# Response to: SZC-SZ0200-XX-000-REP-100041 Sizewell Coastal Geomorphology and Hydrodynamics: Synthesis for Environmental Impact Assessment (MSR1 – Edition 4) BEEMS Technical Report TR311

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## Author Credentials

The authors are specialist researchers in the field of coastal geomorphology and coastal management, each with >30 years research experience. Professor Cooper, Fellow of Geological Society of America and Fellow of the Royal Society of South Africa, has published 230 peer-reviewed journal articles, 45 book chapters and 12 books, including "The World's Beaches", (University of California Press) and "The Last Beach" (Duke University Press). Professor Jackson, a Member of the Royal Irish Academy, Fellow of the Royal Geographical Society and peer-review college member for the UK's Natural Environment Research Council, has published 140 peer-reviewed journal articles, 18 book chapters and 3 books, including the recent (2020) authoritative text, "Sandy Beach Morphodynamics" (Elsevier).

## Sizewell coast in geomorphological context

The 70 km-long Suffolk coast between Harwich and Lowestoft consists of alongshore alternations of topographic highs and lows (Burningham and French, 2018). The highs consist of headlands of soft, erodible Quaternary sediments where cliffs are fronted by gravel and sand beaches. There are local outcrops of consolidated pre-Quaternary lithologies (e.g. Coralline Crag). The lows comprise wetlands impounded by mixed gravel and sand barriers. Both types of coast exhibit distinctive behaviour. The cliffs exhibit historic retreat via progressive (and likely episodic) erosion, punctuated by periods when sediment supply enables frontal beach accretion and shoreline stability or advance. The barriers retreat through erosion and landward rollover (Pye and Blott, 2006) but may also experience periods of vertical aggradation and/or seaward accretion. Alternations between shoreline retreat, stability and advance at any given location depend partly on the rate of sediment supply from alongshore and from cliff erosion but are also influenced by longshore gradients in wave energy, and the surrounding geomorphology and underlying geological framework. Sites of progressive accumulation over several decades and longer are marked by nesses. The cliff and barrier systems are linked inasmuch as the topographic highs provide anchors for development of the barrier planforms and yield sediment for beach and barrier construction. Furthermore, changes in one part of the system affect areas downdrift. Human intervention in the coastal landscape has involved construction of artificial headlands in the form of jetties and sea defences that stabilise cliffs and reduce/eliminate the rate of sediment input from cliff sources.

Nearshore sandbanks form in the lee of headlands and appear to act both as long-term sediment sinks and as modifiers of incident wave conditions. As such, they from an additional component of the coastal system. They interact with the other onshore components via complex and, as yet poorly understood, feedback relationships. At historic timescales, losses of sediment from onshore have been found to be broadly equivalent to accumulation rates on offshore banks, although a straightforward erosion-accumulation relationship between the two was regarded as unlikely (Carr, 1979).

## Main shortcomings in the coastal geomorphology and hydrodynamics study

The construction of the proposed Sizewell C power station and its associated infrastructure has the potential to significantly alter coastal behaviour in both the short and long term and is potentially at risk from coastal processes and shoreline change. This commentary on the coastal geomorphology and hydrodynamics element of the Environmental Statement (TR311 and supporting documents) identifies important errors and omissions in methodology, deductions and content in the assessment of past and future shoreline change. Chief among these are the following:

- *Inadequate future timescale*. Consideration of shoreline change (and mitigation activities) in this report does not extend beyond 2080 whereas the site requires protection until 100 years post-decommissioning (ca. 2200). Since the proposed work is intended as a permanent intervention, it will have implications for the coast in perpetuity;

- *Insufficient spatial scale.* The entire 70 km-long Suffolk coast and adjacent seabed comprises a single large-scale coastal system within which geomorphic changes are intimately interlinked. The geomorphology of this system operates spatially from deep water (far seaward of the Dunwich Banks) involving wave shoaling (energy loss) in water depths down to 30m, to the back beach and beyond. The study only considers the 3 km coastal stretch centred on the site of the proposed Sizewell C development. Although this has been argued to be a discrete cell, it is geomorphologically linked to areas both north and south that form part of the same larger coastal system; changes in the Sizewell area have the potential to affect adjacent areas and vice versa. Any change in morphology of the anchoring headland at Thorpeness, for example, would have large implications for the shoreline planform. This spatial restriction flies in the face of current dogma regarding large scale coastal behaviour and system dynamics. Linked to this is at best a lack of acknowledgement (and at worst a denial) of the long-range impacts (10s of km at century timescales) of both soft and hard coastal defences;

- *Inadequate consideration of the dynamics of nearshore banks*. Significant surface morphological changes have been documented on adjacent banks and their relationship to shoreline behaviour has been shown to be complex. Their decadal scale behaviour and longer-term response to sea-level rise are crucial to predicting future shoreline configuration but these have not been considered.

- *No consideration of complex system behaviour* - i.e. beyond straightforward process-response geomorphology. Contemporary geomorphology recognises that system linkages and resulting feedbacks can lead to “emergent behaviour" unrelated to immediate forcing mechanisms. This possibility is not considered;

- *Use of false assumptions underlying the Expert Geomorphological Analysis*. These relate to, *inter alia*, stability of the offshore Dunwich and Sizewell Banks, consistency of inshore wave climate, limited alongshore impact of the defence structures, explicit exclusion from consideration of high-magnitude/low frequency events and assumption of similar future shoreline sinuosity to the present.

These and other issues are described below following the order in which they arise in BEEMS Technical Report TR311.

## Comments and Discussion of BEEMS Technical report TR311 (and underpinning documents)

## 2. Coastal geomorphology and hydrodynamics of the Greater Sizewell Bay

### Offshore stability of Dunwich and Sizewell Banks and corresponding coastline stability

Offshore wave energy dissipation plays a crucial role in dictating the height and therefore the wave energy reaching beaches and soft sedimentary shorelines, acting as natural buffering zones during storms. The Dunwich and Sizewell Banks are in themselves not fixed or static landforms and are prone to storm and current changes offshore, making their future form (vertical and lateral extent) and therefore buffering ability unclear.

Offshore sandbanks occupy an important position for coastal protection particularly during high-energy storm events. Previous modelling simulation work by Halcrow working only on a single direction scenario and spring tide level, showed that the Dunwich Bank, under modal conditions, reduced shoreline wave heights by 0.5m. Storm waves, however, would likely be reduced much more significantly in height given the substantial energy dissipation role they play.

Directionality of storms can also play an important role on their effective shoreline impact with wave directions traversing over the large stretches of the Banks accentuating the dissipation of wave energy.

Wave attenuation (reaction with the seabed) begins much further out than the nearshore sand bars mentioned and ignoring their presence in modelling is a serious oversight. Ignoring the influence of Dunwich and Sizewell Sandbanks oversimplifies the wave regime that is implemented over the nearshore sand bars and will produce inaccurate and unrealistic modelling results as incident waves will be unrealistic. Full hydrodynamic wave modelling must therefore start sufficiently seaward of (i.e. beyond shoaling zones) of features such as the Dunwich and Sizewell Banks and they should contain multiple wave directionality (largely bimodal (N/NE and S) at this site and be run for a number of return period storm wave heights.

Lowering and/or a major shifting of the Dunwich Banks as acknowledged is occuring by EDF/Cefas, could lead to wave energy being released much closer to the shoreline, with dissipation/breaking focussed more at the shoreline than the present under any such scenario. Modelling under these changed offshore bank configurations are not considered in any modelling by EDF. It is highly likely that historical shoreline retreat will resume to previous levels under any lowered/diminished extent of the Dunwich Banks. Rate of retreat of any adjacent undefended coastline will be dependent on storm frequency and magnitude as well as feed-back involving linkages to nearshore sand bar formation and dynamics. Increased sea levels in the region will add to the vulnerability of the shoreline in this area as storm and even modal wave energy events will occur on a higher base level and reach the supratidal shoreline and beyond.

Modelling simulations, incorporating a range of multiple storm scenarios, has not been carried out. In addition to storm magnitude and return period, directionality of storms appears to have been (be) crucial in the behaviour of this coastline. Specific direction arcs from which storm approach the site may increase the potential for coastline erosion. The modelling appears to be too broadly focussed to pick up such detail.

> Future storm directions more from the North or South could indeed partially avoid the dissipating influence of the Dunwich and Sizewell Banks significantly and retain more storm energy for release at the shoreline. Fetch is as important as duration and intensity of wind events for the formation of extreme waves and future simulations by Grabemann and Weisse (2008) show that the highest waves will generally approach from more northwesterly and southerly directions in their study area 2 (English East coast). Future wave extremes therefore are likely to highly impact the coast, effectively bypassing the Banks, retaining their wave energy more effectively as they are travelling over relatively deeper nearshore waters compared to waves traversing the Banks.

#### 2.3.4.1 Sub tidal sand transport

Report TR 311 states (p. 30) that "*Successive marine surveys of the Sizewell – Dunwich Bank, indicate that there is no present sediment transport mechanism that could give rise to seaward migration; trends over the last 70+ years to date have shown stability (Sizewell) or landward migration of the bank flanks (particularly of the landward flank on the saddle and Dunwich Bank). Hydrodynamic modelling (BEEMS Technical Report TR357) also suggests that the flows patterns that maintain the bank in its present position would still occur even if there were no bank at this location – implying that sediment accumulation at the bank position is a natural condition and that the bank position is therefore likely to be enduring*"

This is highly contradictory to what we know about offshore wave attenuation processes over subtidal banks such as Dunwich. These are submerged at shallow enough depths to invoke <u>very</u> significant wave attenuation (interaction with the sea bed) and energy dissipation (release) and therefore will most definitely have a sheltering effect on the shoreline at present. The above statement contradicts the previous section 2.3.2.2.3 where the Banks are said to play a significant role in wave refraction and energy dissipation responses. In the absence/reduction of such banks, wave refraction effects from obliquely approaching storm waves from a SE direction in particular, would then strike the coast with less obliquity, producing more wave set-up (water levels), heightened water levels from storm surge and ultimately induce an increased risk of coastal retreat. The addition of further human infrastructure along the largely natural  shoreline under these conditions will have consequences for shoreline change dynamics both locally and down coast.

### 2.4.1. Future sea level

TR311 cites the National Policy Statement for Energy (EN-1, sec 4.8.6) as requiring assessment of the impacts of anticipated climate change to "*cover the estimated lifetime of the new infrastructure*".  The report, however, only considers sea-level change up to 2070 and therefore does not cover the entire lifespan of the infrastructure, and perhaps not even the full operational phase, depending on when production begins.  Judging by the current situation it seems reasonable to assume that if production started in 2030, it would end around 2090 (20 years beyond the current scope of future shoreline change) and be followed by a decommissioning period of 100 years, extending to 2190.

UKCP18 provides indicative sea-level rise to 2200 and beyond. The Environment Agency's 2019 report SC150009 cites a median RCP 8.5 sea level for 2200 as 1.8 m (range 1.3 - 2.9 m).  The equivalent figures for RCP 4.5 are 1.1 m (range 0.7 - 1.8m). Since the lifetime of the infrastructure is of this order, future coastal change up to that time ***must*** be considered.  The implications of sea-level rise for the sandbank-shoreline interaction are particularly important- whether the bank migrates, erodes or is overstepped (becomes decoupled from the shoreline) is of great importance for shoreline behaviour. This has not been addressed.

North Sea sandbanks have not been well-studied, but modelling studies on the morphologically similar shoreface-connected ridges (Nnafie et al., 2014) show that they *form* during stable or slowly changing sea level.  During sea-level rise they aggrade (grow upwards), but do not migrate and are ultimately "drowned" (i.e. become disconnected from the active coastal system).  If this is the case, such coasts will undergo dramatic changes in morphology and behaviour with continuing sea-level rise as sandbanks become less important in wave energy attenuation. This possibility has not been adequately addressed in the present report.

### 2.4.2 Future wave climatology

*In TR 311 (p. 50) the southern North Sea and Lowestoft (the closest point of UKCP18 data to Sizewell) are described as showing a reduction in the mean annual maximum significant wave height of around 5% under RCP8.5*

In contrast, Bonaduce et al. (2019) in a study of future wave climates by the end of the 21st century (2075–2100) within the North Sea region (also using a regional wave climate projection under the RCP8.5 scenario), showed that annual 95th percentile significant wave height (Hs), normalised difference between the future run and historical runs in winter, would increase by around 5-10%. This would lead to a more energetic wave region and therefore enhance the erosion potential for the coastline. If the Dunwich and Sizewell Banks were depleted in volume and/or extent, then the erosion potential would be further enhanced under these heightened future wave conditions. See Bonaduce et al.'s Fig. 11. for graphic representation of this.

### 2.4.3.1 Natural increase in sediment supply to the Greater Sizewell Bay

*Report TR311 (p. 52) states that "A natural increase in supply is likely because the Easton – Benacre Cliffs are likely to remain unprotected (see Section 2.4.3.4) and as the cliff-line retreats in this area, the volume of sediment released per unit retreat will rise due to increases in cliff height and available cliff length (Brooks and Spencer, 2012). Cliff exposure will rise with rising sea levels. The likely consequence is a rise in, or maintenance of, sediment supply. Additional sediment will slow rates of shoreline retreat and potentially increase accretion rates where it occurs, and over a long period of time it could counter shoreline retreat (i.e., reduce erosion rates) and result in slow growth of the Sizewell – Dunwich Bank"*

This deduction (which is of course, favourable to the argument for minimisation of shoreline change) assumes that eroded sediment will remain on the shoreline. This perspective is, however, at odds with observations that onshore sediment losses through erosion are matched at historical scales by sediment accumulation on the offshore banks (Carr, 1979). Although the sedimentary linkage between the shoreline and banks is unlikely to be straightforward (Carr, 1979), the banks have historically been a sink for eroded sediment and there is no reason or justification for the assumption that eroded sediment in the future will, instead, remain on the shoreline. This is especially true of sand and finer-grained sediment that accumulates offshore while gravel is preferentially retained onshore.

Furthermore, in contrast to the assertion that increased sediment supply will counter shoreline retreat, ongoing sediment to the offshore banks supply via coastal erosion is likely to lead to changes in bank configuration. As sea-level rises, it creates increased accommodation space for the banks to aggrade vertically. If there is increased sediment supply from more cliffline exposure and higher cliffs being eroded, then changes on the nearshore banks are likely to be more pronounced. Their elevation and distance from the future shoreline is likely to be an important aspect of future shoreline behaviour that has not been adequately considered in the assessment.

## 3. The marine component

3.2. It is stated that "*for much of its operation*" the hard defences would have a natural or maintained beach frontage. This statement does not explain the circumstances under which no beach frontage might exist, nor their likely duration.

3.2.2. 120,000 m$^3$ of shingle is to be added to create the artificial beach. Subsequent maintenance of this "sacrificial" defence is to be considered by a subsequent beach monitoring and mitigation plan (MMP) to be agreed with the MMO (Marine Management Organisation) after approval of the overall scheme. Additional mitigation plans for future impacts on longshore sediment transport as a result of potential future exposure of the hard coastal defences are also to be agreed. There is no mention of what happens after 2080. If the sea defences are to remain, they will continue to act as a headland, affecting the adjacent coast in perpetuity. Ultimately, as erosion continues, the defences could be outflanked, placing adjacent areas at risk.  With the loss of the sacrificial soft defences, the hard defences themselves would come under increasing exposure to weathering and wave action and will require maintenance.  With ongoing sea-level rise, they may need to be raised to continue to fulfil a protective function.  If the defences are eventually to be removed, the fate of any hazardous material would have to be considered.  None of these longer-term issues are addressed.

## 5. Cumulative environmental assessment for coastal geomorphology

With managed realignment and no active intervention designations in terms of SMP on coastal stretches either side of Sizewell, the site will progressively protrude as a headland as the coast on either side retreats.  It will then act as an anchor point that will contribute to future changes in shoreline planform manifest as large-scale coastal configuration changes. There will be an impact on the managed realignment at Minsmere of both this headland development, and any sediment added to the system via mitigation.

As the headland protrudes, waves will have access to the flanks of the hard and soft defences and the hard defences could be outflanked, putting the landward infrastructure at risk.   Edge effects of sea defence structures are well known and lead to enhanced erosion directly adjacent to hard structures (Morton, 1988).  Griggs and Tait (1988), noted that rock armoured structures in California led to accelerated berm erosion and beach scour up to 150 m downdrift of the structure.

Development of a headland would also affect longshore sediment transport past the site and potentially lead to changes in behaviour (frequency of rollover, longshore sediment transport, sediment accumulation) of the adjacent gravel barrier at Minsmere.  These have not been sufficiently considered in the assessment.

It also appears that the alongshore impacts of the armouring structures have been minimised in the EGA.  They extend for only ca. 1 km alongshore.  In contrast, in a large-scale modelling study investigating the century-scale impact of hard structures and beach nourishment interventions that fix the position of the shoreline, Ells and Murray (2012) concluded (p.1) that “both forms of stabilization [hard structures and beach nourishment] are found to significantly alter patterns of erosion and accretion at distances up to tens of kilometers". Under certain circumstances the impacts extended 100 km from the initial human intervention. There is no reason to expect that the sea defences at Sizewell, which is part of a 70 km-long continuous, mobile sandy shoreline, would be any less impactive on areas alongshore. In contemporary coastal management, the consequences for adjacent areas of planned interventions, must be properly considered.

## 6. High level monitoring and mitigation

P.129 states that no works *affecting the coast* could proceed until mitigation plans are agreed. It is important that this be the case and that mitigation is agreed and is legally enforceable for entire operational and decommissioning phase.

### 6.2. Nearshore outfalls

It seems bizarre to state (p. 129) that there is a low chance of impacts on the nearshore bar and then describe measured and apparently unanticipated impacts of similar (admittedly smaller) structures on bar migration patterns at Sizewell B (p. 129). The Sizewell B outfall was noted to have affected the position of the nearshore bar, preventing its migration in comparison to adjacent sections of the bar and leading to shoreline accretion. The fact that the proposed Sizewell C outfalls will be located "on the seaward flank" of the nearshore bar does not mean that it will necessarily have less impact- the very reverse could even be true as it affects incoming waves and sediment movement.

## 7. Future shoreline baseline…

It is not possible to state (p.132) that there will be no regime shift. In fact, the introduction of an artificial headland into a mobile coastal system is the kind of action that could precipitate just such a change. It changes the boundary conditions within which the coastal dynamics operate in the same way that other artificial structures alter their coastal surroundings from long distances alongshore. Ells and Murray (2012, p. 2) note that "even slight shifts in offshore wave energy distribution (as may be expected from global warming related changes in storm patterns) can induce rapid coastline shape change and accelerated erosion). Specifically, with reference to gravel beaches, Carter and Orford (1993) note (p. 158) that “Morphodynamic and morphosedimentary organization of coarse clastic shorelines provides a strong feedback with the incident wave field, and may be overcome only by domain shifts, which often result from sediment supply fluctuations or extreme events.”

Several authors (e.g. Jennings et al. 1998; Carter and Orford, 1993) have documented morphological changes on gravel barriers and beaches that involve changing rates of sea-level rise in similarly geologically complex settings with headlands and embayments. The interaction between sea-level change and rates of coastal erosion influenced changes in sediment supply that can lead to a variety of shoreline behaviours including enhanced barrier rollover and, ultimately, breaching of the gravel barrier. The possibility of such changes occurring in response to changing rates of sea-level rise, sediment supply and feedback between the two has not been adequately considered in the report but cannot be ruled out on the basis of current evidence. They would have important implications for nature conservation at Minsmere, for example.

### 7.2. Expert geomorphological assessment (EGA)

*Methodology*

The EGA involved two stages. In the first, 25-year measured shoreline change trends (1992-2018) were extrapolated 50 years into the future by which time the hard sea defences at Sizewell C were predicted to be exposed to direct wave action as the gravel frontage was eroded. The second stage involved a qualitative assessment to derive future shoreline positions with and without the Sizewell C defences in place. None of these extend beyond 2080, which appears to be no more than 50 years after operations begin. Yet, Volume 2, chapter 5 Decommissioning, Section 5.7.45 refers to “...any future climate change impacts during both decommissioning process on the site and surrounding environment for approximately 100 years following decommissioning”

If production started in 2030 and ended in 2090 with 100 years of decommissioning, we conclude that some assessment of the situation up to at least 2190 is required, by which time sea-level rise is likely to be much more than the scenarios presented here and the likelihood of extreme events occurring in that interval is very much higher.

The first stage of the process assumes straightforward continuation of past rates of shoreline change to which is added an additional amount of retreat. Yet, it appears that the behaviour of the Sizewell shoreline over the past 25 years has not been typical of its longer-term behaviour. The Sizewell shoreline appears to have exhibited retreat for most of the past 500 years, (over 300m) except for a brief interval (1836-1920) when it accreted. This accreted coastline on which subsequent erosion has been recorded is not at all typical of conditions pertaining for most of the past half millennium. It cannot therefore be regarded as typical of conditions in the next century or two. In addition, during most of the past 500 years, sea-level change was minimal in comparison to the past 50 years and the projected changes in the next 100 years and so past changes cannot be used to infer likely future trends.

The Expert Geomorphological Assessment (EGA) is prefaced with the statement "*Shoreline change is driven by several factors whose importance and interaction several decades into the future cannot be accurately predicted (Nichols et al., 2012), either separately or in combination*." This in part, illustrates the challenge in providing a future assessment based on process-response-type interactions such as attempted in the report. In this regard, while we support and advocate the use of EGA (over numerical morphodynamic modelling, for example), there are some shortcomings in this particular example that undermine its credibility.

In particular, in complex coastal systems, such as that under investigation, there is often no direct relationship between process and response. Instead, "autogenic events can arise from feedbacks internal to the system, without any variation in the forcing or boundary conditions" (Murray et al., 2014, p.2). This means that relatively sudden changes in the system can occur without any identifiable cause. An additional and important aspect of considering coastal systems in this way is not only do small scale changes affect large scale changes, but that large scale changes also affect small scale changes.  This latter possibility is often (as in this study) overlooked.  Without acknowledgement of this possibility and of the long-range impacts of coastal structures, the EGA is severely flawed in its approach.

To simplify the future coastline projections several *a priori* assumptions have been made by the expert group.  These assumptions underly the subsequent analysis and their validity is central to the subsequent assessment.  Here we assess some of those assumptions and show them to be invalid.

Detailed studies on past coastal behaviour (Pye and Blott, 2006; Burningham and French, 2018; Reeve et al., 2019) show that changes along this coast are spatially and temporally variable and that there are certainly alongshore linkages between behavioural patterns at different sections of the shoreline and most probably onshore-offshore linkages in terms of sediment supply and storage (Carr, 1978).

Burningham and French (2018 p.134) note that over the past century 89% of Suffolk intertidal beaches have narrowed and steepened through more rapid retreat of the LWM than HWM.  This important change in morphology (in which the final stages of wave energy dissipation occur across a narrower zone close to shore) could very well be indicative of a forthcoming system change (when a critical steepness is reached).  It certainly points to a system-wide change in decadal-scale morphodynamics and argues against linear extrapolation of past trends (when beaches were wider and more gently sloping) into the future.  At the very least, the foreshore steepening points to a reduced sediment volume in the intertidal beach and this decreases the system response time to dynamic impacts, making the coast more volatile particularly under any heightened future wave regime.

The assumption (TR311, p.134) that the worst-case impacts would arise when the HCDF first begins to affect coastal processes and would decline into the future is not tenable.  The presence of the artificial headland of the Sizewell C coastal defences will continue to exert a major influence on coastal evolution from its first emergence and thereafter.

The Agreed principles for the EGA include the following unsupportable assumptions:

- *Use of ‘reasonable foreseeable” conditions.*

  This explicit exclusion of the impact of extreme meteorological events (wind, waves, storm surge, water set-up etc.) from a forecast looking 50 years ahead is extraordinary, as it is statistically probable that a high-magnitude, low-frequency event will occur in that time period. If the analysis is extended to the post-decommissioning stage, as it should be, this principle is even more ridiculous. Consideration of such events is crucial in properly assessing flood risk and coastal erosion risk, especially as even the short-term effects of an extreme event could be sufficient to render elements of the planned infrastructure at risk. While it is likely of very low probability, the potential of tsunami impact should also be considered.

- *Minimisation of SLR component by assuming 68% of SLR up to 2070 is accounted for by extrapolation of historic trend rates.*

  Previous work (Burningham and French 2018) on the Suffolk coast found little evidence of regionally coherent shoreline change, such as might be attributed to SLR. It is disingenuous then to surmise that historic rates of shoreline change incorporate a SLR signal. They could equally be masking or even accentuating any potential signal.

- *The inshore wave climate remains unchanged.*

  This assumption seems to be partly based on an earlier implicit assumption that sandbank morphology does not change. As discussed above, **this is an untenable assumption given observations on adjacent sandbanks that show cyclic and episodic changes at decadal timescales**. These inevitable changes will certainly alter the nearshore wave climate even if the offshore wave climate is unaltered.

Although UKCP18 projections of global climate change do not foresee near-future changes in wave climate, other subsequent studies (Grabemann and Weisse, 2018; Bonaduce et al., 2019) *do* predict changes, particularly an increase in the extreme significant wave heights.  Other work (e.g. Pye and Blott, 2006, and cited in TR403, p. 23.) has attributed some historical changes in coastal behaviour directly to changes in wave climate.  It seems reasonable to assume that if there were historical changes in wave climate during the 20th century (linked to the NAO for example), that in an era of global climate change, future changes can also be anticipated.

Related assumptions regarding longshore transport are similarly questionable. Since the contemporary wave regime comprises almost equal N and S-directed components, even subtle variations in wave regime and/or bathymetry have the potential to cause changes in the net drift direction.  Working on the south Suffolk coast, Blanco and Brampton (2017) linked increased erosion since 2013 to a reversal of longshore transport direction.  This, in turn was linked to two high positive NAO index years following a high negative NAO index in 2013.

- *No shoreline accretion and sinuosity similar to present.*

For poorly understood reasons, long-term shoreline accretion dominated Sizewell's coastal change between 1836 and 1926. This coincided with northward growth of the Sizewell-Dunwich Bank (Pye and Blott, 2005) but the mechanism and relationship between Bank and shoreline remain unclear. Without a knowledge of the reasons for this period of accretion, it cannot simply be presumed that no future accretion will occur.  Changes in sinuosity are natural outcomes of the emergence of headlands and the subsequent development of very large-scale promontories and indentations, e.g. the Carolina Capes, can result from positive feedback operating on initially small scale coastal protuberances like these (Ashton et al., 2001).  Ashton et al. (2001) demonstrated how an initial small perturbation in the shoreline can grow through positive feedback (between the proturberance and longshore drift) to create very large-scale shoreline features.  The accentuated shoreline planform promontories at Sizewell B and Minsmere outfall identified in TR 403, are clear evidence of the possibility of cuspate features to form. This would lead to a major change in coastal planform involving large areas of erosion and accretion and certainly negates the simple assumption of no change in sinuousity.

- *Sandbank mobility and shoreline response.*

While we agree that the migration of the whole bank is unlikely, *the possibility of surface morphological changes is high* (subtidal ridges are mobile). These could cause significant changes in wave conditions onshore. Aldridge et al. (2018) modelled centimetre-scale topographic change on the Sizewell Bank at a one-week scale. Carr (1979) documented significant changes in the volume and morphology of the Sizewell-Dunwich bank between 1824 and 1965 involving migration at rates of $10^1$ m/year. Subsequent detailed work on adjacent banks in the region (Newcombe Sands, off Lowestoft) where more data are available revealed several important aspects of bank behaviour that appear to have been disregarded in this assessment. The most salient issues (from Dolphin et al., 2007, p. 731) are:

(i) “The sandbank exhibits 70–80 year cyclical behaviour in its movement, volume and elevation…”;
(ii) “bank reconfiguration (elongate ↔ deltaic) occurs rapidly (relative to the cycle period), on a bank-wide scale and may be considered to be episodic”;
(iii) Bank changes are affected by waves, tides and morphological changes in adjacent banks;
(iv) Bank-beach interactions are complex; and
(v) Counter-intuitively, “high bank elevations, which can provide the greatest coastal protection by reducing wave energy incident to the shoreline, are actually associated with the most severe erosion in the historical record”. This was explained (p.735) thus: “for shallower banks, optimal ratios of bank length to distance from shore lead to refraction and strong alongshore gradients in wave energy; the latter can lead to a divergence in sediment flux and localised coastal erosion”

These observations appear to undermine the assumptions of the EGA when assessing future stability of the Dunwich and Sizewell banks and related impacts on the shoreline. The fact that the shoreline has exhibited dramatic reversals in shoreline behaviour (Pye and Blott, 2006) attests to the potentially strong influence of bank morphology. Equally, **the statement that increased cliff erosion via bank lowering would lead to augmentation of the sediment volume and prolong the life of the soft coastal defences, is <u>invalid</u>**; the locus of increased wave erosion could just as well be located at Sizewell C as on any cliffed coastline.

Just as the Minsmere Outfall has “had a significant role in anchoring the shoreline immediately adjacent to the outfall structure by trapping shingle moving north and south during storms, resulting in the formation of a promontory and accretion observed over c. 500 m of frontage” (TR311, p 136), so too, is the emergent hard defence fronting Sizewell C likely to have a role.

### 7.3. Future shoreline baseline (without Sizewell C)

In both this and the “with Sizewell C” analyses, the geographical restriction of the study area cannot be justified. On a continuous soft-sediment mobile coast like that of Suffolk, changes in one part of the system are intimately related to changes elsewhere. This basic principle has been established locally through published works by members of the EGA team (Burningham and French, 2018) and is uniformly acknowledged in large scale coastal geomorphology (e.g. Terwindt et al., 1991; Ashton et al., 2001; Sabatier et al., 2009) that underpins modern Shoreline Management Plan applications (Cooper and Jay, 2002). Although sub-cells of shoreline behaviour can be identified, they are intrinsically linked to adjacent stretches of coast; they can both cause, and be affected by, changes in adjacent sections.

The lack of projected recession in the vicinity of the proposed Sizewell C installation in this scenario is perplexing. One would expect edge effects (Morton,1988; Griggs and Tait, 1988) from wave refraction from the existing sea defences at Sizewell B to enhance erosion in this location.

Assumptions regarding the continuation of the slow erosion rate are called into question by the observed long-term beachface steepening (see above). This pattern suggests progressive loss of sediment and an incipient phase change, perhaps even resulting in dramatic change on the upper beach as wave dissipate closer to the backshore. A similar steepening has also been noted on the Sussex coast (Dornbusch et al., 2008; Hurst et al., 2016) where it was deemed responsible for recent changes in rates of cliff retreat. On the sandy Rhone delta coast coastal structures are at risk of being undermined as the regional nearshore slope has steepened, permitting increased wave action at the shoreline. Such potential linkages appear not to have been not considered in the Sizewell investigation. In any case, the accretion and stability observed during the past century is at odds with the longer-term observed erosion at Sizewell and needs to be viewed in the context of the wider coastal system.

### 7.4. Future shoreline position with Sizewell C.

The single variation from the "without Sizewell C" scenario is that erosion would be higher up to ca. 1 km north of the Sizewell C hard defences. This deduction is untenable, in view of the much greater alongshore impacts of coastal structures at long timescales discussed above (Ells and Murray, 2012). Confining the longshore impact of the emergent hard defences headland to ca. 1 km is not consistent with observations and simulations elsewhere. Sabatier (2009), for example, reported impacts from sea defences > 10 km alongshore from their location while Ells and Murray, (2012) simulated longshore impacts for 10s (up to 100) km from sea defences.

It is also argued (Tr137, p.140) that "The existing 'mound' of high ground at this location (the Sizewell Bent Hills) would have a similar bounding effect on the beach roll-back without Sizewell C". This is not true because the natural hills would erode, changing shape and yield sediment to the coastal system whereas the sea defences will not.

Slott et al. (2010, p.17) concluded "*long-term effects may spread on the order of tens of kilometers away from the nourishment area itself*" while Ells and Murray (2012, p.6) noted that "*stabilization through hard structures can have long-range effects in the long term*." and (p1) conclude that "In centurial model experiments where localized stabilization is maintained in the context of changing climate forcing, both forms of stabilization [nourishment and hard sea defences] are found to significantly alter patterns of erosion and accretion *at distances up to tens of kilometers*" (italics added). The accentuated shoreline planform promontories that have developed in a relatively short time at Sizewell B and Minsmere outfall, provide evidence of the propensity for cuspate features to develop.

When the hard defences are exposed through shoreline recession, the *a priori* assumption regarding future shoreline sinuosity is needed to enable the assertion that the headland would not protrude as much as the Minsmere outfall. Since such an assumption is not justified (see above), it cannot be concluded that the hard defences would have no impact on sediment supply to the adjacent beaches. The extension of this line of reasoning to suggest that drift line vegetation might be re-established and erosion of the SSSI would be postponed, also cannot be justified. Any implied environmental gain should therefore be discounted

### 7.5. Additional Mitigation

Shoreline mitigation involving replenishment and recycling is considered viable given the low erosion rates (p 147). However, as stated above, the past century has not been typical and more rapid erosion has been the longer-term condition. The foreshore steepening could be indicative of a return to such erosive conditions. If this is the case, the volumes of sediment required for nourishment/recycling may be very much greater than anticipated and the costs and logistical implications may need to be more fully considered in the event that more frequent nourishment is required. A shortfall in the perceived amount of sediment necessary would leave infrastructure at risk. In addition, neither the system-wide and long term impacts of nourishment (they can extend for 10s of kilometres alongshore and cause impacts for decades: Ells and Murray, 2012) nor the longevity and fate of emplaced sediment volumes, have been properly considered.

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