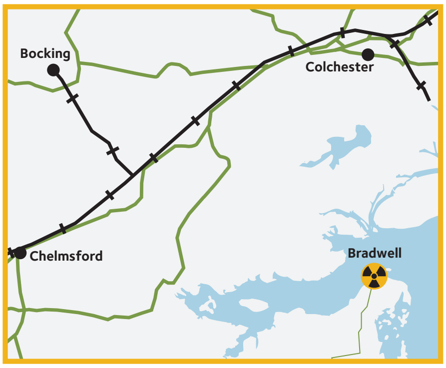
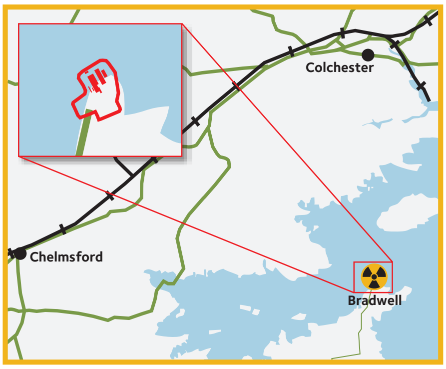


Impact of storm surge height of 1m, predicted for 2080



Impact of sea level rise of 6m, worst case scenario for end of century

Sizewell

Located on the Suffolk coast, the reactors at Sizewell have been constructed behind the tidal beach area at an elevation of between 5m and 10m AODN. The construction of the power stations involved modification of the hinterland and backshore. This included building up and stabilising the sand dunes at Sizewell Gap and there is also some management of the shingle beach and dunes in front of the power station site. Apart from a few localised areas, this coastline has no hard defences. The power station site has hard defences and although the current outlet from the station has an influence in holding up longshore sediment transport in the area, the station site defences do not currently have an impact on shoreline evolution.

The coastline as a whole is subject to rapid erosion, but this varies in time and space as local factors become more or less influential along the coast. There are a number of nesses – large mobile promontories of sand or shingle, that provide key stores of sediment – which have an important bearing on the behaviour of the coastal system. Thorpeness, to the south of Sizewell, is relatively stable in comparison to the other nesses and provides some anchoring control on future coastal development. The Dunwich and Sizewell offshore sandbanks also have some short-term stabilising influence on the adjacent coastline, predominantly under storm conditions. There is a continuous cycle of change to the beach profile at Sizewell, with wave action causing a two-way exchange of sand between the beach and the backshore and dune sediment stores (Photos 8 and 9). This process of change within the system is important to the physical resilience of the region, allowing the systems to naturally adjust to external pressures.

There is a long-term southerly movement of sedimentary material through this region with the episodic erosion of the soft cliffs at Dunwich and Minsmere being the main sources of sediment (see maps) (it has been estimated that over the past 400 years the average rate of erosion of these cliffs has been one metre per year). Historical evidence suggests that the north-south alignment of the coast on the pathway of sediment movement has maintained a stable coastline profile (i.e. a relatively fixed outline or shape of the coast) for the last 100 years. Combined with current management of the shingle beach and dunes fronting the power station the current inundation and erosion threat at the station is relatively low.

Although the coast is generally stable, under rising sea levels there would be natural retreat with cliff erosion, particularly during storm events. The stability of the cliffs would also be affected by any significant change in the Sizewell offshore bank. If the bank were to reduce in height the shoreline would be more vulnerable to wave attack and greater erosion would occur. However, the bank could well migrate inland with the beaches, maintaining similar levels of protection to today.

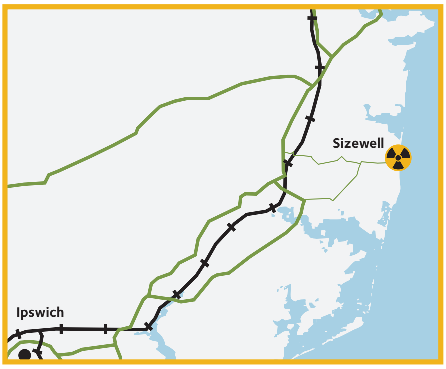
The key to shoreline stability at Sizewell is the availability of sediment. The main risk to the site is that supply from the north decreases, resulting in a thinning of the beach and increased wave attack on the shoreline leading to coastal retreat. The cliffs between Dunwich and Minsmere are likely to continue to experience episodic erosion, releasing sediment into the system. With potential increases in the magnitude and frequency of storm surge heights, this erosion may increase in intensity. Despite the cliffs releasing both sand and shingle into the system, the beaches fronting the cliffs are unlikely to increase in size, due to the general landward movement of the coastline as rising sea-levels inundate the land. Any attempts to defend this section to limit erosion and prevent migration would have highly significant impacts on the Sizewell frontage.

With a continued feed of sand and shingle from the Dunwich/Minsmere cliffs, the stabilising influence of Thorpeness and possibly the offshore banks, the rate of any retreat of the sand dunes or cliffs between Minsmere and Thorpeness may be expected to be relatively low. Change would be greatest at the northern end where the dunes are most closely tied to the cliff line, with breaching possible. This would result in flooding of some parts of low-lying Minsmere (Photos 10 and 11). However, despite the general stability in the region of the power station, the coastline is considered to be vulnerable to change, and over the longer timeframe of this study extensive coastline retreat is a possibility. This would have high significance for the siting of any new nuclear plant within the area. With an extreme sea level rise such as would be caused by the collapse of the WAIS, there would be significant erosion and inundation across the region and subsequent changes to the physical dynamics of the coast. The current mean-high water spring tide (MHWS) at Lowestoft is 1.02m AODN, and with a 6m sea-level rise sections of the power station under 7m AODN would be flooded.

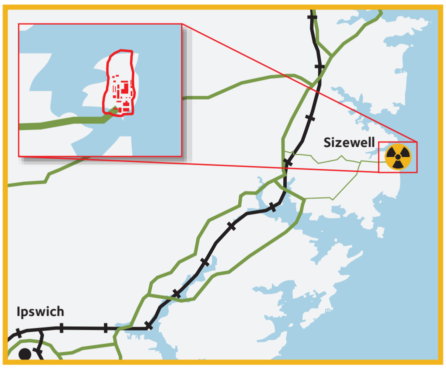
Photos 8 and 9. Continuous cycling between the beach, back beach and dune system is particularly important to maintaining the resilience of the system under storm events

Present day

Impact of storm surge height of 1m, predicted for 2080



Impact of sea level rise of 6m, worst case scenario for end of century



Photos 10 and 11. Climate change is likely to have the greatest impact at the northern end of the system at Sizewell, resulting in possible breaching where dunes hinge on the cliff line and flooding of low-parts of Minsmere.

Discussion and conclusion

In summary, with expected sea level rises and increases in storm surge over the next 200 years as predicted under a high-emission scenario, Dungeness appears to be highly threatened. Bradwell is under significant threat in both the short and long term and Hinkley Point is also vulnerable. The situation at Sizewell is less clear, but none of these sites are completely threat-free as a location for a new nuclear power plant. It is also important to note that even the lowest estimates of sea-level rise could significantly increase long-term dependence on defence at the stations and increase the current rate of loss in the physical stability of the environments in which the stations are situated.

This brief review suggests that it is currently difficult and costly, and in the future is likely to be increasingly unsustainable, to maintain the presence of power stations in three of the four sites studied. In such circumstances, it is tempting to question the reasonableness of the original decision-making process. How did structures with a very long overall life-span, and which it was vital to protect against damage, come to be placed in such vulnerable locations? Clearly knowledge of the evolution of coastal environments and the processes defining the present behaviour of these environments has increased. It is important that this knowledge is harnessed and fed into the emerging debate on the building of new nuclear power stations to ensure that future generations are not loaded with spiralling costs of defence or a potential multiple environmental disaster.

Reflecting on the decision-making process draws a wider range of questions into consideration that this study does not address, including social, political and economic issues. Some of these questions, for example the engineering and social infrastructure which supports the operation of a nuclear power station, are beyond the remit of environmental debate. Yet, there are clear cases when geomorphological and hydrodynamic considerations intersect with social dimensions. Ensuring that there is full consultation and participation across the range of relevant expertises and interests is essential to promoting a transparent decision-making process and reducing conflicts of interest in final decisions on new nuclear sites.

It could be argued that the mere physical suitability of a site for development should not warrant an automatic decision in favour of that development and in the face of other interests. The Sizewell site, for example, is currently relatively stable. However the erosion of the cliffs at Dunwich and Minsmere - critical to maintaining that stability - presents a threat to other interests in the area. A decision on whether to locate a plant in this area may entail a decision between protecting property (including housing and potentially an important RSPB reserve at Minsmere) and allowing erosion to continue to release sediment so as to ensure the stability of the Sizewell site. The ability of the current decision-making process to handle potential dilemmas in an effective manner is questionable. This calls for clear and transparent procedures in reaching decisions on new nuclear build.

If a line were to be drawn at a very fundamental level, ensuring no new reactors could be built in areas where they may be jeopardised from the evolution of the physical coastal system: logically, the risk of adding further complexities and challenges to an already difficult situation would be minimised. Some might consider this a rather over-cautious approach. However, in the face of uncertainty concerning the long-term response of the physical environment, to equally or even more uncertain predictions concerning long-term increases in sea-level and storminess, this seems the most reasonable approach towards ensuring the long-term protection of the coastal environment.

If a decision on new nuclear build hangs on the ability to predict the future relatively accurately and reliably for the next 200 years, this makes a strong case for adopting a radical approach to the decision-making process.

A series of simple but important conclusions emerge from this review. There is clearly a gradation in the current threats to, and potential future impacts of climate change on, the four nuclear power stations examined. There must be a careful review of any potential site before conclusions are reached on their suitability for the siting of a new reactor. It is also of great importance that physical change at power station sites is considered within the wider context of the surrounding coastal system. Finally, the fact that three out of the four stations examined are currently actively defended to protect against flooding or erosion must be considered a clear warning signal as to the long-term future of new nuclear build at the sites.

Endnotes

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Appendix 1

TIDAL INFORMATION FROM MEASURING STATIONS CLOSE TO THE NUCLEAR POWER STATION SITES STUDIED

Tidal guage	Highest predicted tide (above Ordnance Datum (OD) Newlyn)	Mean high water spring tide (above OD Newlyn)
Lowestoft	1.42m	1.02m
Felixstowe	2.28m	1.90m
Sheerness	3.35m	2.91m
Dover	3.56m	2.99m
Ilfracombe	5.44m	4.47m

This review was commissioned by Greenpeace and authored by Middlesex University Flood Hazard Research Centre.

The Flood Hazard Research Centre (FHRC) has been active since 1970 and therefore comprises one of the oldest research centres in the world concerned with water and environmental management. It comprises of a group of committed social and environmental scientists working to improve policy making and implementation in the fields of hazard, coastal and integrated water management.

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