A Rapid Coastal Processes Information Gap Analysis:

Linking national scientific capacity with coastal management needs

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The document presents a rapid coastal processes information gap analysis carried out for Coastal Partnership East in 2021-22, focussing on the English context. It explores aspects of our technical capacity to understand coastal change processes, linking these with coastal management needs for adaptive planning going forward.

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Executive Summary

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This report presents a rapid coastal processes information gap analysis carried out for Coastal Partnership East in 2021-22 focussing on the English context. It explores aspects of our national technical capacity to understand coastal erosion processes, linking these with coastal management needs for adaptive planning going forward.

As the language of coastal resilience and adaptation becomes more mainstream in the national coastal governance context, opportunities to proactively design viable ways of living with coastal change – anticipating rather than reacting to acute episodes of erosion risk in coastal places – are coming to the fore. Sound evidence of historic coastal change and best available future projections based on good data are critical foundations for co-developing pathways toward coastal transition, which are economically sound and politically justifiable. Thus, it is important that we enable and nurture our national capacity to create high quality coastal processes science for informing strategic coastal management planning for future resilience.

How can we accelerate user-informed coastal processes science to support the delivery of adaptation in practice?

Are there identifiable gaps and opportunities across the research-practice-policy nexus that would help us improve knowledge co-development and learning?

This study drew upon expert interviews with technical and coastal management specialists representing academia, consultancy, coastal management practice and policy communities to identify perceived gaps and opportunities for the co-development of coastal processes science. It captures the current status of coastal processes science in England, focussing on three broad themes: coastal processes science, coastal monitoring and data, and coastal processes knowledge co-development.

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A: What is the status of coastal processes science in England? What are the key gaps and opportunities for progressing science to support coastal adaptation in practice?

The full report documents a list of key projects that are currently ongoing, and some past work that has been notable in setting the current scene around how we understand coastal processes in England. This is a rapid review so includes national projects and some more applied examples but may not capture all relevant work underway. They include the National Coastal Erosion Risk Mapping 2 project, Shoreline Management Plan Refresh and Explorer and other studies in train through the Environment Agency and Defra's joint research programme, as well as academic research and studies conducted through coastal partnerships or other organisations. Research in this field is developing rapidly so the information included is accurate as of summer to autumn 2021 when the study research was undertaken.

Through the process of questioning what is being done and how we do, interpret and apply coastal processes science in England, some key over-arching challenges emerge:

- **Balancing uncertainty and precision**: Accepting future uncertainty in coastal change projections but planning with conviction in anticipation of expected trends and trigger points
- **Dynamic system complexity**: A complicated and dynamic coastal frontage is difficult to model and requires innovation and interpretive assessments, sometimes multiple approaches
- **Scale of analysis**: No one-size-fits-all approach to assessing erosion risk. National assessments can identify hotspots; local analyses work at a scheme level. There are few regional system scale examples.
- **Relative importance and interaction of different coastal change drivers**: Including sea-level rise, wave changes and local geology. What changes and feedback oscillations might we see in future?
- **Coastal catch-up** following beach nourishment as well as hard structure failure or removal
- **Appropriate capability and expertise**: Both technical and on adaptation (including community engagement expertise) in different coastal science and management institutions
- **Asking the right questions**: Practitioners need to be informed and intelligent 'clients' with time to engage with the science so that it is effective; technical work must reach out to end-users
- **Adaptation choices are critical**: adaptation or any strategic coastal management decision-making a key factor influencing the form of any future coast including cliff position
- **Resourcing science and strategic coastal management**: There is a need to allocate FCERM funding for both short-term coastal management as well as long-term strategic planning and the science to underpin this
- **Importance of investing in innovation**: Investing in research is critical for making progress.

The key gaps and opportunities in coastal processes science and its applications going forward are deemed to be:

- **Depending on historic rates of erosion is not enough**; sea-level rise, falling beach levels, new defence options or removal of defences, and adaptation choices all present challenges before unseen and need to be better understood
- **Sediment transport, processes and natural erosion management**: We need better mapping near-shore transportable source material to support more strategic coastal management planning
- **Long-term regional-scale holistic modelling capability is needed** to understand coastal system functioning effectively over whole frontages. Creating a regional coastal change assessment tool that coastal managers can explore would be useful for strategic planning purposes
- **Mechanisms are needed for mapping regional baseline data** (social, economic and environmental) and information to fully characterise local coastal places
- **Up-skilling the sector** through investment in training would help to reverse the national decline in expertise
- **Resurrect a CoRDDi type framework** and establish a widely accessible coastal information/research hub
- **Socio-political constraints and levers are critical** and play a role in our ability to unlock the science needed to support local-scale coastal adaptation within a joined-up national context. These include the non-statutory status of SMPs and role of CCMAs, absence of an effective national policy delivery framework including guidance and funding, that adaptation is not yet an established FCERM option and that it goes well beyond coastal management, and short-term political interests and expectations of permanence.

B. How are we faring with our approach to coastal monitoring and data analysis? Are there gaps and opportunities here?

England has a good approach to monitoring and data compared to other places worldwide. This has dramatically improved in the last 20 years with the establishment of the National Coastal Monitoring Programme. This is perceived to be an extremely valuable source of long-term, good-resolution and openly accessible coastal monitoring data, which provides full coverage of the coast including digital terrain models (DTM's), lidar, bathymetry, topography and more.

An analysis of where there are gaps in coverage around the way we monitor our coast found the following key areas where more information could be valuable to both enable more comprehensive coastal change assessments: The 'White Ribbon' - gap between bathymetry and lidar coverage; Shallow sub-surface; Shore platform; Sediment fluxes; Impact of interventions; Register of coastal assets; Monitored distance off-shore; Beach dynamics and storms, the need for more trends analysis and current limitations; and, R&D to enable better data use.

The key emerging technical opportunities and potential in this field to increase and develop our monitoring capacity and improve the efficiency of data collection are: earth observation and satellite derived data, use of drones and autonomous surface vehicles, seismic monitoring and telemetry tools, laser scanning, marine synoptic radar systems, use of 5G and new techniques and capacity in data visualisation and interpretation.

We face ongoing challenges in terms of coastal monitoring and data to support coastal processes science and research which can inform adaptive coastal management. These are not easy to resolve but need to be transparent and acknowledged in this sector:

- Inherent uncertainty around advance monitoring needs to support adaptation
- Capacity and expertise - to be able to identify what is needed of regional monitoring going forward, what to ask of the data and in interpretation of analyses
- Need for long-term data sets to make future projections – the national coastal monitoring programme is now enabling this and the data record is lengthening all the time (and must continue)
- Data size and storage
- Non geophysical data needs and restrictions on accessibility of data
- Collation of disparate data, i.e. the wealth of data held by parties other than the NCMP and not openly accessible
- More information is available for defended than eroding sections of coast because where there are schemes, there is more monitoring and analysis.

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C. What could we do to better co-develop knowledge around coastal processes to advance progress on adaptation policy and in practice?

The research-practice-policy community in this field is fairly tight, well networked and is expanding as interest in how to 'do' well-evidenced adaptation and resilience in England grows. There are a small number of extremely committed expert individuals in the sector who, to date, have been critical in advancing this agenda within and across consultancy, the public sector (i.e. local authorities, coastal partnerships, the Environment Agency), and academia. The significance of passionate and skilled people – and the effectiveness of them aligning at the right time – should not be underestimated.

This study highlights the importance of being a well-informed and intelligent client in commissioning or guiding coastal technical studies, but coastal managers are increasingly stretched with little time or other resources to keep in touch with learning in the FCERM and academic research community. This is one of a host of institutional constraints to advancing collective learning facing consultants, academics and public sector FCERM staff.

This work particularly highlights that we need more effective knowledge co-development mechanisms going forward, which better link the practice-policy realm with that of the technical science around coastal processes. Across policy and practice there are some extremely effective mechanisms enabling collaborative working, knowledge sharing and collective learning nationally (particularly the Coastal Groups Network and the LGA Coastal SIG). The professional view is, however, that science in this field is not developing as well as it could do, considering what is technically possible; there is a particular disconnect between the academic and practitioner-policy communities.

There is an opportunity for more meaningful collaboration across the research-policy-practice nexus. Resurrection of the Environment Agency's CoRDIi framework would be extremely valuable and would enable a stronger link with UKRI. The SMPR and SMP Explorer process and the NCERM2 projects present a known opportunity to bring together information on coastal change into one user-hub, which is much needed. Traditional mechanisms such as conferences and routine publications remain essential, and having time and opportunities to network informally and creatively is of great importance in progressing our collective knowledge and capability in this field.

In sum, high quality scientific evidence is a critical foundation for innovation in developing politically and economically justifiable approaches to coastal adaptation. We need this evidence to underpin strategic coastal planning for future resilience. There is a need for more effective collective knowledge development to improve translation into practice:

- At local to national scales, asking well-informed questions of the science so that it effectively supports a robust pathways approach to delivering adaptation
- Producing fit-for-purpose evidence to better understand the potential evolution and implications of long-term coastal change to develop timely adaptation policies, options and transition plans for coastal places
- Being able to integrate and incorporate new and nuanced coastal change information into adaptation and transition planning processes in the future.

In England, we have good national expertise and capability in the technical science of coastal processes and coastal change but could do more to increase capacity and skills in this sector and to more effectively extrapolate this into policy and practice. The examples given in this report indicate that there is huge potential to accelerate progress in this field, which largely depends on two things:

a) Funding - given a pulse of strategic national investment, coastal processes science and skills development carefully tailored to the needs of those responsible for managing coastal change now and into the future would be extremely effective.
b) An enabling national coastal governance context – this does not yet encompass or enable the development of a robust delivery framework to deliver adaptive coastal transitions although great progress is being made thanks to the continuing efforts of the coastal change community across the science-policy-practice nexus in the UK.

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1. Context

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This rapid coastal processes information gap analysis was commissioned by Coastal Partnership East (CPE) in 2021-22[1] to support their ongoing work, particularly in preparation for two programmes of work to be carried out to 2027 in Norfolk and Suffolk funded under the national Flood and Coast Innovation Programme (FCIRP)[2]. This report will also be made available to the UK's flood and coastal erosion risk management (FCERM) community to inform the co-development of research in this field amongst and between other organisations. Focussing on the English context. It explores aspects of our national technical capacity to understand coastal change processes, linking these with coastal management needs for adaptive planning going forward.

> How can we accelerate user-informed coastal processes science to support the delivery of adaptation to coastal change in practice?

Over the last 20 years the attention being paid to the challenge of coastal change (erosion) has accelerated, particularly in recent years in light of Defra's FCERM Policy Statement (2020)[3], the Environment Agency's FCERM strategy (2020)[4], corresponding action plan (2021)[5], and before that the Committee on Climate Change's notable report on Managing the Coast in a Changing Climate (2018)[6].

As the language of coastal resilience and adaptation becomes more mainstream in the national coastal governance context, opportunities to proactively design viable ways of living with coastal change – anticipating rather than reacting to acute episodes of erosion risk in coastal places – are coming to the fore. Sound evidence of historic coastal change and best available future projections based on good data are critical foundations for co-developing pathways toward coastal transition, which are economically sound and politically justifiable. Thus, it is important that we enable and nurture our national capacity to create high quality coastal processes science for informing strategic coastal management planning for future resilience.

> Are there identifiable gaps and opportunities within the research-practice-policy nexus around coastal processes science that would help us accelerate knowledge co-development and learning about coastal change?

This study draws upon expert interviews with technical and coastal management specialists representing academia, consultancy, practice and policy communities to identify perceived gaps and opportunities for the co-development of coastal processes science. The review and findings capture the current status of coastal processes science in England.

For clarity, the term 'coastal partnerships' is used in places in this report, as a short-hand reference to local authority coastal risk management partnerships.

[1] Based on a well-reviewed but unsuccessful proposal to NERC in 2020 for an embedded researcher placement under the Climate Resilience Programme led by Day & Nicholls (TYN), co-developed with Goodliffe (NNDC)
[2] https://engageenvironmentagency.uk.engagementhq.com/hub-page/fcrmfund
[3] https://www.gov.uk/government/publications/flood-and-coastal-erosion-risk-management-policy-statement
[4] National Flood and Coastal Erosion Risk Management Strategy for England - GOV.UK (www.gov.uk)
[5] National flood and coastal erosion risk management strategy for England action plan - GOV.UK (www.gov.uk)
[6] Managing the coast in a changing climate - Climate Change Committee (theccc.org.uk)

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1.1 Aims of the study

The study aimed to do three key things:

- **Scope existing coastal processes science capacity and available tools for assessing the evolution of coastal change over time**

Taking into account, for example, climate change scenarios and management policies, specifically for the highly complex CPE frontage – Norfolk and Suffolk, but also more widely. Coastal management teams are often based within resource-poor local authorities and do not always have the capacity to be at the forefront of national progress yet want to implement adaptation to coastal change; this work aims to clarify the status of current science, who leads on this and what kinds of tools and information may be available to inform adaptation planning at local levels in the near future.

- **Capture the key needs of coastal managers in planning adaptively for vulnerable erodible frontage**

What kind of tools and information about coastal change do risk coastal managers need and want to have access to in order to plan adaptively for the future of their coastal systems and communities? What evidence (e.g., about what may be at risk over time) is required to support resilience planning, community engagement in developing adaptation options, the case for national policy and guidance on coastal adaptation, making the case for new forms of funding, etc.?

- **Identify key gaps and opportunities for developing coastal processes science to support more coastal adaptive management practice for eroding sections of coast**

What are the key barriers to progress and where are there clear R&D or opportunities for other kinds of effective investment that would have high value for the coastal management community?

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1.2 Method

A qualitative approach was taken for this work, focussing on detailed discussions with key experts (technical and practitioner) in the field. The method consisted of:

- One focus group held internally with a core team from CPE
- 13 interviews nationally with representatives/experts from the following sectors:
    - Academic
    - Private [consultants]
    - Environment Agency and Coastal Groups
    - Local Authorities

This is a fast-moving field and time was limited to conduct the study. There are other known experts who could have been consulted but were not on this occasion. Recommendations have been made in a separate and confidential document to suggest further lines of enquiry and contacts on this topic.

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1.3 Main themes

The methods (focus group and interviews) were designed to address three key themes of interest, and the findings are presented in the context of these:

A. Coastal processes science
- Key current projects
- Notable past projects
- Core challenges in coastal processes science
- Research-practice-policy gaps and opportunities (national and CPE scale)

B. Coastal monitoring and data
- Key initiatives and programmes
- Monitoring and data needs for coastal change assessments and modelling
- Monitoring and data gaps, opportunities, and challenges

C. Coastal processes knowledge co-development
- Who has the expertise?
- How is knowledge and learning on this topic linked and shared?
- Broad information and knowledge development needs and opportunities

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2. Coastal Processes Science Overview

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Learning more about any section of coast involves understanding:

1. How the coast has evolved to date
2. What the driving influences of coastal change are, and what these are likely to be in the future
3. How these drivers interact within the coastal system, what the key feedbacks are and how these dynamics may evolve over time

A huge amount of expertise is required to investigate any one of these three aspects and indeed to integrate them to understand current and future coastal change.

This section summarises known work to date in this fast-moving field with respect to assessments of coastal change, tools, technical capacity and concepts. It then highlights some key contemporary issues that experts (consultants, academics, practitioners) see as important in this field currently and areas which are perhaps worthy of more consideration or investment going forward at the national scale. Included in the separate Appendix A (for CPE use only) is a reflection prepared in Autumn 2021 on key considerations for CPE in the development of its FCRIP programme and other upcoming activities.

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2.1 Key current projects

This section highlights key projects that are currently in play and ongoing. Research in this field is developing rapidly so the information included is accurate as of summer to autumn 2021 when the study research was undertaken. Listed here are the most notable projects, for which more information is given in the remainder of this section. This list captures projects cited by the interviewees who participated in this study and may not be entirely exhaustive.

2.1.1 National Coastal Erosion Risk Mapping project phase 2 (NCERM2)
2.1.2 Shoreline Management Plan Refresh (SMPR) and explorer (SMP Explorer)
2.1.3 Shore and coastal erosion sensitivity to accelerating sea level rise: Improved understanding of the sensitivity of coastal cliff recession around Wales and England to future sea level rise.
2.1.4 Coastal monitoring and historical coastal change
2.1.5 Coastal Modelling Environment (CoastalME) software
2.1.6 BLUEcoast
2.1.7 National Coastal Monitoring Programme
2.1.8 Practical approaches to transfer or decommissioning of FCERM assets7
2.1.9 Improving our understanding of the UK's Coastlines
2.1.10 SCOPAC Research
2.1.11 Other related projects in progress or up-coming

[7] https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/practical-approaches-to-the-transferring-or-decommissioning-of-fcerm-assets

2.1.1 National Coastal Erosion Risk Mapping project phase 2 (NCERM2)

NCERM2 is a project under the EA/Defra joint research programme. A tender has recently been awarded for this work, which will be delivered in full in December 2023. Over the last year there has been a development phase to work with experts to establish needs and high level outputs, and refine the scope of the work. Various projects will feed into the NCERM2 (including those on cliff toe sensitivity to SLR and the historic rates of erosion work). NCERM2 follows 'NCERM1'[8][9]. The Government's 2005 response to Making Space For Water included a commitment for the EA to develop national erosion maps akin to the Flood Map. NCERM was therefore developed between 2007-2011 by Halcrow (now Jacobs), who also developed the underlying methodology (known as RACE[10]). UKCP02 provided climate change evidence and NCERM outputs were sensitivity tested against UKCP09. A summary assessment of homes and non-residential properties at risk was provided from the data in 2012. NCERM2 seeks to significantly update the analytical capability and quality of outputs. The aims of the project broadly include:

- Ensuring the provision of technically reliable information based on a RACE model, enhanced by recent erosion R&D and the latest available input data
- Ensuring NCERM2 data is more accessible and well understood by the main users by improving online representation and useability of raw data
- Improved governance and maintenance of NCERM alongside SMP information including improvements to auditability and future maintenance
- Actively involved partners
- Improve and increase our understanding of erosion risk to a range of receptors

There have been particular discussions around challenges such as:

- The scope of intended end-users: should NCERM2 be geared toward use by informed practitioners (e.g. coastal managers, planners) only, or also as a public facing source of information? This question may affect the level of access and/or format of outputs. Usefulness to a range of audiences, transparency and open availability of technical information is an important principle from a coastal management perspective in seeking to conduct credible community engagement on adaptation. There is a perception that the information that coastal managers have and use for options development and suchlike, should be openly available so that people can access it in an equitable way for inclusive negotiation of transition planning ideas.
- Format of outputs: to what extent are erosion risk lines on 2D maps, or even zones/ranges appropriate given that it is easy to misunderstand or misinterpret ranges of uncertainty? Engagement support will be commissioned within this project to support this challenge.
- To what extent NCERM2 can erosion link into planning outcomes, CCMAs and other mechanisms, as is the case for flood zones.

For the Anglian region in particular, the outputs of NCERM1 were not originally accepted as the outputs were not 'realistic' and did not demonstrate enough erosion so could not be adopted. NCERM1 also focussed on cliffed areas but didn't take adequate account of 'low' erosion, for example areas of beach and dune erosion. The Southern Coastal Group for example had to make a strong case for this type of low-lying erosion to be included. Thirdly, NCERM1 incorporated SMP erosion bands/lines, which were not necessarily the most appropriate reference points for erosion risk predictions; they were developed to inform a strategic policy direction, albeit based on the best erosion information at the time. Due to local system dynamics and phenomena such as coastal rebound or catch-up (see section 3.5), erosion rates in some places may exceed what is shown by the bands in SMPs. Since NCERM1, many technical advances and fixes have been identified to resolve such omissions and a lot of learning and new research will be feeding into this second iteration of NCERM.

[8] https://data.gov.uk/dataset/7564fcf7-2dd2-4878-bfb9-11c5cf971cf9/national-coastal-erosion-risk-mapping-ncerm-national-2018-2021
[9] https://www.arcgis.com/apps/webappviewer/index.html?id=9cef4a084bbb4954b970cd35b099d94c
[10] https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/risk-assessment-of-coastal-erosion

2.1.2 Shoreline Management Plan Refresh (SMPR) and explorer (SMP Explorer)

This is a project under the EA/Defra joint research programme. Coastal groups were consulted in 2017 and agreed with the EA that SMP's should be 'refreshed' rather than comprehensively reviewed; the SMP2 epochs were originally to 100 years and we are now at approximately year 20 in their outlooks. Since the second generation SMPs were published, there have been three tranches of new climate projections, approximately 25 pieces of relevant legislation change, and action plans are not up to date (partly as nobody 'owns' an SMP). So the refresh acts as a 'health check' to ensure that SMP policies are still appropriate and that the SMPs are still fit-for-purpose.

> *"We have had at least three tranches of climate projections which aren't factored into the SMPs and over 25 major pieces of legislation change…so we need a review to make sure the SMPs are fit for purpose."*
> Interview B12

The SMP Refresh aims to improve the profile, impact and deliverability of SMPs by making them more accessible, clearer and more consistent with the most recently available policy, strategy and evidence. Led by Jacobs and RHDHV, the process will scrutinize the SMP erosion zones and is essentially a health-check to ensure that SMPs are fit for purpose – in many locations the SMPs are the best information that coastal local authorities have got so are central sources of risk information when it comes to informing planning and CCMA assessments.

The SMP Explorer is part of the SMP Refresh project and will constitute an online digital map-based tool. Phase one was commissioned in Spring 2019 (Jacobs and RHDHV) and delivered in 2020. Phase 2 is underway and will deliver in April 2023, and will incorporate NCERM2.

2.1.3 Shore and coastal erosion sensitivity to accelerating sea level rise[11]

"Shore and coastal erosion sensitivity to accelerating sea level rise: Improved understanding of the sensitivity of coastal cliff recession around Wales and England to future sea level rise" is part of the EA/Defra joint research programme. It is complete and due to be published imminently. This project came about in recognition that methods to date for dealing with the effects of SLR and CC (e.g. wave growth) on coastal cliff recession were based on a conceptual model developed for beaches and dunes: a peer-reviewed approach that could incorporate the dynamics of cliffs and shore platforms, perhaps with a beach on top was necessary. Acknowledging the complexity and diversity of the coastal geology of England and Wales, and cost restrictions, it was necessary to develop a method that is quick and relatively easy to apply and based on existing information. This method provides a national, broad-brush assessment to give indications of cliff recession that account for UKCP18 SLR and wave growth. The results are intentionally conservative. It is the first approach to quantify the effects of tidal range, wave severity (which varies by region) and glacial isostatic adjustment. The latter emerges as an important factor controlling the future sensitivity of cliffs.

2.1.4 Coastal monitoring and historical coastal change[12]

This EA/Defra joint research programme project by the British Geological Survey (BGS) is in progress at the present time. It will review and collate historical coastal change evidence and create a methodological framework to document historical coastal change. It will create a strong national baseline, which is important to understand in any future modelling exercises. It will help to validate future-facing models; the fundamental test for confidence in the function of a model is if it can accurately replicate past conditions.

[11] https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/shore-and-coastal-erosion-sensitivity-to-accelerating-sea-level-rise
[12] https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/coastal-monitoring-and-historical-coastal-change

2.1.5 Coastal Modelling Environment (CoastalME) software[13,14]

Coastal Modelling Environment (CoastalME) was developed by Andres Payo and is designed to support long-term modelling; it incorporates some selective models including a version of SCAPE and other tools which are more specifically able to move sediment around the system (see also Payo et al., [15]. CoastalME is set up to represent the availability of sediment drawn from different geologies; it incorporates sub-bottom (i.e. below beach and sea-bed) properties and highly detailed digital terrain models to assess the risk of coastal flooding and coastal erosion over decades to centuries time scales. Gradients in wave-driven longshore transport related to coastline shape provide a cornerstone principle for combining different landform specific models. It simulates coastal morphology evolution as a set of dynamically linked raster and geometrical objects that evolve through time driven by variant or stationary boundary conditions and following certain user defined morphodynamic principles. Put simply, it is possible to change the rules and look at system interactions. This has potential and it would be interesting to see what it could do with the CPE frontage.

CoastalME was originally developed by Andres Payo at the British Geological Survey (BGS) through the iCOASST project (see section 2.2) and developed significantly in the BLUEcoast project (next heading). As part of BLUEcoast, CoastalME was applied in Happisburgh for the first time since proof of concept in iCOASST. It enables account to be taken of sediment transport by waves, i.e., characterising the transportable material in the nearshore area of the coast via a thickness model which brings together Lidar, bathymetry, borehole and sub-surface non-intrusive sensor data.

2.1.6 BLUEcoast[16]

BLUEcoast recently completed, in December 2021. It aimed to inform coastal management by reducing uncertainties in the prediction of medium-term (years) and long-term (decadal and longer) regional sediment budgets, morphological change and how the coast recovers after sequences of storms. The project is undertaking observations and experiments to develop modelling tools that will be used to evaluate coastal resilience and scope alternative management options. BLUEcoast is addressing unknowns in sediment dynamics due to overlapping processes in the water column, on and within the seabed, and at the water-land interface. Relationships between the beach and cliff erosion are critical and this project provides evidence from observation and the development of modelling capacity to depict known change. The research is focused on both physical and biological dynamic processes and their role in coastal recovery after storm events. Recovery means different things in different contexts; even where there are coastal cliffs that will always retreat, it is possible for the protective capacity of the platform in front of a cliff (e.g. after a storm) to recover. Key questions are:

- What is the role of sediment type (grain size, cohesiveness, lithology, biological characteristic) and coastal geomorphology on mediating coastal evolution?
- Which processes dictate the cross- and/or alongshore sediment fluxes of sediment from source to sink?
- What role is played by biotic factors in the ecosystem and to what extend do biotic processes mediate coastal change or stability?
- Which processes govern the recovery period of coastal systems?
- What role is played by local and antecedent conditions?
- How sensitive are coastal systems to changes in external forcings, including the sequencing and frequency and magnitude of extreme events, and including the confounding effect of human interventions?
- How do biological and sedimentary factors combine to determine system resilience and tipping points?

[13] http://www.coastalme.org.uk/doku/doku.php
[14] https://coastalmonitoring.org/ccoresources/iCOASST/COASTAL_ME/
[15] Payo, A, Favis-Mortlock, D, Dickson, M, Hall, J W, Hurst, M D, Walkden, M J A, Townend, I, et al. (2017) Coastal Modelling Environment Version 1.0: A framework for Integrating Landform-Specific Component Models in Order to Simulate Decadal to Centennial Morphological Changes on Complex Coasts." Geosci. Model Dev. 10(7): 2715-40. https://doi.org/10.5194/gmd-10-2715-2017
[16] https://projects.noc.ac.uk/bluecoast/

Using three distinct coastal types, which incorporate the range of conditions, BLUEcoast aims to deliver improved scientific knowledge and enhanced modelling capability for dynamic coastal environments. The new knowledge and model capability developed will then be applied to deliver scenarios for two particularly challenging coastal locations (one being East Anglia).

2.1.7 National Coastal Monitoring Programme

See Section 5.1.1.

2.1.8 Practical approaches to transfer or decommissioning of FCERM assets[17]

This EA/Defra joint research programme project is producing information to help practitioners through the process of transferring and decommissioning FCERM assets. It collates and will present practical information on planned transferral and decommissioning. The report is specifically targeted at asset managers with RMAs, although it'll also be of interest to landowners and other stakeholders. Expected completion is spring 2022.

2.1.9 Improving our understanding of the UK's Coastlines (UKHO)[18]

The Geospatial Commission launched this Coastal Zone Mapping project in 2020, which is being overseen by the UK Hydrographic Office. It includes representation from British Geological Survey (BGS), Department for Environment, Food and Rural Affairs (DEFRA), Environment Agency, Natural England, Ordnance Survey and the UK Hydrographic Office.

Generating an accurate picture of the coast can be extremely difficult, as this is a place where many different geospatial data sets coincide. Land surveys typically stop on the beach at the point before the surveyor's feet get wet, and bathymetric surveys stop before survey vessels run aground. In addition, these two types of survey typically comply to different standards, use different datums and are conducted by a range of different organisations. This can make it extremely difficult to bring data together and create a complete picture that supports better use of our coastal environment. The project aims to create a better understanding of challenges faced by coastal geospatial data users including the context given above and find new ways to overcome them. Recommendations have been developed and are presently open for feedback.

2.1.10 SCOPAC Research[19]

Prior to the formation of England's seven strategic coastal groups, the regional group for central southern England was SCOPAC – The Standing Conference on Problems Associated with the Coastline. It was born of a need for neighbouring LA's and organisations to work together more closely, communicating regularly, sharing knowledge and collaborating, in order to develop a more holistic understanding of the complex coastal issues facing the region without the limitations of LA boundaries. SCOPAC and the Southern Coastal Group (est. 2008) merged in 2020 with the aim of streamlining deliverables in research, policy, the environment and engineering. The SCG and SCOPAC research provides a mechanism for local and region-wide issues to be investigated, that may not ordinarily be undertaken by a single Local Authority. The knowledge shared not only benefits officers and members but can lead to much larger research projects being commissioned by central government.

Much of the SCG and SCOPAC research (new, past and ongoing) is only possible because of the regional coastal governance arrangements and sharing of resources and expertise. It is of interest nationally and has strong links with academic partners (e.g. the storm analysis work with Dr Ivan Haigh at the University of Southampton which has demonstrated using regional coastal monitoring data an increase over the last decade in wave height and bimodality).

[17] https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/practical-approaches-to-the-transferring-or-decommissioning-of-fcerm-assets
[18] https://ukhodigital.blog.gov.uk/2020/06/25/improving-our-understanding-of-the-uks-coastlines/
[19] https://southerncoastalgroup-scopac.org.uk/

2.1.11 Other related projects in progress or up-coming:

- EA Measuring Resilience to Flooding and Coastal Change (recently complete, in publication)[20]
- EA Working Together on Climate Adaptation (recently complete, in publication)[21]
- Update to the coastal handbook - underway[22]
- EPSRC funded Port and Coastal Towns Network (iPACT)[23] - North Norfolk is a case study. The network led through Southampton University will identify people-focused, infrastructure-based solutions to the complex problem of improving social well-being and prosperity in coastal communities through resilient and sustainable regeneration.
- NERC funded Resilient coasts: optimising co-benefit solutions (Co-Opt)[24] led by the National Oceanography Centre will deliver a new integrated and interdisciplinary system-based framework that will effectively support the required transition from hard 'grey' defences to softer 'green' solutions in coastal and shoreline management.]
- Examples such as Coastal Partners' Hayling Island Coastal Management Strategy 2120[25], which is incorporating updated erosion zones, which in turn feed into the economic assessment.
- The Flood and Coastal Resilience Innovation Fund[26]. This includes:
    - A Flood and Coastal Resilience Innovation Programme (FCRIP) of projects, one of which has been awarded to CPE
    - The Coastal Transition Accelerator Programme part of which has been awarded to North Norfolk District Council
    - The Adaptation Pathways Programme

[20] https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/measuring-resilience-to-flooding-and-coastal-change
[21] https://www.gov.uk/government/news/working-together-on-climate-adaptation
[22] https://www.gov.uk/government/publications/the-coastal-handbook-a-guide-for-all-those-working-on-the-coast
[23] https://www.southampton.ac.uk/smmi/news/2022/03/23-port-and-coastal-towns-network.page
[24] https://noc.ac.uk/projects/co-opt
[25] https://coastalpartners.org.uk/project/hayling-island-coastal-management-strategy-2120/
[26] https://www.gov.uk/guidance/flood-and-coastal-resilience-innovation-programme

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2.2 Notable past projects

This section highlights key projects that may have been completed many years ago in some cases but are still cited as being highly relevant in the field, and/or which heralded important learning at the time.

2.2.1 FutureCoast
2.2.2 Tyndall Coastal Simulator
2.2.3 iCOASTT
2.2.4 Studies on coastal catch-up
2.2.5 Key local observations and knowledge
2.2.6 Beach modelling: Lessons learnt from past scheme performance
2.2.7 Coastal Erosion and Climate Change – Guidance for Policymakers, Planners & Stakeholders
2.2.8 Economics of Coastal Change Management in England[27]
2.2.9 Other (not an exhaustive list but things mentioned by interviewees)

2.2.1 FutureCoast

The Futurecoast[28][29] project was commissioned by Defra in 2002 to support the Shoreline Management Review process and to inform coastal managers about how to consider future coastal change. It collated and assessed available knowledge on past change at different scales and described the way in which our coastline might be expected to evolve in the coming decades. It covered the whole country and built up a huge body of information on the geology, geomorphology, historic mapping, driving forces (waves, currents, tidal conditions) and more. Thus, FutureCoast was able to look in depth at mapping coastal change, likely coastal evolution and looked to help provide a tool combining mapping and narrative (as opposed to a model) of how coastal systems interact to drive likely change. This work is widely cited as a significant step forward in conceptualising the factors affecting coastal change.

Some suggested that conducting a baselining update exercise on the same principle as FutureCoast would be well-placed using the now much-longer data record collected by the NCMP to provide all local authorities and coastal partnerships with a good baseline and something that they could use on a regular basis. See more in section 4.5.

2.2.2 Tyndall Coastal Simulator (TCS)

The original model that morphed into the Tyndall Coastal Simulator (TCS) was developed approximately 20 years ago partly through modelling for a strategy study for NNDC by Mike Walkden, which led to SCAPE[30] (SCAPE deals with a profile across shore, and this was combined with a longshore model for the North Norfolk coast depicting material moving along the coast to demonstrate the size of the beach at each cross section).

> *"I genuinely think that the Tyndall regional coastal simulator has not been surpassed in terms of regional simulations of long-term coastal change."*
> Interview A10

Over the years the TCS has been variously updated and applied; for example, it was used approx. 6-7 years ago in approx. 2014) as part of the work done for NNDC's coastal strategy (fronted by Mott McDonald – TCS work subcontracted to RHDHV). They ran some long-term simulations, probabilistic work, and the results were deemed to be really good and interesting. The TCS still has strong currency and potential and its integrated/holistic and long-term capability has not been surpassed in terms of regional simulations of coastal change. A book was edited by Nicholls et al. (2015)[31] to

[27] https://www.theccc.org.uk/publication/economics-of-coastal-change-management-in-england-jacobs/
[28] https://coastalmonitoring.org/ccoresources/futurecoast/
[29] https://www.jstor.org/stable/25098438
[30] https://coastalmonitoring.org/ccoresources/iCOASST/SCAPE/
[31] Nicholls, R.J., Dawson, R.J., and Day, S.A. (2015) Broad Scale Coastal Simulation: New techniques to understand and manage shorelines in the new millennium. Springer. https://link.springer.com/book/10.1007/978-94-007-5258-0

summarise the components of the TCS including its potential applications for North Norfolk (Day et al., 2015)[32] and the interface concept (Mokrech et al., 2015)[33]. The work is also summarised in an extremely highly cited paper by Dawson et al. (2009)[34].

Importantly, SCAPE and the TCS approach enable the inclusion of coastal management / engineered interventions to explore the effects of, for example, reducing erosion, and the effect of removing defences for example, to understand the likelihood of accelerated erosion. Future scenarios (in relation to climate change but also management planning options) can be explored to understand the likely response of the coastal system. The power of the coastal simulator was and is really its prognosis element; its ability to project one hundred years into the future with some confidence that what we were seeing was useful and would relate to what you might see in the real world.

2.2.3 iCOASST

Summary: The iCOASST project aimed to help forecast what the UK's coastline will look like in the future, up to 100 years' time. It took a system-level perspective to understand and predict coastal change. This four-year project brought together UK universities, research laboratories and leading consultants to develop new methods to characterise and forecast long-term changes to coastal sediment systems. iCOASST was funded by the Natural Environment Research Council (NERC) and partnered by the Environment Agency (EA), who intended to use these methods to improve long-term flood and erosion risk management. iCOASST included two demonstration case studies in Liverpool Bay and on the Suffolk coast. Coastal system modelling done by UCL had good potential according to interviewees. Uncertainty if the tool they were developing ever made it into mainstream access (think not). Barend van Maanen (Exeter Uni, estuarine sediment specialist) did a piece of work as part of this on the Bawdsey inlet; a modelling tool designed to deal with slugs or lumps of sediment being released from one side of the estuary and attaching themselves to the other side of the estuary mouth and then being recycled. Fairly site specific but you could see it being applied elsewhere.

2.2.4 Studies on coastal catch-up

Studies have been conducted by various consultants, the EA and by BGS on the coastal-catch up phenomenon for sites in Dorset, The Solent and North Norfolk, for example. This is an emerging area of interest - see Box 2.2 for a contextual explanation of why this is and section 3.5 for more on this topic.

2.2.5 Key local observations and knowledge

This general category on local coastal observation and knowledge is included as it is a source of information which much not be underestimated. Individuals within local coastal communities (e.g., small business owners, fishers, local councillors, etc.) and local authorities (e.g. coastal managers and engineers) there exists a huge resource in terms of experiential knowledge of coastal conditions and dynamics, often over very long timescales. This should be considered an important asset as well as knowledge archive for anyone involved in locational coastal research or development/delivery of management options. In North Norfolk for example, local observations over recent decades include:

- Beach lowering
- Movement of beach material west to east
- Relative stability around Sheringham and Cromer because of substantial defences and stable sub-base
- Shift in beach material over time from being sandy to being shingle (and more erosive of defence structures) on the in-shore beach at Cromer.

[32] Day, S.A., et al. (2015) Many stakeholders, multiple perspectives: Long-term planning for a future coast. pp. 299-323 in Nicholls, R.J., Dawson, R.J., and Day, S.A. (2015)

[33] Mokrech, M., et al. (2015) GIS platforms for managing, accessing and integrating model results: The Tyndall Coastal Simulator experience. pp. 273-298 in Nicholls, R.J., Dawson, R.J., and Day, S.A. (2015)

[34] Dawson, R. J. et al. (2009) Integrated analysis of risks of coastal flooding and cliff erosion under scenarios of long-term change. CLIMATIC CHANGE, 95(1–2): 249–288. https://doi.org/10.1007/s10584-008-9532-8

Box 2.2. Summary explanation of coastal catch-up in Happisburgh; understanding coastal geology is critical in any location

- **Most of the East Anglian coast is protected. A segment of defences at Happisburgh were removed in the 2000's and quick coastal 'catch-up' was observed.**

Walkden et al. (2016)[35] estimate that the erosion seen after the defence removal – marked by the cliff position – is probably landward of where it otherwise would have been if the defences had not originally been constructed and natural processes had been left to evolve. In other words, the retreat has accelerated and overshot its likely current line.

- **If we keep removing defences along the East Anglian coast, would we expect to see similar behaviour?**

The answer is unclear because Happisburgh has a very peculiar subsurface; the crag formation is an old deposit. If Happisburgh erodes further, then the platform that would be exposed (the Crag) is very rich in sand and gravel. Eventually, if this section of coast kept eroding, it may provide enough sediment to keep a healthy beach. Cliff would be lost, but the platform erosion would eventually give more time through natural beach recharge. [*Important issues in the context of adaptation and ethics in decision-making are noted but not addressed here*]. An initial quantification suggests that the amount of sediment released from the Happisburgh Crag platform is similar to the amount of sediment being lost although there is a lot of uncertainty around the actual volume.

- **Calculating potential catch-up or the 'value' of sediment released for beach protection is very different in any particular place.**

Elsewhere, beach platforms are constituted of different geology. Further north, the chalk will erode differently to the crag; the platform adds nothing to the sediment budget because it will dissolve rather than adding material to the coast. *Edited from a quote from interview A14*

2.2.6 Beach modelling: Lessons learnt from past scheme performance

Beach recharge and management, such as re-profiling and recycling, accounts each year for several million pounds of the UK's coastal flood defence capital and maintenance expenditure. Decisions on the development of such schemes are often informed by beach modelling including numerical, physical and empirical approaches. This document by the Environment Agency (2014) provides the technical detail behind the report on lessons learned from previous schemes that has been developed with the aim of improving understanding in this area. The research has specifically investigated the lessons that can be learned from the actual performance of schemes compared with original model expectations by reviewing case studies for 11 sites and drawing on anecdotal information gathered through engagement with industry practitioners. It also provides details on the range of modelling tools and techniques available (the report reviews all the models on the market at date of publication and how they were validated) and includes the full case studies from which the lessons learned have been taken and which are summarised in the lessons learned report.

2.2.7 Coastal Erosion and Climate Change – Guidance for Policymakers, Planners & Stakeholders[36]

This guide by Moore and McInnes (August 2021) looks at the implications of future climate change, sea-level rise and coastal erosion risks to global communities and infrastructure. It demonstrates that strategic coastal planning, management and adaptation are key to mitigating future losses and ensuring that coastal development, communities and infrastructure are resilient and sustainable in the long-term. This non-technical guide summaries Jacobs' domain expertise in coastal planning and management aimed at government authorities, communities, developers and stakeholders.

[35] Walkden, M., Watson, G., Johnson, A., Heron, E., and Tarrant, O. (2016) Coastal Catch-up Following Defence Removal at Happisburgh. Coastal Management, Jan 2016: 523-532 https://www.icevirtuallibrary.com/doi/10.1680/cm.61149.523

[36] www.jacobs.com/sites/default/files/content/file-uploads/CECCGfP_final.pdf

2.2.8 Economics of Coastal Change Management in England[37]

This report, by Jacobs (2018), accompanies the CCC's report, 'Managing the coast in a changing climate', published in October 2018. It was commissioned by CCC's Adaptation Committee to assess the assets at risk of coastal change, to conduct a national cost-benefit analysis (CBA) of measures to manage these risks, and to supplement this with a series of case studies which outline the development of adaptation pathways for communities with particular coastal challenges. It looked at SMP policies and the economic viability of these, looked at broad ranges of potential options and constraints to these, and explored different settings for adaptation (Great Yarmouth was a case study).

2.2.9 Other (not an exhaustive list but things mentioned by interviewees):

- SCOPAC sediment transport study (2012) https://www.scopac.org.uk/sts/
- Beachlinks to Sandbanks (Blinks) (UEA, 2004-2008 led by Chris Vincent[38][39] - looked at the relationship between beaches in Norfolk and Suffolk and the nearshore banks. Went back to original war data on hydrography and digitised the survey data.
- Early formative research led by Professor Keith Clayton, UEA - Research by Clayton in the early 1990's identified the problem of lack of sediment input from the coastal cliffs leading to the beaches diminishing (books available in UEA library). And the identification of the Sheringham area as being the turning point of the net drift. Also work by Colin Wye on coastal slips and local cliff erosion rates; this work tallied well with the first SMP and is still very useful to the NNDC coastal engineers.
- Southern North Sea sediment transport study[40] – early 2000's. Unsure of the status of this or if it will be updated – suggestion that this is needed.
- Work done by UEA to develop a Norfolk and Suffolk coastal information hub – unsure where this project got to and what happened to it as this could be a useful source of information going forward. There weren't the resources to maintain and administer this, and perhaps it needed to be a national initiative. To be followed-up.
- Work done by Cranfield University for the Eastern RFCC mapping research – also usure if this went ahead and where it is.

[37] https://www.theccc.org.uk/publication/economics-of-coastal-change-management-in-england-jacobs/
[38]https://www.researchgate.net/publication/228493122_Variability_in_Sandbank_Behaviour_at_Decadal_and_Annual_Time-Scales_and_Implications_for_Adjacent_Beaches#fullTextFileContent
[39] https://www.jstor.org/stable/26481684
[40] https://www.north-norfolk.gov.uk/media/3112/southern-north-sea-sediment-transport-study-phase-2-main-report.pdf

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3 Core Challenges in Coastal Processes Science

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Through the process of questioning how we 'do' coastal processes science in England, how we interpret it and how we apply this knowledge and expertise, some key over-arching challenges emerged from this study. We need to acknowledge and understand these to identify what the research-practice-policy gaps and opportunities might be going forward:

3.1 **Balancing uncertainty and precision**: Accepting future uncertainty in coastal change projections but planning with certainty for obvious trends
3.2 **Dynamic system complexity:** A complicated and dynamic coastal frontage (as Norfolk and Suffolk is) is difficult to model and requires innovation and interpretive assessments
3.3 **Scale of analysis:** There is not a one-size-fits-all approach to assessing erosion risk – national assessments can identify hotspots, local analyses work at a scheme level but there are few examples at a regional system scale
3.4 **Relative importance and interaction of different coastal change drivers:** Including sea-level rise, wave changes and local geology
3.5 **Coastal catch-up** following beach nourishment as well as hard structure failure/removal
3.6 **Appropriate capability and expertise:** Both technical and on adaptation (including community engagement expertise)
3.7 **Asking the right questions of the science:** Practitioners need to be informed and intelligent 'clients' with time to engage with and understand the science so that it is effective
3.8 **Adaptation choices are critical:** adaptation is a key factor influencing the form of any future coast including cliff position
3.9 **Resourcing both short-term and strategic coastal management:** How we balance and allocate FCERM funding for short-term coastal management as well as long-term strategic planning.
3.10 **Importance of investing in innovation:** Taking risks when investing in research is critical for making progress

The interviews yielded rich discussion around what was originally intended to be mainly technical content around the science of coastal erosion. As often tends to be the case in contemporary discussions about long-term coastal system dynamics, issues concerning the socio-political challenges of delivering coastal adaptation, policy and funding, institutional governance and other factors became as prominent in the conversations as the technical focus. Indeed, these are inextricably linked to how we approach the production of underpinning science to inform coastal management going forward. See section 4.9 for this content.

> *"In the medium to long term, we need to prepare ourselves for what things might be like in 50-100 years time. There are a lot of challenges coming our way even without climate change, with ageing infrastructure or defences which will be removed or will fail at some point. If you add in the impacts of climate change and sea-level rise, which is hard to quantify at the moment under the range of scenarios, what will all that look like and mean? I think we need to help people understand and visualise it so that we can have proper conversations about it and start to politically think about it."*
> Interview A9

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3.1 Balancing uncertainty and precision

Accepting future uncertainty in coastal change projections but planning with certainty for obvious trends.

For flood mapping and modelling, it is possible to be relatively precise, but there is a lot of uncertainty when it comes to erosion

There is often vast geo-technical uncertainty and multiple other factors to consider in modelling erosion futures. It will never be possible to get an absolutely accurate prediction for how the coast will be at any point in the future because we do not know how climate change will manifest and as erosion occurs, we will be working with different geologies for example. In flood modelling, tidal water tends to behave in predictable ways whatever the location. However, local geology means that erosion rates can be episodic depending on the manifestation of landslips or cliff failures – and as a cliff-line retreats, this may change. This highlights the importance of having a good baseline knowledge of our coastal geo-morphology – see more in section 5.1.2.

The complexity of erosive frontages means there is a risk of overreliance on modelling. This ultimately must be understood to be a tool for exploring scenarios of coastal change.

- The degree of precision sought by any end-user in coastal erosion risk modelling/mapping analyses and outputs must be carefully and transparently considered.
- Over time, uncertainties due to feedbacks and 'surprises' in the behaviour of the coastal system (e.g. frequency of storms) mean that any erosion line or zone on a map under all scenarios will be increasingly inaccurate into the future.
- Projections can change when more or different information or modelling techniques become available for future analyses, or if there are unexpected changes in the physical state of the coast.
- Only a certain number of model runs are ever possible so inevitably can only be expected to give a general trend. This still requires expertise in interpretation, to sense check assumptions.

The above considerations are particularly important in the production of public facing information, with recognisable local features where people can identify local features, if not individual properties.

- The publication of SMPs, for example in the early 2000's, which demonstrated potential erosion zones over time epochs (still inevitably including lines), led to much worry and fear for some communities because people inevitably focus on the landward edge of any risk zone, which effectively becomes a line. We have come a long way since that point but the issue of how projections of evolving risk are communicated must be handled carefully.
- In the design of schemes, it may be reasonable to take up a 'worst-case' scenario to underpin a case for economic viability, but this does not mean that that scenario is necessarily expected (within or beyond the lifetime of the scheme) – the point is, it is still a viable scenario and a scheme must be able to withstand such an eventuality.

While we cannot be precise about future erosion rates, we can be proactive and sure about management trajectories, informed by a range of likely change.

Erosion is non-linear. It is often episodic with large losses every so often; rates on an annual or decadal scale are particularly hard to predict. In some ways it is easier to model 100 year scenarios – even factoring in sea-level rise and other climate change impacts. When it comes to managing a coast, anticipating how that change will manifest over shorter term epochs is the challenge.

For areas which are already erosion hotspots (including multiple parts of CPE's frontage), coastal managers know that change is inevitable. The timing of this change may be uncertain, but we can be certain enough that proactive work to put adaptation measures in place is a robust and sensible direction of travel, to avoid acute future risk situations. An example scenario: in a complex cliff area with one access road to a holiday park (a notable local economic asset), which would be cut off with by a landslip. Sooner rather than later it would be wise to locate an alternative access road so that when the event occurs, the impacts are localised and not detrimental. So, decisions can be taken in this regard without needing a huge degree of precision regarding the eventual cliff top line.

> *"There are places where change is inevitable; we might not be able to say exactly when it will happen, but we know it will. So we should be investing and being proactive to put in place adaptation measures so that when the eventuality does occur, mitigation [of harm] is in place."*
> Interview B7

Other key factors concerning timescale and circumstances around the drive for precision in erosion projections:

a) Practitioners and development planners tend to think about timescales of 30-50 years during which time an understanding of erosion rates and how it may manifest is useful. Here, erosion assessments are vital to appraising the viability and benefits of schemes.
b) In some places the line can be held relatively sustainably for a long time at a moderate cost through 'buying-time' mechanisms or schemes such as rock berms, beach nourishment, sandscaping and other interventions. Modelling helps us to understand how these interventions are likely to perform and how long they are likely to be effective for.
c) It is becoming increasingly clear that we need to invest more thought and funding into adaptation planning in some locations where there may be trigger points or thresholds beyond which a line definitely cannot be held and where erosion hotspots may later become apparent (see also Section 4.4) – this includes FCERM asset decommissioning and likely failure points. Here, erosion assessments are needed to inform coastal management decisions and the development of longer-term options with communities (e.g. around retreat/relocation for example and the likely timing).
d) For longer-term trajectories, we need more capacity for certainty in the *planning and management decisions* at least in addition to refining our ability to generate coastal change risk projections.

> *"If money was no object and you threw all the best people you could at it, how much extra certainty would it give you in terms of your management decision making capability? This would probably increase a bit, but there would still be a big chunk of uncertainty and that is probably the nub of the whole problem - it's about judgement and making sound decisions based on the availability of evidence."*
> Interview B5

With sea level rise factored in, there may only be a small degree of difference in the extent of retreat over a 100 year period, where we already expect progressive erosion. Over long time periods, feedbacks within a system lead to quite small changes overall. For example, episodes of erosion input sediment into the system which may have a temporarily protective effect. Over 100 years this is unlikely to substantially change the erosion rate. Decisions can be taken in this regard and flexible plans put in place based on trigger points and thresholds which prompt transition decisions to be made, without needing a huge degree of precision regarding the eventual cliff top line after a certain future point. This point links to the concept of adaptation pathways is becoming increasingly well recognised and adopted in contemporary programmes and projects.

Finally, it is imperative to be very clear about the baseline being used for any erosion projections; where they start from and what the residual lifetimes of various coastal assets and features might be (beaches as well as cliffs).

NCERM2 will help us to collectively advance thinking and practice on this topic, and the appropriateness of outputs upon which to plan and make adaptation decisions concerning coastal erosion risk.

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3.2 Dynamic system complexity

A complicated and dynamic coastal frontage is difficult to model and requires innovation and interpretive assessments

Every coastal system has interlinked components which interact and feedback to drive coastal change. The CPE frontage covers one of the most complex and 'trickiest' bits of the UK coast to understand and model. Where a section of coast has pure beach and dunes behind it, then it is possible to use a reasonable conceptual model to understand its behaviour, and likely response to climate change impacts. If a site behaves like a pure cliff and shore platform, then the well-tested and established SCAPE model can be applied with good confidence. But as soon as we are faced with a frontage of a mixed character - which a lot of the Suffolk and Norfolk coast is - it becomes very challenging to use a simple, cheap conceptual model to describe it.

Additionally what you do in one location has a knock-on effect elsewhere and this is further complicated by the off-shore sandbank systems. Thus, there is a necessity to have to start simulating and looking at the exchange of sediments, which involves a huge realm of complexity. The Solent frontage is another good example of a particularly complex area because it has so many drift divides. Underlying geology is another factor complicating outlooks for soft coastal frontages; as erosion progresses, the underlying geology may change leading to the emergence of features such as headlands which may move a system from one state to another.

Innovation is needed and there are cost implications. Interpretive assessments of coastal change are useful but require relatively more investment than modelling for simpler systems. This kind of work is important in places where we do not fully understand the system dynamics, and where there may be shore dependency on offshore sandbanks, sediment supply, and trying to make sense of stochastic fluctuations seen in the shore plan shape.

Shifting spits and sandbanks are not well understood; interpretive work is necessary to explore the range of hydrodynamics and sediment transport processes, and to look at consequent flood risk if banks fully roll back to quantify and assess the value of managing an active spit system is a challenge and is costly but probably worthwhile (e.g. Muddiford sandbank, Christchurch Harbour, Dorset).

> *"It is actually quite complicated and forensic. How do you piece all of these bits together to work out what is going on? There is not a tool or even a model that could be produced that could predict that change."*
> Interview A3

We also have observed changes in local systems to contend with (see Box 3.2 for more on this). For example in North Norfolk where beach material is transported from west to east and flint shingle has substituted sand in some places as the core beach material. Thus, one of the consequences of this sediment transport process is a change in beach behaviour and local dynamics because flint is much more erosive and damaging to coastal structures in rough sea conditions than sand (this makes it difficult to know what is expected over the lifetime of capital defence schemes, as well as how the character of beaches may change and behave in the more distant future.

Box. 3.2. Oscillations in a complex coastal system – Norfolk and Suffolk

- Some work was recently carried out at Hemsby in East Norfolk; a system in flux. 20 years ago there was an accreting dune system in this location, advancing seaward. In recent years the area has experienced rapid retreat and loss of chalets from the dune area. Locally funded rock armour failed. This area is complicated to understand and manage because of a deep water offshore channel created by sandbanks gradually shifting in-shore, essentially causing the beach to be undercut and erosion of the dunes. All of this behaviour was observed through the monitoring data collected in the area.
- At Winterton, just north of Hemsby, there is a ness which moves North and South over decades as well as annually. This influences the way in which sediment reaches the local section of coast, also the ways in which the tides, currents and waves behave.
- At Gunton and Corton in Suffolk, there has been accretion in the past, as well as erosion. Observing the trends, an 'oscillation' is apparent where the material in the system has re-orientated across approximately two kilometres causing erosion at one end. This is not typical and we are observing a shift in the waves hitting the coast because of offshore banks altering the pattern.

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3.3 Scale of analysis

There is not a one-size-fits-all approach to assessing erosion risk – national assessments can identify hotspots, local analyses are needed at a scheme level but there are few examples at a regional system scale.

The level and type of analysis depends on the context of each case location, the questions being asked and the budget available. Work to assess erosion rates/risk can be undertaken at any scale but the degree of detail will necessarily vary depending on the approach taken. A national scale assessment can identify hotspots for further analysis. Place-based or scheme-level assessments look more closely at localised erosion problems, system dynamics and particular asset or scheme lifetimes and risks.

> *"A challenge we face is trying to get tools that are consistent and can be used around the country whilst also accepting that our coasts and risks are very different – so you have to make compromises and understand that you are going to get issues with accuracy in any one location."*
> Interview A8

However, it is also necessary sometimes to have a bigger picture of the system if the coast is to be managed strategically, as scheme level interventions or decisions can have system and landscape-scale impacts. Sections 2.1 and 2.2 explain how the NCERM2 and SMP Refresh and Explorer projects aim to make the currently available information more visible and accessible. However, there are no examples of erosion scenarios or assessments for regional scale, or sub-system frontages, which would give a bigger picture of the system that CPE, for example, are managing excepting the work done by the Tyndall Coastal Simulator project (section 2.2.2) many years ago. This is discussed further in section 4.4.

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3.4 Relative importance and interaction of different coastal change drivers

Including sea-level rise, wave changes and local geology

The location of future shorelines will be a composite of many factors and events, some of which are obvious long-term drivers of change. The scale of analysis is important here too.

Sensitivity analyses in SCAPE and the TCS, for example, suggest strongly that sea level is probably the most dominant variable influencing broad coastal change trends over the long-term. Wave changes (direction and height) will modify patterns created by sea level and have hotspots of impact, but won't fundamentally create conditions for change along a whole frontage; wave direction changes for example may modify the littoral drift and can accelerate or decrease erosion by around 10% but SLR is much more significant at this scale (e.g. Dickson et al., 2007[41]).

> *"A lot of the frontage is hold the line, which has implications in terms of how management is delivered. There is still a coastal change risk even if your policy and approach is largely to defend, you still need to think about the whole."*
> Interview B7

Other drivers are more significant at local scales in the way they manifest; the combination of rainfall and soft geology leads to episodic change in the cliff-top position in areas with soft cliffs (such as in many locations around Norfolk and Suffolk where landslips occur). Periodic cliff slips exacerbated by wet conditions can be very significant locally (but are a negligible factor in terms of the overall rate of erosion of a section of frontage in the long-term). For example, ten metres could be lost in a single event, then nothing for many decades. How erosion manifests locally is of key importance

[41] Dickson, M. E., Walkden, M. J. A., & Hall, J. W. (2007). Systemic impacts of climate change on an eroding coastal region over the twenty-first century. Climatic Change, 84(2), 141–166. https://doi.org/10.1007/S10584-006-9200-9

for coastal risk management authorities dealing with the consequences for homes and other assets at acute risk and trying to understand how to deliver adaptation.

In terms of long-term erosion trajectories, the management *choices* we make around coastal protection and adaptation are in some ways the most significant.

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3.5 Coastal catch-up

Following beach nourishment as well as hard structure failure/removal

Hard defence degradation or removal can lead to a subsequent period of accelerated erosion – a rebound or 'catch-up' effect, which is a big unknown in assessments of coastal change. It is possible to examine this phenomenon and studies are underway (see Box 2.2) to assess what happens if, a) structures fail or are removed, and b) at the long-term effects of beach nourishment. Nourishment may be seen as delaying an erosion situation by disconnecting the cliffs and the shore platform from the waves (so time essentially stands still as long as the beach remains). Recent assessments demonstrate however, that this is not always the case; it is possible that when beach nourishment stops, there can be a lot of coastal catch-up associated with the nourishment. The catch-up effect from hard defences can even be quite small in comparison to that of a nourishment scheme (e.g. effect shown and quantified in studies for BCP Council [Poole Bay]).

For some locations this rebound or catch-up phenomenon is of particular significance (for example, Happisburgh in North Norfolk) and is a largely unknown driver of local erosion, which warrants further research as currently big assumptions are made in economic assessments for schemes on this issue.

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3.6 Appropriate capability and expertise

Both technical and on adaptation (including community engagement expertise)

Expertise and resources within coastal local authorities and partnerships varies nationally; governance arrangements are different and some areas may have just one or two coastal engineers and no capacity to do the breadth of work spanning policy and adaptation funding as well as operational maintenance. The last five years have seen a significant shift toward the formation of partnerships across multiple local authorities as a way of sharing and maximising resources and expertise, and the ability to grow skilled teams which can tackle longer-term strategic as well as short-term operational deliverables. Issues still remain:

a. Technical

Coastal managers within local authorities and/or coastal partnerships need to be able to understand the implications of coastal change in their areas, but do not always have the capabilities to use technical coastal processes models and tools or to interpret results. This type of work is most frequently outsourced to consultants, for example storm impact analysis.

> *"It is all very well to have abstract projections of SLR but unless we have the means to understand how these are likely to manifest locally and drive change then they are impossible to use. This kind of information needs translating into something that local coastal managers can use."*
> Interview B9

The often very complex results of coastal modelling, technical assessments and analyses or even national guidance on sea level rise for example, can be abstract and difficult to understand, requiring expertise for interpretation, and a lot of time. This makes the outputs of this kind of work often inaccessible to the very people or teams that have commissioned it (let alone the general public, who in coastal contexts are increasingly wanting to/being invited to be party to the fundamental technical information that demonstrates the erosion challenge, or options for management). Skill is needed to critique the outputs, to understand the models being used and how they have been validated, and the ranges of scenarios they use – quite apart from then what the implications are at a local scale, and communicating these to people.

> *"You have to be so careful interpreting a technical report or a scientific data into something that is understandable to a different audience without either losing its meaning or some sort of downplaying or downgrading the original information or the original sort of message. Some professionals are better at it than others."*
> Interview B5

On the flip side, at a local or scheme scale, often outputs need to be simplified by consultants for a client as the decision-making and management process can not necessarily work with the complexity of the outputs – but this runs the risk of compromising the meaning or implications of the results.

These points have a knock-on impact when we consider community engagement processes around coastal change and the need for transparent information (see also a comment on this in the context of NCERM2 in section 2.1.1). Third party use and interpretation of information is important to enable in transition planning that aims to be equitable and participatory. How technical information this is presented, translated and made available to bolster the decision-making underway needs to be proactively considered.

In terms of applying technical information, even where model outputs may be translated into GIS systems to show information in an understandable way, that is useful for local decision making, not all local authorities have in-house GIS capability. So even if model outputs can be translated into GIS systems, they could still be inaccessible for some organisations. The type of outputs from initiatives such as NCERM2 therefore require some deep consultation with practitioners about the end-user issues; this work is being undertaken as part of the project.

b. Adaptation

It has long been recognised that coastal adaptation is needed and over recent years the language of adaptation and resilience has become more prominent in policy and practice, yet we still do not have an FCERM institutional setting to support the delivery of this (see more in section 4.9). In other words, much debate and thought has been put by a range of parties into the issue of coastal adaptation, but the practice of delivering change management or coastal transitions is still young. Particularly in relation to adaptation in town and country planning and in a socio-political sense engaging with communities facing uncertain futures. Even if guidance and resources were made available tomorrow, coastal management teams have not had, and still do not necessarily have, the skills to put known needs and ideas around coastal transitions into practice.

Having more capacity, support, and tested tools for addressing the social and political challenges around adaptation and putting adaptation transition plans together is a particular necessity. Coastal adaptation is not an 'add-on' but needs to be properly resourced and staffed in its own right, to drive it forward. This means by resourcing people with appropriate qualifications and skills (including in effective community engagement and training in handling public expectations and socio-political implications of options development), in addition to those with geomorphological and engineering capability (able to deliver capital schemes and conduct day-to-day beach management and maintenance) on a more mainstream basis. Until relatively recently[42] (and still, in some places), local authority coastal management teams were predominantly comprised of individuals with mainly engineering and geomorphological expertise working on administratively define frontages.

Key recent progress in enabling our collective capability to deliver adaptation:

- Our most recent FCERM strategy explicitly uses the language of adaptation and resilience
- Management of coastal frontages at a broader system scale through the establishment and evolution of the Shoreline Management Planning process and the refresh that is underway
- Establishment of coastal partnerships such as CPE, where resources and expertise across local authorities can be shared and is growing
- Strengthening knowledge exchange development networks (e.g., through the LGA Coastal SIG, and the network coastal groups, for example)
- Testing of new types of adaptation options through the new Flood and Coastal Resilience Innovation Fund
- The drive to develop more integrated (multi-benefit) and nature-based solutions

[42] The release of the Making Space for Water by Defra in 2005 heralded a shift in our national FCERM approach from a default one of engineered protection toward enabling a more naturally functioning and balanced system.

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3.7 Asking the right questions of the science

Practitioners need to be informed and intelligent 'clients' with time to engage with and understand the science so that it is effective.

> *"The issue really for coastal managers is that they do not have the experience or knowledge in this very niche technical area, to know what they are asking for, what they want it to show them and to know where to challenge it."*
> Interview B7

The interplay between science and practice – and the delivery of coastal adaptation – is really important in this field, especially when it comes to the development of tools for understanding coastal change (relating to points made in section 3.6 and section 4.5).

- The importance of coastal management practitioners being informed and intelligent clients was emphasised by many interviewees. Often they simply do not have the time to spend thinking about the questions they need to ask or may not have the expertise to know enough about the work or analyses that they are commissioning.
- The science-user interface can be a difficulty. Naturally, many people want tools to be very simple, but what we are studying here is very complex and so it is important to understand what you are working with and the appropriate queries to investigate.
- It is also hard to know when new information or tools are needed as opposed to asking different questions of what exists: even if we can do a new assessment, do we need one? It is important to build on what has been done before rather than replicate it but knowledge sharing gaps and other factors may mean that this is not obvious (see section 4.8 for more on this).
- Adequately defining and agreeing the scope of work: as work progresses, questions can change and become more sophisticated – there is a balance from the beginning in terms of deliverability and ambition; anticipating what may become possible but remaining realistic and within scope.
- Related to this is the management of expectations in relation to what can be delivered based on project specifications (as above).

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3.8 Adaptation choices are critical

Adaptation is a key factor influencing the form of any future coast including cliff position.

> *"A big uncertainty is the issue of adaptation. The interplay between sea level and how we adapt I would say is the key factor that gives you a future coast, a future cliff position."*
> Interview A1

One of the biggest challenges in this field is not technical but socio-political and concerns when and how we choose to adapt rather than defend. In other words, a significant uncertainty when it comes to the technical challenge of understanding future coastal change is the interplay between sea level and adaptation decisions. Adaptation is a key factor influencing the form of any future coast including cliff position – ultimately this depends on the management choices we make. It is possible to play with other factors but to some extent you need to look initially at these two features, which are complex in themselves, and then do more refined analyses with other factors afterwards.

Undoubtedly, a critical part of this is how we go about engaging with – involving and empowering – communities in coming to terms with the erosion hazards they are facing. In some ways this is more difficult and important than assessing the nuances of physical erosion risk; if people, through the legacy of historic protection and development, did not live in these locations with an expectation of permanence (and/or were easily able to relocate activities away from risk zones) then erosion would not necessarily be an acute problem. More on this in section 4.9.

There is a lot at stake when we think about future coastal policy options, and adaptation choices. Preventing erosion can lead to narrow, steepening beaches and thus the character of an area can change (and associated tourism value through change of aesthetic for example), and also incur growing maintenance expense over time. If we are not going to stop cliffs and beaches from eroding then the process has to be understood and managed. Various temporary defence options which 'buy-time' by slowing erosion for an interim time whilst options are collaboratively developed have a strong place as part of this process. An example of this is the placement of rock berms, also the Sandscaping Scheme in Bacton, North Norfolk, which is a mega-renourishment which has an approximate 20-year lifetime. Other similar options include, for example the recycling of material from off-shore sandbanks where it can be shown that beach material migrates to these.

All of these things are adaptation choices and play a role in influencing the form and timing of our evolving future coasts so must be explicitly considered in our coastal processes investigations.

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3.9 Resourcing strategic coastal management

How do we resource the science we need and allocate FCERM funding for short-term coastal management as well as long-term strategic planning.

We have good capability in the UK around the technical science of coastal processes, but this is not being utilised to its fullest. There is the potential to do a huge amount more. The main barrier is obtaining the financial resource to do this. Amongst the expert community there is a wealth of ideas about what could be done better to understand how sections of our coast are changing, how we might update this information annually to see how change adjusts to the available latest information and predicting based upon the available tools how change may happen in the future.

> *"The capability is there = we could do so much more. We have got the minds, ideas and people to do it but we do not have the money. That is the biggest issue of all – getting the resource in terms of money."* Interview A3

Consistent with the need to resource adaptation capability at local scales is the broader need for more transparent consideration nationally of how we balance and allocate FCERM funding to fulfil short-term coastal management needs *as well as* long-term strategic coastal planning – including the science to support this.

In other words, how do we manage the complexities of the beaches on a frontage over the next 20 years, alongside concerns about the implications of retreat and changing dynamics over 80-100 years +? Section 4.1 elaborates further on the grey area in between; how recently observed changes in coastal dynamics are adding to the operational load in short-term coastal management and suggest issues to be taken into account for longer-term coastal change trajectories.

> *"As a practitioner…the EA and its Grant-in-Aid funding should be more focussed on [near-term coastal management] and UK Plc should be looking - perhaps through academia - at the longer-term issues. We [practitioners] should be at the top table as stakeholders but not leading this out of Grant-in-Aid. UK science budget should be allocated to this."* Interview A11

The current funding system through FCERM Grant-in-Aid is inadequate for funding long-term strategic work by coastal management teams on adaptation. It is hard to link adaptation benefits to specific outcome measures that presently bring funding, such as the protection of homes. Presently for longer-term, strategic adaptation work nationally and locally it is really hard to get funding. Projects like CLIFF are going a long way to filling this gap but there is more potential and huge need for an injection of national research funding to develop this kind of work.

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3.10 Importance of investing in innovation

Taking risks when investing in research is critical for making progress.

An example of synergy between a client's real need and interest in coastal processes and some research that they were prepared to take a risk on:

- In 2001 NNDC were very progressive in understanding their coast and needed a strategy study. They went to [a consultancy] which suggested bringing in some work from a particular university. This involved a risk [that the academic work may have come to nothing] but the client/NNDC took it and it worked.
- This is what produced the world's first regional coastal model over 35km which broke barriers in terms of the spatial and temporal scale, structures and human interventions in the system that could be represented.
- The model picked up long-shore interaction and coastal catch-up and was so good that the Tyndall Centre was able to develop this in the Coastal Simulator work.
- The Tyndall work focussed on refinement.

An example of speculative investment:

- BCP Council invested some funds speculatively to look into potential coastal catch-up.
- The embedded technical expertise within the team enabled them to recognise this potential problem, with an understanding that this would be significant for their business case for ongoing nourishment.
- A study was commissioned which was hugely productive; both client and consultant learned new things about both this section of coastal system as well as the catch-up phenomenon in general.
- Relating back to Section 3.6, BCP were only able to instigate the investigations to explore the potential for catch-up because they had:
    - Technical expertise, experience, skills and training within the team
    - Capacity to do some initial scoping
    - Capacity to secure funding.

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4. Research-practice-policy gaps & opportunities

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This section gives an overview of the key national research-policy-practice gaps and opportunities that emerged from the discussions that informed this study.

The professional view is that nationally, science in this field is not developing as well as it could considering what is technically possible. The key points which arose in conversations with interviewees about gaps and opportunities in coastal processes science and its applications going forward are:

4.1 **Depending on historic rates of erosion is not enough**; sea-level rise, falling beach levels, new defence options or removal of defences, and adaptation choices all present challenges before unseen
4.2 **Sediment transport, processes and natural erosion management:** Mapping near-shore transportable source material to support more strategic coastal management planning
4.3 **Up-to-date methods for understanding overtopping**
4.4 **Long-term regional-scale holistic modelling capability** is needed to understand coastal systems
4.5 **Creating (regional) coastal change assessment tool** that coastal managers can explore would be useful for strategic planning purposes
4.6 **Mechanisms for mapping regional baseline data** (social, economic and environmental) and information to fully characterise local coastal places
4.7 **Up-skill the sector** through investment in training to reverse the national decline in expertise
4.8 **Resurrect a CoRDDi-type framework** and widely accessible coastal information/research hub
4.9 **Socio-political constraints and levers** to unlock the science needed to support local-scale coastal adaptation within a joined-up national context

Appendix A specifically looks at some opportunities in this field with respect to Coastal Partnership East's activities at the time when the study fieldwork was carried out in summer 2021. Note that owing to some delays in the write-up of this work, associated workplans and discussions may have evolved or changed so this material may not be up to date at the time of report completion.

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4.1 Depending on historic rates of erosion is not enough

Sea-level rise, falling beach levels, new defence options or removal of defences, and adaptation choices all present challenges before unseen.

North Norfolk (and to some extent Suffolk) may actually have a relatively sophisticated understanding of their coastal system compared with other places in the UK which also face significant coastal change, e.g. the Isle of Wight (IOW). This is because of past research interest in the area, including the Tyndall Coastal Simulator work. In most places erosion analysis has been relatively crude, just based on extrapolation of historic trends and observation of changes such as beach lowering, scheme-based assessments and the limited information available in the SMP. But there are many unknowns on erosive coasts, for example how sections are likely to change where defence structures may be ageing, failing and/or allowed to fail in line with SMP policy.

Analysing historical trends is important but may miss system feedbacks, trends or changes in dynamics that could become more significant in future. For cliffed frontages that have been defended for many decades, there may not be any data or information on record on baseline or 'natural' change in these locations. For cliffs defended at the toe and therefore not eroding due to coastal processes, we still need to know about the character of these cliffs to manage both residual risks from drainage/groundwater as well as likely future evolution if the SMP policy is due to change so any past monitoring data is still critical.

Beach lowering and the changing character of beach material is a factor in North Norfolk. Here, the long-shore drift travels from west to east; flint shingle is being transported onto the beaches east and has, for example, changed the character and behaviour of the previously sandy beach on the Cromer frontage. This has implications for the resilience of the existing coastal defence structures there and requires an unforeseen maintenance load as flint has a fiercer effect on the concrete than sand during high sea conditions. This observation is only known based on the recent past.

So coastal managers need to know more about where and how quickly beach levels might drop, what levels they may drop to and where the sediment is likely to go – if so, will some beaches change in physical character and what might this mean for the assets, structures and geomorphology in those locations? What could 1/100, 1/500 and 1/1000 year storm damage look like?

These considerations sit somewhere in between the day-to-day demands of beach and operational coastal management demands and strategic adaptation planning aspirations – see section 3.9 for more on this.

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4.2 Sediment transport, processes and natural erosion management

Mapping and quantifying nearshore transportable source material – the amount of sand, gravel and fine material that moves along the coast in the near-shore area – would support much strategic coastal management decision-making. This relates to many of the points made in this report so far about our difficulty in understanding sediment transport processes, and our need to do this better.

Understanding sediment transport is critical if we are to progress with promoting the principles of, and practically delivering 'natural erosion management'. We know that protecting one part of a coastal frontage means holding back material that may naturally provide a beach (and thus protection) elsewhere. Equally that in the SMPs some frontages have managed realignment or no active intervention policies because they provide down-drift sediment to another community. Quantifying and valuing these coastal system dependencies and relationships would be beneficial in future to:

- Ascribe a quantitative measure of the value of land lost in acknowledgement of the cost of managing a transition process for these locations. In other words, recognising the benefit brought by allowing a frontage to erode.
- Understand better how we might use sediment transport processes more strategically for protection elsewhere in the system, i.e. linking what is happening in one place to what is happening in another.
- Align the erosion context with well-established funding streams and understanding around natural *flood* management.

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4.3 Up-to-date methods for understanding overtopping

The key method (EurOtop[43]) for understanding overtopping only applies to defence structures, not for beaches or other natural features. The Environment Agency has been notified but this topic tends to drop down the priority list.

[43] http://www.overtopping-manual.com/; https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/updated-wave-overtopping-and-assessment-manual-eurotop-and-calculation-tool-bayonet-gpe

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4.4 Long-term regional-scale holistic modelling capability

Section 3.3 reflects on the scale of coastal modelling activities, and notes that for England, there are few examples of regional or sub-regional coastal system scale modelling or holistic assessments to help coastal managers and other parties understand how dynamic coastal systems could evolve.

Few examples exist

The Tyndall coastal simulator is one example of a regional system assessment which projected forward as far as 100 years hence (although this was done a long time ago - see section 2.2.2). Box 4.4a gives some examples of this scale of modelling work done for the BCP frontage where expertise and resource have been available to enable this. For the Sandscaping Scheme implemented in North Norfolk in 2019, a long-term model was developed which was not entirely regional but extended beyond the immediate scheme frontage; this demonstrated that in an early scenario where the sand might have been placed further north, the scheme delivered a lot less benefit than was envisaged. This was a good example of a new development with a model capable of dealing with large spatial scales over a long period of time, and which was holistic so incorporated the shore platform as well as the beach and the cliff. Some unique insights were gained through this exercise into the prospect of a large-scale nourishment – the value of having a large-scale and long-term model was very apparent.

Need for whole system recognition

Where regional-scale modelling was raised as a coastal processes science gap, interviewees spoke about their need to understand coastal systems over broad, regional-scale frontages. This is what is required to inform an understanding of how whole frontages might change over time, and thus, appropriate adaptation choices and planning. This focus is on coastal systems, regardless of political or administrative boundaries. We could term this 'whole system recognition'.

Things have moved on a lot over the last 20 years to better enable this through the SMP and coastal partnership approaches but there is further to go in a way that may not be captured by the NCERM2 and SMP Refresh and Explorer projects. Box 4.4b presents the concept of creating a digital twin for the North Norfolk frontage.

Quantifying and valuing sediment released into the system

Having system scale capability, and modelling outputs at a regional scale could assist in acknowledging and quantifying the value of sediment supplied into the system from eroding locations. This sediment fulfils a crucial function by providing beach material plays a role in natural protection elsewhere (both erosion and flood risk, by building up beaches beneath soft cliffs or low-lying frontages).

Data integration extents

A data integration tool that could also incorporate some socio-economic information about the coast into coastal assessments would be valuable. Ideally this would enable some manipulation to explore the potential impact of adaptation. The aim of this would be purely as a decision-support tool not a model – assumptions would be substantial and need to be explicit.

Capability and capacity

One key issue is whether potential users would have capability and capacity or expertise in-house to obtain or run the necessary software and interpret the outputs (in whatever form – a further field for investigation) – see more in section 3.6.

Stepping back, within the realm of research and consultancy this is also a factor. Often there are not suitable tools to do a piece of data analysis or modelling so people with the right skills, expertise and experience are needed – expertise cannot always be codified! Sometimes trying to tackle a problem with multiple interactions simply requires people who understand.

Box 4.4a. Example of recent regional coastal assessment work by BCP

- Two Bays model: a regional hydrodynamic and sediment transport model refined for Poole and Christchurch Bays which has many applications, one of which is to look at different re-nourishment scenarios (e.g., a Sandscaping type approach). This kind of regional numerical model could be developed elsewhere.
- Sediment transport model: builds upon the SCOPAC sediment transport study (see section 2.1.10), which has been evolved over the last 15 years and builds upon the conceptual understandings from modelling, monitoring data review and literature to come up with a sediment transport budget and pathways. BCP has used the new model to sense-check that and vice versa. Use of the model and understanding the outputs depends on geomorphological assessment by experts who understand the processes and data to interpret it; BCP Council has invested in this experience and can now use the model in-house to explore different scenarios.
- Developing a new cliff management study for the BCP frontage: first stage is to map the geology and hazards posed to underpin a less reactive and more proactive approach going forward to understanding and managing the cliffed frontage, which although defended at the toe in most places, is still susceptible to slips and falls driven by drainage and groundwater issues. BCP has appointed a specialist Principal Engineering Geologist in-house to lead on this strategy and related matters.
- There is an important point to be made here about team capacity – see Section 3.6 for more on this.

Box 4.4b. Potential to build a Norfolk coast digital twin

It would be interesting and possible to set up a standing model of the Norfolk coast that could be maintained, in other words, *a digital twin.*

- This would need to be hosted by a university or the CCO for example, where it could be semi-automated and driven by wave observation and other data. It could then tick along predicting risk – shore and cliff top position – and the likelihood of failure.
- It would need to be based upon open-source tools like SCAPE or CoastalME (see Section 2.1.5). Input files such as wave data need to be purchased or provided on the understanding that this data can be used for approx. 5-10 years for simulations by different parties. More data is open source now which makes this less of an issue.
- Calibration and validation:
  - It would be important to regularly observe what the skill of the model in replicating real change. If and when this accuracy decays, a re-calibration would be needed.
  - Calibration is the time-consuming element, which would need to be separated out from the general running of the model and creation of future simulations.
- Using it to run scenarios would be possible: this could be set up on the web and anybody could choose to put defences in and out and run as many simulations as they wanted.

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4.5 Creating an interactive tool

Creating a coastal assessment tool coastal managers could interact with directly would be useful for strategic planning purposes.

Some coastal management interviewees described an 'ideal world tool', which could be helpful in helping them to understand the potential significance of, and interplay between, drivers of coastal change on a coast where erosion is non-linear. This would be an interactive assessment tool that could enable a user to manipulate linked drivers and inputs or different scenarios at a regional system scale. For example, how might the regional system respond and evolve if:

- Defences were removed and sediment released in some locations
- Prevailing wind and wave directions and wave heights changed
- Different sea level rise scenarios came to pass
- Beaches continued to lower or a ness system or headland forms

Being able to do this would have great value from an adaptation planning perspective because it would enable:

- Better understanding of key coastal system dynamics (with a view to looking out for changes in observed trends and thus potential increases in erosion risk)
- Exploration of how climate change scenarios may affect coastal dynamics
- Identification of likely future erosion hotspots and areas where detailed investigation is needed
- A sense of broad system responses to different management choices (including the addition or removal of FCERM structures)
- Focussing of questions that need to be asked

> *"Being able to demonstrate what the impacts of different management options could be and therefore why we may or may not want to take it would feed in well to the adaptation pathways approach that we want to take."*
> Interview A9

> *"You could use it with people to look at how things might evolve - to give others an understanding of uncertainties and what may prompt the system to behave in different ways."*
> Interview A9

Enabling this kind of 'what-if' exploratory analysis, or simple sensitivity analysis, at an early stage in the adaptation process would help coastal managers understand feedbacks and interactions in the system and could be a good basis for outsourcing more detailed technical analyses to consultants (with questions well defined). It fits well conceptually with the adaptation pathways approach as well.

Nothing quite like this has been developed to date because of the complexities in the system, particularly south of Winterton in East Norfolk, and into the Suffolk frontage. See Section 3.2. It is critical to remember that different types of tool are fit for different purposes and this has to be an up-front and critical consideration before investment is made. It may not be possible to create one single product or model – but it is possible to think differently about how to enable what is needed through an integrated assessment. This would have to be very location specific and would require investment initially to capture a good baseline.

There are different ways of accessing the knowledge and components to build a tool of this kind but there is a sense that it could be feasible for North Norfolk and could be developed given funding and careful consideration as to the aims, purpose, intended application and types of output. The fact that the North Norfolk coast has been so heavily monitored and studied before increases the possibility of doing this kind of work – a feasible budget would need to be scoped - £100K was mentioned as a ball-park figure. Creating a tool along the lines of that described above for places other than Norfolk could be possible, but there may not be the same level of data available. The TCS, Scape and other [integrated assessment] models having been applied to Norfolk in the past mean that there are unlikely to be any major surprises in terms of results, but for other places there is less expectation around what kind of results any model might produce.

> *"Cost estimates can be infinite but potentially for around £100K it may be possible to develop something like this for Norfolk here a lot of work already exists – but this would need scoping with the right people."*
> Interview A1

This kind of tool or some of the outputs could possibly also play a role in providing resources for local community engagement on adapting the coast. It could potentially be used with other audiences and as a communications or local engagement or education tool to give others an understanding of uncertainties and what kinds of management choices may prompt the system to behave in different ways. A tool like this could also be used periodically/routinely by consultants to produce some kind of regular trends or outlook reporting.

> *"It is conceivable to do an assessment for any location where you build up different elements with data to demonstrate what is seen in terms of trends occurring, plus other offshore information about the sediment and sediment budget. Using those it could be possible to predict how the system could change in the future. Effectively you would say that on the basis of what we then see, we might expect or anticipate certain changes. You could play with the inputs to see what changes and as extra monitoring data is acquired year on year, inputs can be altered to understand trigger points and likely timings."*
> Interview A3

FutureCoast (see section 2.2.1) was mentioned as being a great concept and way of taking people through what could happen on their frontage. It was originally designed to be reasonably interactive with some virtual tools built in – this has promise in the view of some coastal managers and consultants. One downside was that it relied heavily on the information put in, and there is uncertainty over whether regionally we have the best available information to input. However, since its original development, we have a much fuller and longer data record. Thus, the idea of FutureCoast could warrant some follow-up investigation at a national scale by those with more expertise and knowledge of the work. Certainly, conducting a baselining update exercise on the same principle as FutureCoast would be well-placed to provide all local authorities and coastal partnerships with a good baseline and something that they could use on a regular basis.

Future initiatives of this kind certainly need to consider a) modelling, b) data access/ownership, and c) interface accessibility:

- Developing coastal models is just one (albeit challenging) aspect of the work
- Accessible data is a separate issue and what makes it place specific – is what is freely available through the coastal monitoring programme enough?
- Would need to interface with the GIS tools available to local authorities, to ensure it could interface with the planning system, NCERM2, SMP information, etc.

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4.6 Mechanisms for mapping regional baseline data

Mapped social, economic and environmental and other information to fully characterise local coastal places.

Coastal management is multi-disciplinary, a sustainable development issue which fundamentally concerns physical environmental processes, but these do not occur in a vacuum – they are intrinsically related to the socio-economic context of any coastal frontage. Indeed coastal change becomes political because the remit and responsibilities that coastal management authorities and other institutions have on the coast are guided by national policy, a legacy of past development decisions and so on. In thinking strategically about the future, it is critical to have a full picture of a place: to understand what gives any locality its character and what underpins its vulnerabilities. For example, local assets (historic, grey, green, defence, social, etc.), demographics (underpinning vulnerability), development, natural habitats and other things.

A useful resource would be to have a GIS based system where management authorities could combine, map and access all relevant and available baseline information. Being able to identify a place on the map and extract a broad range of data and information to characterise a locality would be extremely valuable (perhaps also including a layer including area-specific research, surveys, local reports, trends reports, etc.).

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4.7 Up-skill the sector

Through investment in training to reverse the national decline in expertise.

Nationally, there are fairly few people – across local government, private sector consultancies and academia – who have good expertise in coastal change science (very few people are competent to run a SCAPE model or CoastalME for example). Nationally, this is a bottleneck to progress and relates to both the technical (using or understanding the outputs of coastal change/assessment models) and adaptation aspects of coastal management.

The point made in section 3.6 about appropriate capability and expertise within coastal management teams is related to this. Having trained in-house specialists in coastal partnerships (e.g., an approach being taken by BCP Council) could become possible and would streamline the link between the hard science and delivery of coastal management challenges. Partnerships and local authorities linking up to share resources may also be a model for working on this in the future.

Expertise in government agencies, departments and authorities is important (e.g. County Council Highways Teams, Network Rail, Utilities, Natural England, Historic England, etc.). This is because bottlenecks can be caused when projects need review/input from under-resourced or capacity-lacking bodies.

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4.8 Resurrect a CoRDDi-type framework

The importance of good knowledge co-development mechanisms is critical to enabling progress in impactful coastal processes science. Investment and interest in this field is evolving rapidly and there are some particularly effective networks around the policy-practice interface, but these do not appear to have strong links into the coastal processes science community; or perhaps there are some very strong ad-hoc links between various coastal partnerships or coastal local authorities and particular academic institutions for example, but this tends to be based upon the geographic circumstances or interest/contacts of key individuals and is not 'mainstream'.

Many interviewees talked enthusiastically about the value of resurrecting a CoRDDi-type framework based on experience of a historic initiative by the Environment Agency which went by this name. See section 6.3.2 for more on this.

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4.9 Socio-political levers

Unlocking the science needed to support local-scale coastal adaptation within a joined-up national context.

Any contemporary technical discussion around coastal processes or coastal change will inevitably touch upon the socio-political issues around adapting to coastal erosion. Socio-political factors are integral to how we progress the scientific agenda – what elements of coastal processes do we want and need to understand more about? Why? And how will this information help inform future transitions as soft coastlines inevitably retreat?

4.9.1 The non-statutory status of SMPs and role of CCMAs
4.9.2 Absence of an effective national policy delivery framework including guidance and funding
4.9.3 Adaptation is not yet an established FCERM option
4.9.4 Adaptation to coastal change goes beyond coastal management
4.9.5 Short-term political interests and expectations of permanence

Other publications address these points in a great deal more detail (not least the CCC, 2018[44]). Here they are noted specifically in relation to reflections from the reported study on advancing coastal processes science in England in a way that supports our aspirations to mainstream the delivery of coastal transitions, adaptation and resilience. In this instance, these socio-political factors are intentionally termed 'levers' because they are sometimes constraints or limits to progress, but have great potential as accelerators of opportunity.

4.9.1 The non-statutory and hidden nature of SMPs, and the role of CCMAs

Shoreline Management Plans (SMPs) outline a strategic trajectory which should be followed regardless of economics but SMPs are non-statutory, however not every SMP has a corresponding management strategy. Also, at present SMPs are hard to access as the key information is buried in complicated documents hosted on regional coastal group web pages in PDF documents. It is not obvious what the key issues and needs are within the SMP units or where adaptation plans are really needed. This should change with the development of the SMP Explorer (section 2.1.2) and standardised action plan template. Presently the action plans associated with SMPs haven't been kept up to date consistently due to lack of institutional ownership.

"It can feel like what's the point of having the SMP sometimes… because they are non-statutory they can be made to fit whatever narrative you want. Politics does rule the day with its short-term views at the local level."
Interview B13

The non-statutory status of SMPs is problematic in terms of delivering adaptive coastal management because it leads to an ad-hoc and inconsistent uptake of SMP outlooks in town and country planning and other sectors. In some places, SMPs are strongly embedded in local planning processes, but this is not the case everywhere.

Local political priorities operate on short-term cycles, and often SMPs do not fit the political 'vote-winning' narrative where they have difficult implications (see section 4.9). This means that sometimes policy units which strategically are put forward as No Active Intervention units for example, can end up only being adopted under a Hold the Line policy because of political controversy and pressure.

In the national planning policy framework, it is recommended that places at risk of significant change should have Coastal Change Management Areas (CCMA) – in brief, zones in at-risk coastal locations defined to limit development occurring there. SMPs therefore do have 'teeth' in CCMAs, because they become material considerations for planning decisions.

"We need to get to a point where adaptation plans accompany CCMA's so that you get to a point where you can actively plan and implement the adaptation for places that are facing increasing risk."
Interview B7

[44] https://www.theccc.org.uk/wp-content/uploads/2018/10/Managing-the-coast-in-a-changing-climate-October-2018.pdf

New development can be limited where CCMAs are in place, but they don't deal with what is already in those zones. Some interviewees noted that we need to reach a stage where adaptation plans accompany CCMA's to enable proactive planning and implementation of adaptation options for places that are facing increasing risk (including, for example, temporary use developments to enable local economic activity and community viability in erosion-risk zones). See Kirby et al. (2021)[46] for more context and discussion about the role of CCMAs in England.

4.9.2 Absence of an effective national policy delivery framework including guidance and funding

Ultimately there is a fundamental need for national policy and guidance to underpin an adaptive coastal management delivery framework. This includes working towards, for example:

> *"We still need to get erosion risk much more front and centre in the national thinking to help us do what we are trying to do locally. The Coastal SIG is very important and is giving us a vehicle to get things done at a national level. It doesn't work at a local level without that national framework."*
> Interview B9

- Bringing the erodible coast to a level alongside our capacity to manage and plan for the flood coast
- More enmeshed engagement with the Department for Levelling Up, Housing and Communities (previously Ministry of Housing, Communities and Local Government) – see also section 4.9.4
- Advancing projects such as CLIFF around innovative funding and finance to identify both public and private sector funding and finance solutions
- Critiquing powers within the Coastal Protection Act to ensure that they enable rather than constrain coastal risk management authorities to deliver on adaptation.

Funding is a unanimously cited constraint to delivering adaptation, and links to the need for more investment in research around coastal change adaptation challenges, and importantly how these transparently link to outcomes that bring funding – see also section 4.9.3.

> *"There is the knowledge and understanding as to how you can manage quite a few of the situations that we're facing as a region. But how you fund solutions for those is far more uncertain and unclear. That's the difficulty."*
> Interview B5

4.9.3 Adaptation is not yet an established FCERM option

Coastal partnerships and local authority teams in many locations are working hard, with the Environment Agency to establish adaptation as a credible FCERM option but at the moment we do not have clear policy and guidance to enable this.

> *"The view has always been that by moving a property, you are not protecting it but re-building it and therefore you can't claim OM3. I prefer the wording 'households better protected'…I should be able to claim if I move a household out of the risk zone."*
> Interview B4

Although the language is shifting away from protection, defence and resistance toward narratives around adaptation, transition and resilience, our national FCERM status quo in practice still focusses on the protection of homes. It does not enable place-based approaches to be taken yet, which deliver wider benefits beyond simply protecting property (see point 4.9.4). The current outcome measure arrangements mean that funding options favour defence (protection of homes) because this is how FCERM funds are allocated at present – not yet to adaptation. Where there are managed realignment or no active intervention policies where people live, there is no corresponding way of appraising any kind of scheme. In other words, we have not yet been able to use Grant-In-Aid (GIA) funding effectively for adaptation.

Work is underway to address this including via the CTAP and FCRIP programmes for example. In the future this is going to be important, particularly taking into account the likely impacts of climate change which may render a number of locations uninhabitable. We collectively need to think about options like rollback and relocation for both erosion and flood frontages, and thus GIA options which enable protection of 'households' rather than property as such.

Some would say that the coastal practitioner community already know what is needed to deliver adaptation, and that it is socio-political factors that constrain this rather than the availability of science or data (including lack of capacity, see sections 3.6 and 4.7). There is certainly a necessity to assemble information and good evidence to improve the case for funding adaptation and there two obvious key types of information relevant here:

- Technical information such as the intended outputs of NCERM2 to identify the likely properties, land and other assets that will be lost over various future epochs
- Quantification of the benefits of adaptation – versus the costs over time of doing 'nothing'

4.9.4 Adaptation to coastal change goes beyond coastal management

Adaptation to coastal change is bigger than coastal management; it is about the viability and sustainability of all facets of coastal places. Community cohesion, connectivity and so on are at stake if there is what could be perceived to be a small amount of loss. Erosion zones can be defined on the basis of physically defined risk bands, but it is very apparent in trying to understand what is needed for delivering adaptation for resilient future coastal communities that every element of local and County level government must be integrated into addressing the coastal change challenge.

> *"We want to deliver place-based approaches with wider benefits, not just protecting homes. Just because with flood or erosion risk we can't afford to protect, doesn't mean we don't want to help communities in the longer term. It's not about traditional outcome measures for us."*
> Interview B13

> *"Even somewhere like Sheringham for example, we are seeing and noticing the beaches dropping. What are the repercussions of this? It is not just about the sea defences, it is about tourism and all the other things."*
> Interview A9

The point made in section 4.9.3 above about the language being used in this context is important here in too. Although we are moving toward talking about transitions, resilience, viability and so on, the technical terms around coastal change are still very focussed on loss and are militaristic in tone; hold the line, managed retreat, no active intervention, defence, protection. This can be unhelpful in conversations about likely future change and what local options might. The language tends to focus the issue on the physical coastline not the functioning of the wider coastal zone and communities that are part of this.

4.9.5 Short-term political interests and expectations of permanence

> *"The short-term views that political cycles bring with them are a massive barrier to conversations around adaptation and things like that because it doesn't fit with winning votes...there could be a change but perhaps only after a massive catastrophe where recovery to the status quo is simply not feasible."*
> Interview B13

At both national and local scales there is a resistance to working across boundaries, and to addressing difficult discussions about coastal futures. The short termism brought by political cycles is a huge barrier to conversations around adaptation because this is so challenging. This has led to a palpable sense of fatigue amongst interviewees that despite periods of progress and proven benefit around adaptation options (e.g., the Pathfinder programme, 2009-11[45]) the government hasn't appeared to act upon or promote learning from these. Thus the work is at risk of duplication or re-invention in other locations at great cost, or opportunities for collaboration and learning are missed.

There is now an all-party parliamentary group (APPG) for coastal communities[46] which was established in 2019 which is raising awareness at the national political scale. And lobbying by the coastal management community for a coastal minister in government.

Expectation of protection and a fixed coastline is also widespread. In the East, this is probably in part due to the legacy of coastal 'control' since the 1950's. It is hard to communicate why hard defence (particularly where there are ageing defences which will not be replaced and may even undergo planned removal) is not a sensible nor aesthetically pleasing plan. Despite the current political reluctance, these difficult conversations do need to be had.

> *"It's not that we don't have enough data. It's that there hasn't necessarily been the socio-political will to deliver when it comes to adaptation."*
> Interview B4

Moves to use the term coastal change in place of erosion are welcomed by some, for example because many see erosion as a local authority problem and switch off from it whereas coastal change puts a different perspective on the issue) and contested by others ('call it what it is').

Concern was voiced in this study that it will take a catastrophic event to substantially focus attention at the coast. But also worry that the political narrative would still, a) continue to focus on maintaining the status quo around protection rather than adaptation and taking an opportunity to build back differently, and b) continue to draw upon the narrative around needing to avoid compensation rather than accept that although adaptation is complicated, it needs to be properly funded.

> *"There is an ongoing lack of recognition of the long-term benefit of investing in adaptation…Our window of opportunity to be proactive in many places is shrinking."*
> Interview B7

Adaptation to coastal change has been talked about for more than 20 years and is becoming urgent. The ongoing lack of political recognition of the long-term benefit of investing in adaptation now means that our window of opportunity to be proactive in many places is shrinking fast. We face reaching a point where many more properties and infrastructural assets are at acute risk and we continue to be forced to be reactive alongside there being significant (and foreseeable) disruption to local communities and economies because local authorities have been unable to implement adaptation actions that they have long-known were needed. These crises will become more expensive to deal with and perpetuate reactive decisions that won't solve the problem.

[45] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69508/pb13720-coastal-pathfinder-review.pdf
[46] https://www.parallelparliament.co.uk/APPG/coastal-communities

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Theme Summary A: Coastal Processes Science

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The full report documents a list of key projects that are currently ongoing, and some that have been notable in setting the current scene around how we understand coastal processes in England. This is a rapid review so includes national projects and some more applied examples but may not capture all relevant work underway. They include the National Coastal Erosion Risk Mapping 2 project, Shoreline Management Plan Refresh and Explorer and other studies in train through the Environment Agency and Defra's joint research programme, as well as academic research and studies conducted through coastal partnerships or other organisations. Research in this field is developing rapidly so the information included is accurate as of summer to autumn 2021 when the study research was undertaken.

Through the process of questioning what is being done and how we 'do' coastal processes science in England – how we interpret it and how we apply this knowledge and expertise – some key over-arching challenges emerge:

- Balancing uncertainty and precision: Accepting future uncertainty in coastal change projections but planning with certainty for obvious trends
- Dynamic system complexity: A complicated and dynamic coastal frontage (as Norfolk and Suffolk is) is difficult to model and requires innovation and interpretive assessments
- Scale of analysis: No one-size-fits-all approach to assessing erosion risk. National assessments can identify hotspots; local analyses work at a scheme level. There are few regional system scale examples.
- Relative importance and interaction of different coastal change drivers: Including sea-level rise, wave changes and local geology
- Coastal catch-up following beach nourishment as well as hard structure failure/removal
- Appropriate capability and expertise: Both technical and on adaptation (including community engagement expertise)
- Asking the right questions of the science: Practitioners need to be informed and intelligent 'clients' with time to engage with and understand the science so that it is effective
- Adaptation choices are critical: adaptation is a key factor influencing the form of any future coast including cliff position
- Resourcing both short-term and strategic coastal management: How we balance and allocate FCERM funding for short-term coastal management as well as long-term strategic planning
- Importance of investing in innovation: Investing in research is critical for making progress.

The key points which arose in conversations with interviewees about gaps and opportunities in coastal processes science and its applications going forward are:

- Depending on historic rates of erosion is not enough; sea-level rise, falling beach levels, new defence options or removal of defences, and adaptation choices all present challenges before unseen
- Sediment transport and natural erosion management: Mapping near-shore transportable source material to support more strategic coastal management planning
- Up-to-date methods for understanding overtopping
- Long-term regional-scale holistic modelling capability is needed to understand coastal systems
- Creating (regional) coastal change assessment tool that coastal managers can explore would be useful for strategic planning purposes
- Mechanisms for mapping regional baseline data (social, economic and environmental) and information to fully characterise local coastal places
- Up-skill the sector through investment in training to reverse the national decline in expertise
- Resurrect a CoRDDi type framework and widely accessible coastal information/research hub
- Socio-political constraints and levers to unlock the science needed to support local-scale coastal adaptation within a joined-up national context.

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5. Coastal Monitoring and Data

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How do we currently monitor and collect data about our coast? In assessments of coastal change, what kind of data is most important and where are there gaps? Where is there potential to get better monitoring for data which allows more innovation in modelling? This section these questions and presents a sense of where we are to date with coastal monitoring and data, and near-future outlooks.

In general, England is deemed unanimously by interviewees as having a good approach to monitoring and data compared to other places worldwide. This has dramatically improved in the last 20 years with the establishment of the National Coastal Monitoring Programme, which is perceived to be an extremely valuable source of long-term coastal monitoring data. Previously, approaches to coastal monitoring were inconsistent and unstandardised, and much data was held behind pay-walls meaning that it was relatively inaccessible. Now we have good resolution, openly accessible, full coverage of the coast including digital terrain models (DTM's), lidar data, bathymetry and topography.

This section begins with an explanation of the key coastal monitoring and data initiatives and programmes followed by a brief capture of some of the key data and information needs as expressed by some of the technical experts interviewed as part of this work. Sections 5.3-5 examine what the key gaps, opportunities and challenges may be in the realm of coastal monitoring and data, as perceived by interviewees. In summary:

5.3 Monitoring, data and information gaps

- 'White Ribbon' - gap between bathymetry and lidar coverage
- Shallow sub-surface
- Shore platform
- Sediment fluxes
- Impact of interventions
- Register of coastal assets
- Monitored distance offshore
- Beach dynamics and storms
- Need for more trends analysis and current limitations
- R&D to enable better data use

5.4 Emerging opportunities in coastal monitoring & data

- Seismic monitoring of cliff erosion and telemetry tools
- Laser scanning
- Earth observation via satellite derived data
- Use of drones and autonomous surface vehicles (ASV's)
- Marine synoptic radar systems
- Use of 5G
- Interpretation and visualisation

5.5 Ongoing coastal monitoring & data challenges

- Uncertainty around advance monitoring needs to support adaptation
- Capacity and expertise
- Need for long-term data sets to make future projections
- Data size and storage
- Non geophysical data needs and restrictions on accessibility of data

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5.1 Key initiatives and programmes

Presently the two key sources of data about coastal processes come via the National Coastal Monitoring Programme and through the work and data collection carried out by the British Geological Survey. For more in-depth information and signposting for the full range of sources of coastal data, refer to the UKHO project, 'Improving our understanding of the UK's Coastlines' as outlined in section 2.1.9.

5.1.1 National Coastal Monitoring Programme (NCMP)[47]

The Channel Coast Observatory (CCO) lead the national network of regional coastal monitoring programmes of England[48] and host the national coastal monitoring website. This national network was established in 2011. It comprises 6 areas, or regional programmes (in the east, the Anglian Coastal Monitoring Programme – see Box 5.1), which are all undertaking coastal monitoring expressly to provide the evidence that is needed to underpin flood and coastal erosion risk management.

> *"The programme was robustly set up. I think that 20 years on it is doing exactly the job that it should be doing. We would always love to see more data but you have to be realistic…It would be impossible to do what we do without the regional monitoring data that we have, but do we need more? I think it needs to be proportionate to what we are trying to deliver."*
> Interview B13

This network of regional coastal monitoring programmes is cohesive and closely connected to share learning. Some of the regional programmes began collecting data under different institutional arrangements many years earlier but it is only since 2011 that the approach has been standardised and co-ordinated as a national programme. Some of this metadata is included in the national coastal monitoring data archive as long as it meets the necessary standards. The regional programmes are all set up and run slightly differently, some with more or fewer people on their teams with different types of expertise. The Southeast and Southwest programmes have particularly well-resourced and strong teams, with the breadth of knowledge to be able to do strong analytical work and detailed reports for their local authorities (not so possible in the ACM, see Box 5.1).

The NCMP network is funded through the Environment Agency's grant-in-aid scheme in phases (a six-year phase has just started, in 2021). The NCMP works closely with the regional Coastal Groups to ensure that the programme is supplying the information needed. Every six years the regional programmes and national lead prepare a review and business case for the next phase, identifying objectives and needs going forward to ensure that all the monitoring is consistent and fit-for-purpose by region. It was suggested by some interviewees that it may be appropriate to do an independent review at some stage in the coming years to assess the types of data available, what else may be needed, and whether the programme needs more substantial funding.

The regional structure enables close working with the coastal groups to ensure a strategic overview of the types of data that need to be collected, consistency in the ways in which collected, stored, archived and made available. All the regional monitoring programmes abide by a set of standards and various quality control procedures so that the data collected nationally is at the same specification to facilitate research and analysis across the whole of England.

Standard data collected by the National Coastal Monitoring Programme and available on the national coastal monitoring website includes:

- Topographic data: beach change, beach volumes.
- Bathymetric data (very expensive)
- Lidar

[47] https://coastalmonitoring.org/
[48] There is a Welsh observatory, which the NCMP works closely with. Northern Ireland are also potentially setting up an observatory, defining coastal cells and starting to map historical change.

- Aerial photography (this is used for habitat mapping as well) and includes historic data going back to the 1040's that has been digitised and archived.
- Data on the drivers of change - wave buoys, tide gauges and met stations (these enable analysis of relationships between wave and tide conditions)
- Ad hoc or periodic surveys:
- Cliff mapping in some areas
- Post-storm surveys (including historic data for example that collected following the 1953 storm surge)
- The current monitoring phase is developing a national register of man-made coastal assets. Natural coastal assets are well mapped; the mapping for man-made ones is more incomplete.

Whilst the types of data collected are consistent and standardized, there is also some flexibility to address different problems at local scales as the frequency and spatial distribution of the monitoring is risk based (additionally in some locations there is local capacity to do some in-house surveying but not everywhere has this). The whole of the coastline is split up into survey units; each of those is assessed based on geology, exposure to waves and tides, assets, and policies in place so that a score can be assigned, and a judgement can be made accordingly about the frequency and distribution of surveying. A good example is East Riding of Yorkshire where cliff erosion is so rapid that more frequent LIDAR surveys are flown than elsewhere because there is a specific need.

> *"We use the monitoring data in every single study we do – it is critical to what we do. In some places it has meant that we can move away from proposing that systems need to be modelled because we can get a better sense of what is going on by using the monitoring data. It is excellent and adds huge value."*
> Interview A3

All coastal monitoring data is archived by the CCO and is freely available through the centralised national coastal monitoring website under open government licence, which anybody can access in order to carry out analysis. Users of the data can see how it's been collected and treated so that there is transparency. The CCO does do some basic reporting; some analysis is done by the CCO for example after major storms and they also produce routine annual trends reports. But essentially, they provide the data for other parties to use.

The core function and value of the data is to strategically underpin FCERM activities nationally such as defining coastal flood boundaries, validating flood forecasting models and surge forecasts, and other tools and projects within the Environment Agency (e.g. NCERM2). It has additional benefits and is collated in such a way that it is useable more widely, e.g., for schemes and plans by risk management authorities so that they do not have to collect their own data as they have access to a consistent and long-term data resource. It is also used by consultants and academics, and at local scales for things like beach management, incident response or for informing recovery.

> *"We have a coastal monitoring programme that's that as good a programme probably anywhere in the world in terms of the time scales and the investment into it."*
> Interview A5

The participants interviewed for this work unanimously deemed the national coastal monitoring programme as being a very positive and important part of the progress made in coastal processes science over recent years, and what will be possible going forward. It is worth noting that the programme has also saved the public sector millions of pounds in fees to consultants.

Box 5.1. Coastal monitoring in the Anglian Region

The earliest monitoring work in the Anglian region goes back to the 1980's – the Anglian Coastal Management Atlas was a trailblazing example of coastal monitoring and data collection. As a result, the region has one of the longest strategic monitoring coastal datasets possibly in the world. Aerial photography, topographic profiles and beach profile data for example has been collected since the mid 1990's for some locations.

The current **Anglian Coastal Monitoring Programme (ACM)** was set up in 2011, which has meant that data collection is more standardised and consistent (within and across all the regional programmes).

- The ACM covers the area from the Humber Estuary down to the Thames Estuary and currently has funding through to 2027.
- It is the only one of the six monitoring programmes in England led by the EA – others are led by Local Authorities. This is a main reason why the resourcing for the ACM is not the same as for other programmes around England.
- The ACM is overseen by a group chaired by CPE and delivered through the Environment Agency's geomatics team who do most of the actual monitoring. It is a sub-group of the East Anglian coastal group.
- It is generally deemed to be taking a good approach, balancing the different types of data collection needed (balance between strategic profiles, the proportion of aerial photography and lidar for example).
- There are always elements where more data collection would be useful but this can be very expensive (e.g. bathymetric – current 5 year surveys are adequate).
- Because of a lack of resource, the programme has not been fully functioning over recent years and whilst data has been consistently collected, capacity to do analysis has been limited. Whilst they aim to provide occasional trends reports (approx. every 5 years), this deliverable has not been achieved in recent years due to resourcing constraints – which are now being addressed. The team has recently delivered a trends report and developed a new methodology for doing so, and is investing in resourcing capacity to do other analyses for use by Local Authority coastal management teams depending on what is needed based on local coastal change and upcoming schemes.
- Over the last two years, the ACM has been progressively more interactive in terms of what the customer needs (e.g., EA area and local authority staff).
- Good relationships with the other regional programmes enable a lot of learning in the ACM from innovation in areas where there is more expertise and opportunity.

5.1.2 British Geological Survey (BGS)

The BGS focusses on sub-surface data and hosts various open access data sets. With respect to the coast, BGS is interested in local geology and cliff compositions, beach thickness, sand and gravel profiles, and beach platform information. This sub-surface information is critical for understanding erosion behaviour over time, particularly for East Anglia (e.g., Payo et al. 2018[49]). BGS have, for example, done work looking at the relationship between the 'beach wedge' (area of sand between the mean high water mark and the cliff toe, which is a proxy for beach volume) and the annual recession rate of the cliff top. The data for Suffolk and North Norfolk demonstrates that there is a lot of recession where you have a small area of beach. As beach volume increases, the cliff recession reduces substantially; when you have a beach with enough material, it protects the cliff effectively. When you decrease that amount of sediment then cliffs are more vulnerable to erosion if wave and tide conditions combine in particular ways.

[49] Payo, A, Walkden, M, Ellis, M, Barkwith, A, Favis-Mortlock, D, Kessler, H, and Lee, J. 2018. A quantitative assessment of the annual contribution of platform downwearing to beach sediment budget: Happisburgh, England, UK. Journal of Marine Science and Engineering, 6(4), 113. https://doi.org/10.3390/jmse6040113

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5.2 Needs for coastal change assessments & modelling

There are broadly two types of information used in assessing coastal change – hydrographic (relating to the ocean such as tides and waves which are driving forces of change) and geomorphologic (relating to the earth such as cliffs, sediments and beaches). Within these broad categories, various types of data are collected, and subsequently many types of analyses can be carried out to examine and model interactions between the two (i.e. coastal change). This section attempts to capture the types of data available, used and perceived to be most useful to specialists looking at coastal change and seeking to model future coastal evolution.

5.2.1 Critical information for future coastal change assessments
5.2.2 Useful analyses for informing assessments of coastal change
5.2.3 The value of long-term data sets

5.2.1 Critical information for future coastal change assessments & modelling

Particular examples of necessary baseline information given by technical specialists:

- Location of cliff top
- Location of cliff toe
- Shore/beach profiles – demonstrate size, depth and steepness of beaches; these offer a lot of confidence and can be very precise
- Lidar data which gives 3D snapshots and has many potential applications because it enables a user to generate information about the spatial variability across a frontage.
- Geological composition of cliffs: understanding the geology is a hugely important factor in understanding local beach behaviour, the impacts of storms, cliff falls, etc. This knowledge informs our understanding of the way cliffs erode but also the sediment released and how this behaves in terms of providing beach material vs. mud which does not contribute to beach processes
- Beach platform geology: the material beneath the beach is important as this affects the rate of erosion (a relatively high chalk base means slower erosion)
- Mapped coastal defence assets
- Condition of defence assets and likely lifetime
- Types of intervention
- Hydrodynamic information with long datasets; captures climatic variability

Key types of data for coastal modellers:

- Historic mapping
- Aerial photography
- Satellite information – this area is improving quickly, see section 5.4.3 for more on this:
    - LandSat satellite data (GoogleEarth is based on this), which provides 25-30 years of evidence/observed coastal change at national scale; the lines that can be derived from this information now have similar accuracy to the ones on OS maps but map every few days so there is a lot of data on the rate of change.
    - Crude shoreline position data is available from Deltarus for the last 30 years - not high resolution +/-50metres but still useful and the time series is always getting longer
    - Enables some analysis for any location in the world even if local data has not been collected

Some of this information is available on the national coastal monitoring website, which has been much improved recently to make it more user-friendly. However this does not host other types of information or sources of data that are not standardised as part of the national programme. The recent study by the UKHO examines this issue and make some recommendations – see Section 2.1.9. This includes the need for an additional central website or hub for coastal processes and management information and data signposting.

Sometimes additional surveys have to be commissioned for certain projects, e.g., when there is data which enables analysis of beach changes but not what is happening below the water line, e.g. at Hemsby – see Box 3.2 – where a deep channel is moving toward the shoreline and where there has been accelerated erosion but uncertainty as to whether the two are linked or if the reason for erosion could be an absence of sediment supply.

5.2.2 Key analyses for informing assessments of coastal change

CCO interpretive reports

These are used to summarise trends and link geomorphic trends to weather and storms. Occasional analysis of specific conditions, for example 'bi-modal' sea states. These can be more severe in terms of driving more rapid losses or severe losses during a storm. The CCO are able to run some analysis of their data sets to start mapping out where bimodal seas are more common.

Regional trends analyses

Due to resourcing constraints these have been lacking for the Anglian region over recent years but steps are being taken to rectify this situation, including the outsourcing of some analysis where the ACM team are unable to deliver in-house.

SANDS Asset Management System[50]

Developed by the precursor company to Jacobs and since updated (it was previously called the shoreline and nearshore data system), SANDS is a key piece of software that can capture and store various types of coastal data to do different analyses, to great graphics and trends analyses of change over time. This kind of positional trends analysis is useful in coastal management as it can simply visualise data. National investment in this tool would be effective to further improve its function.

5.2.3 The value of long-term data sets

Adding new types of data is interesting and has a place but can initially be of limited value in the present; long-term data sets are necessary in order to start seeing and analysing trends. We are now starting to see the huge value in having invested in consistent, high-quality data through the national Coastal Monitoring Programme for many years as this provides credible evidence of coastal change.

In the Anglian region we have data going back to the 1990's if not earlier (see Box 5.1), which is proving to be extremely valuable in helping us to understand the regional coastal system. This investment in our lengthening data record needs to continue otherwise we would rapidly go back to square one and waste all the investment that has gone before.

> *"There is huge value in monitoring consistently over a long period of time, including in the lower risk areas where you may need to adapt in future. The baseline data is also really invaluable in understanding how to design schemes going forward."*
> Interview A6

[50] https://www.sandsuser.com/

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5.3 Coastal monitoring & data gaps

Interviewees strongly communicated that the national coastal monitoring programme is effective, and that the timely reviews allow for tweaks within the regions. From a practitioner perspective, the data record is seen as invaluable and critical to what they need to deliver – a lot can be done by people who have the right skills and understanding to analyse and interpret it.

Whether more is needed depends on the perspective of the range of users. More data is always of interest and enables more robust and accurate analyses, but this need has to be balanced with what is possible. From a coastal processes science point of view there are gaps, which would help immeasurably in understanding some of the system complexities better.

Thus, even if there is potential to improve the resolution of data and efficiency in its collection, there are still perceived gaps – in other words, areas of 'user need' – where monitoring remits cross (for example between rivers, estuaries and the open coast). One of the big challenges is in ensuring consistency, in data quality, how conditions are assessed and so on. These are the key areas highlighted by interviewees in this study and explained in more detail in this section:

- 'White Ribbon' - gap between bathymetry and lidar coverage
- Shallow sub-surface
- Shore platform
- Sediment fluxes
- Scheme specific analysis (impact of interventions)
- Register of coastal assets
- Monitored distance offshore
- Beach dynamics and storms
- Need for more trends analysis and current limitations
- R&D to enable better data use

5.3.1 'White Ribbon' - gap between bathymetry and lidar coverage

The 'white ribbon' is the small strip between what is captured by bathymetric and lidar monitoring, which lies just below tide level (i.e., the sub-tidal, or nearshore approach bathymetry). It is not covered by normal bathymetric monitoring because it is too close to the water surface to get picked up by a side scan. It is not covered by lidar from inland because this does not go below the water level. It appears white on data maps, like a ribbon. Whilst challenging to measure, the white ribbon is an important bit of shore in terms of coastal dynamics because this is where most energy dissipation happens. If it changes, (e.g., disappearance or movement of a sand bar), the energy reaching the coast will be significantly affected and this is the factor which drives the onshore changes that we see. To create a seamless topo-bathymetry model, it is necessary to do interpolations in that area. We do not have a nation-wide approach to create a seamless topo-bathymetry dataset, so this is an important priority for coastal modelling purposes.

5.3.2 Shallow sub-surface

We do not currently have a good national capture of how much sand, gravel and fine material lies in cliffs and on the nearshore along our coast to inform predictions of coastal evolution. For some places this can be approximated where there are strong layers of contrasting geology, but elsewhere this is difficult to estimate, e.g., in Happisburgh where the crag formation is similar to the loose material above it but is just more compacted so difficult to measure the thickness of the beach.

5.3.3 Shore platform

This is a big data/information gap. The shore platform is important when it comes to coastal catch-up and when it comes to the coast responding to changes in sea-level. It is not really measured except when there is no beach there at all.

5.3.4 Sediment fluxes

The importance of sediment fluxes is great in unpredictable systems (such as parts of the Norfolk and Suffolk coast) but these are not understood. For patches of the coast, we have the potential to gain more knowledge, beyond the historic trend analysis and expert geomorphological assessment that is currently standard. This would require some investment in medium to long term modelling – in some places there is great value in doing this. For some areas, there is a strong dependence on subtle fluctuations in wave climate:

- Changes in sandbanks can affect the whole pattern of waves arriving at the shore
- This process can affect the transport of sediment along and near the shore
- This can affect sediment offshore, which affects other things

5.3.5 Scheme specific analysis (impact of interventions)

An area for improvement in monitoring is of the impact of coastal management schemes or interventions, particularly in cases where sediment is introduced through beach nourishment or moved around (e.g., shifting sediment from one side of a groyne to the other). Some interviewees suggested that currently, the monitoring of coastal management interventions tends to be too short and too localised; there will usually be a strong focus on the actual location of a scheme over a short time. Relatively little monitoring focuses on the up- and down-drift areas and in the 3 dimensions (including down into the seabed) while systems are still evolving and before dynamic equilibrium has been reached.

The regional monitoring programmes do seek to enable this through the six-yearly review process, which identifies things within each regional frontage that are likely to change (schemes, projects, hotspots). The Benacre managed realignment project in Suffolk is a good example of a scheme that will require significant and detailed monitoring, and this is factored into the current phase of the ACM Programme. However, the monitoring of new interventions is often funded separately to mainstream monitoring through the NCMP because a higher resolution and frequency of data collection is needed. Usually, funds are allocated for monitoring over the first few years of a scheme, but as noted above, too often this is not long enough to understand the behaviour or influence of an intervention on the surrounding system.

In future innovative or new types of schemes, there is an opportunity to do more scheme specific monitoring and analysis to help show how these interventions behave in the system and inform future decisions. It is thus important that monitoring establishes a sound baseline and takes an adequately broad view over time and space, also so that unexpected benefits and other influences (such as temporary impacts from unexpected fluctuations in prevailing conditions) can also be captured. It is necessary to enable dynamic monitoring to really understand what success looks like in those sorts of schemes. It is also crucial to involve the relevant regional monitoring programme, in this case the ACM, at an early stage in the design of schemes so that better monitoring can be tailored to help understand the performance and success of any scheme.

5.3.6 Register of coastal assets

The NCMP is in the progress of establishing a register of coastal defence assets.

- This will be useful but will not necessarily consider assets that are not explicitly designed for coastal defence, but which serve as a defence. These may be owned by many different parties, and some do not have an owner because they are historic structures. Understanding what is there, ownership and maintenance status is complex.
- Local authorities do not all apply the same standards as the EA, so national reporting of asset condition through the monitoring programme will need to define standards carefully.

5.3.7 Monitored distance off-shore

Dutch monitoring includes beach profiles up to 8 metres sea depth, every 500m about twice a year. And much less frequently they collect profiles that go out to 16 metres depth and that means you are way out into the sea – 5 or 6 kilometres. This is not the case in the UK.

The ACM was originally supposed to do annual profiles out to 1km offshore every 5 years but they have been missed from time to time – increasingly this bathymetric information about the sea bed is becoming critical in understanding the changing system so the hope is that this data collection will not be missed in future.

5.3.8 Beach dynamics and storms

Some 'fantastic' models exist that can replicate beach drawdown during a storm, but not how a beach builds up again. This kind of thing is an important dynamic in local beach behaviour in many locations around CPE's frontage. More generally, having better understanding about the role that dynamic beach volumes play in coastal change processes is really important because at the moment a static profile is often assumed.

It is essential to have good pre- and post- storm data and to enable more monitoring around those events, and to develop techniques that enable this in an affordable way. The collection of storm-related data is built into the flexibility that the regional monitoring programmes have.

5.3.9 Need for more trends data analysis and current limitations

Having appropriate, standardised and consistent data is important, but analyses of many types are needed to enable coastal dynamics to be understood, changes evidenced, and data translated into useable and accessible information.

Analysis is extremely variable and may not be maximising the potential value of the coastal monitoring data that we collect in England. Within each of the six coastal monitoring regions, different amounts and types of analysis are done by the regional monitoring programme. This depends on what is deemed necessary for that frontage. But also, the in-house capacity (expertise and resource) that the programmes have to do analysis. Sometimes resources allow for some out-sourcing from the regional monitoring programmes of analyses to consultants. See Box 5.1 for some reflections on the situation in the ACM.

Trends reports are particularly valuable and often relate to SMP areas. They are very useful documents as they give a description of anything that has significantly changed, for example where beaches are steepening or flattening, which can be an indicator of future problems. They could be improved by being hosted in a GIS format, for example.

It is always possible to do more analysis of coastal monitoring data, but beyond the broad trends reports, the analysis is dependent on user needs. A local authority, coastal partnership, consultant or other party may also undertake analyses using the freely available raw data. For example, in relation to specific schemes and this is the scale at which most coastal data analysis is done.

Identifying the questions that need to be asked of the data, and interpreting analyses is not always straightforward. This can often be a challenge particularly at a local authority scale where resources for specific expertise as well as time for strategic thinking are sparse (where attention is necessarily taken up with day-to-day coastal management challenges).

Nationally it could be beneficial to do more analysis; ensuring the identification of effective focus for this will require investment in some collaborative thought – see Section 6.3.

5.3.10 R&D to enable better data use

A particular window of opportunity at the R&D scale in the context of coastal monitoring and data is around developing some of the many ideas that are in circulation around how to translate the excellent monitoring data that we have into useable products for analysing coastal change as per many of the suggestions in this section.

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5.4 Emerging opportunities in coastal monitoring & data

This is a fast-developing field due to the rate of technical advance methods of data collection, storage, and analysis. As tech capacity increases, new methods make data collection easier and costs fall, more and different types of coastal monitoring will become accessible and flexible. Topographic data collection, for example, began with stakes in the ground and kinematic GPS. Now, laser scanning is becoming accessible and commonplace, radar and other technologies are also emerging. The use of drones is making much data collection more efficient and satellite technology has huge potential to add depth and additional information to the monitoring we already do.

It may not be that we need additional or different types of monitoring, but higher frequency or better spatial density. The CCO - as lead on the NCMP - relates to developments in this field, as a partner or user case in a range of current projects, thus able to drive the development of some products even if they are a few years off being useable.

The interviewees in this study talked particularly about the following emerging opportunities, each of which is explained in a little more detail in this section:

- Seismic monitoring of cliff erosion and telemetry tools
- Laser scanning
- Earth observation via satellite derived data
- Use of drones and autonomous surface vehicles (ASV's)
- Marine synoptic radar systems
- Use of 5G
- New techniques and capacity in data visualisation and interpretation.

5.4.1 Seismic monitoring of cliff erosion, remote sensing and telemetry tools

Many projects are starting to look at new systems for how you might monitor cliff movement; sensors on beaches and cliffs that would detect early signs of slippage for example. This is interesting but unless you have them everywhere or in the right spots to detect movement then this method may not be that useful. Remote sensing methods could be useful for areas such as groyne bays, where a measure of beach level variation against a sea wall is needed.

5.4.2 Laser scanning

Laser scanning is not a completely new technology but is not used as a mainstream source of coastal monitoring data due to cost and data load. It has been applied in the Anglian region on vertical cliffs where it is not possible to capture structure and form using any other routinely available technology. Another example is laser scanning of Chesil Beach demonstrating changes in beach level during a storm.

Laser scan survey data can be captured and delivered within days, which is very valuable for complex scheme-based work. The value of laser scans will increase as computer performance increases; they create huge point cloud datasets that non-specialist computers cannot handle. As institutions upgrade to better equipment to support the hosting and analysis of laser scan data, requirements to capture this format of information is likely to increase. Expertise is needed to analyse the data sets generated by laser scans; the ACM team does not have this and so analysis must be put out to contract.

5.4.3 Earth observation via satellite derived data

Resolution/pixel size is improving rapidly and becoming less of a constraint on the use of satellite-derived data. It cannot replace the granuality that we have in Lidar or aerial photography but it is likely to contribute a lot more in future to coastal monitoring.

One of the key areas in which satellite data and imagery can add value is in a broad perspective as it can help us identify where to study change in more depth. Work currently being done on this includes:

- Coastal change from space is a project being run by ARGANS and the European Space Agency to explore how satellite data might be integrated into coastal management decision making. This is an international project led by BGS in the UK. Includes 3 test locations in England, testing shoreline discrimination methods, bathymetry from space and habitat mapping. This project is finished and CCO is currently assessing the data.
- Blueco is a European Space Agency project being led by NOC Liverpool. Investigating how earth observation products may be used for monitoring. CCO is advising on sites, consulting on potential data products and providing data for validation. This work could offer a lot of potential for intertidal mapping, for example.
- A new project (title unknown) has just started and is being led by NOC Southampton and will be doing daily passes over the Severn Estuary. Likely to give some useful information about flooding and water levels in the Severn Estuary initially, and then potentially will roll out.

5.4.4 Use of drones and autonomous surface vehicles

Drone and autonomous surface vehicle (ASV) technology has got a lot of potential for coastal monitoring. Drones can be used for Lidar surveys, and photogrammetry to get topographic data – this is likely to be a growth area over the next six years. For example, Lidar is captured annually during winter between November and February. This is dependent on tides and the weather and so there is often a long delay in the data being provided. Drone surveys can offer a much quicker turnaround of data capture, processing and delivery meaning that it can be accessed and used more promptly. ASV's will likely play an increasing role in collecting bathymetric data. Much is possible for example using quad bikes for laser scanning, but this method may not be appropriate for much of the Anglian coast because along many stretches of frontage there are groynes every hundred metres or so.

5.4.5 Marine synoptic radar systems

Being trialled in the NCMP Northwest region and with Southampton University. These are land based and scan the water surface; they use waves and roughness to come up with wave parameters and then infer what the bathymetry is like to generate rapid understanding of the dynamic changes of the seabed. This technology would be useful in particularly dynamic areas where it is hard to deploy other types of monitoring.

5.4.6 Use of 5G

There is potential to deploy certain types of technology more widely and more cheaply to capture data. For example, new types of wave buoy may be able to use 5G networks. There are some R&D projects underway using 5G to trial cliff monitoring early warning systems[51].

5.4.7 New techniques and capacity in data visualisation and interpretation

Development in survey and monitoring techniques, computing power and so on mean that opportunities to visualise data in more sophisticated ways are opening up, for example 3D visualisations of cliffed frontages over time.

[51] This information is anecdotal via an interviewee and details of these specific projects have not been obtained for this report.

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5.5 Ongoing coastal monitoring & data challenges

Interviewees articulated a number of challenges in relation to coastal monitoring, data and information needs which will require more time and effort to clarify or solve. These are explained in a little more detail in this section:

- Uncertainty around advance monitoring needs to support adaptation
- Capacity and expertise
- Need for long-term data sets to make future projections
- Data size and storage
- Non geophysical data needs and restrictions on accessibility of data
- Collation of disparate data
- More information is available for defended than eroding sections of coast.

5.5.1 Uncertainty around advance monitoring needs to support adaptation

One difficulty is that it is not always clear in advance where more intensive monitoring is needed; where we have some changes in policy towards adaptation for example, it is not often clear what that is going to mean, or what the implications are (e.g., what the triggers of significant physical/social/economic change may be, and how to monitor these). There may be a need for different sets of data, or more data from some locations – ideally this information is needed in advance of any changes but at present we do not have guidance on what we should be monitoring.

5.5.2 Capacity and expertise

A lot of different analyses can be done with various types of monitoring data but there are some hurdles here:

Types of monitoring and need for regional feedback: It is crucial to think more going forward about what types of monitoring is really needed in terms of resolution, frequency of collection and so on. The national reviews of the coastal monitoring programme allow for this and the ACM, for example, is currently rationalising its topographic monitoring. Interviewees did note the importance of local authority coastal managers/partnerships and other data users feeding back into the regional monitoring programmes to enable ongoing improvement and refinement of the survey units so that the monitoring is fit-for-purpose.

What to ask of the data: Knowing what to ask of the data and what analyses to request is an issue. Sometimes local authority coastal management teams, or even coastal partnerships may not know what they can potentially ask of their regional coastal monitoring programme, equally they may not know what their regional coastal monitoring programme's capacity and limitations are with respect to data analysis (e.g., the ACM are data collection experts and do some analysis but are not coastal processes or modelling specialists).

> *"One of the key things is identifying the questions that we want to answer with the data that really helps inform what needs to be collected and the analysis that needs to be done."*
> Interview A9

> *"There's a real variation in what Local Authorities are able to contribute in terms of their time and therefore [the regional monitoring programme] understanding what they need in a in a detailed enough way to be able to recommend additional monitoring or specific pieces of analysis to help them develop their coastal management processes."*
> Interview A6

Interpretation of analyses. Being able to explore and understand why trends are happening also requires expertise. The data can mean very little without the knowledge to assimilate the outputs and provide possible explanations.

As noted in some of the other sections in this report, local authorities do not always have capacity and/or expertise in this respect so have to rely on out-sourcing to consultants, which they cannot always afford. Regional monitoring teams aren't necessarily funded to do analysis at present either, additional funding to the core Regional Coastal Monitoring Programme would be needed to enable the

regional teams to support local data users, or to project-manage out-sourced analyses if they do not have the capacity. Building relationships on this topic is worthwhile (not necessarily waiting for quarterly meetings with all stakeholders). Section 3.6 also addresses this point.

5.5.3 Need for long(er)-term data sets to make future projections

The high-resolution, high-quality data needed to make future projections of change is not available yet so there is greater uncertainty in our modelling now than there will be in future, as data sets lengthen and improve.

5.5.4 Data size and storage

A significant spend within the NCMP budget is for data storage, archiving, and ensuring the website can run and be accessed effectively. Some coastal monitoring data sets are archived and made available to users upon request but not downloadable directly because they are too big (e.g., terrestrial laser scanning data). It is also difficult to store this data, and to make it available (often standard profiles are taken through the data to simplify it and make it more accessible). From a user perspective this is an issue too because it is necessary to have the software to handle the data. In time, data storage will become cheaper and the tech capacity to handle the data will improve so presently it is all kept.

5.5.5 Non geophysical data needs and restrictions on accessibility of data

We have a good handle on the geophysical and hydrodynamic data needs but in terms of resilience and adaptation, we need other types of data set too. Much data exists, which would be of interest to coastal risk management authorities, but which is not openly available, e.g., on numbers of homes lost to erosion. Much of this is held by the private sector (e.g., held by insurance companies) and is not publicly available but is needed and would be useful for adaptation planning.

One interviewee recommended an article by Lazarus et al. (2021)[52] as a relevant and timely reference in this respect. Lazarus et al. note that in the UK, coastal data resources are scattered and fragmented and need to be transformed into a systematic, integrated portal for quality-assured, publicly accessible open data to support analyses of coastal risk and resilience: *"Such a portal would support analyses of coastal risk and resilience by hosting, in addition to data layers for coastal flooding and erosion, a diverse array of spatial datasets for building footprints, infrastructure networks, land use, population, and various socio-economic measures and indicators derived from survey and census data. The portal would facilitate novel combinations of spatial data layers to yield scientifically, societally, and economically beneficial insights into UK coastal systems."*

5.5.6 Collation of disparate data

Data is collected for many different purposes by many different organisations – including a lot in the eastern region, which lies outside of that overseen by the ACM (e.g., by Port Authorities, and Cefas and even by the local authorities). This is not necessarily joined up or collated in any way but doing so could be very useful for the purposes of more effective coastal management. As part of marine licencing for a cable route, prospecting for sediment extraction sites or gas pipelines for example, data would be collected but there is likely to be a condition attached to this which means it remains held rather than being spread across multiple licences.

[52] Lazarus, E.D., Aldabet, S., Thompson, C.E.L., Hill, C.T., Nicholls, R.J., French, J.R., Brown, S., Tompkins, E.L., Haigh, I.D., Townend, I.H., Penning-Rowsell, E.C. (2021) The UK needs an open data portal dedicated to coastal flood and erosion hazard risk and resilience. Anthropocene Coasts, September 2021. https://doi.org/10.1139/anc-2020-0023

5.5.7 More information is available for defended than eroding sections of coast

Historically, more detailed information has been collected and analysed in places where coastal protection schemes have been, or are being, developed and closely monitored than for open frontages. The latter are more likely to be erosion hotspots where more information is needed, but less exists. Increasingly, challenges are being seen in places where there were not challenges previously, where there are not defence assets.

> *"The irony is that the places where we have the most challenges at the moment in terms of managing the coast and reacting to problems are usually in the places where we don't have schemes, so we have less data."*
> Interview A9

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Theme Summary B: Coastal Monitoring and Data

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England has a good approach to monitoring and data compared to other places worldwide. This has dramatically improved in the last 20 years with the establishment of the National Coastal Monitoring Programme. This is perceived to be an extremely valuable source of long-term, good-resolution and openly accessible coastal monitoring data, which provides full coverage of the coast including digital terrain models (DTM's), lidar, bathymetry and topography.

An analysis of where there are gaps in coverage around the way we monitor our coast found the following key areas where more information could be valuable to both enable more comprehensive coastal change assessments:

- The 'White Ribbon' - gap between bathymetry and lidar coverage
- Shallow sub-surface
- Shore platform
- Sediment fluxes
- Impact of interventions
- Register of coastal assets
- Monitored distance offshore
- Need for more trends analysis and current limitations

The key emerging technical opportunities and potential in this field to increase and develop our monitoring capacity and improve the efficiency of data collection are earth observation and satellite derived data, use of drones and autonomous surface vehicles, seismic monitoring and telemetry tools, laser scanning, marine synoptic radar systems, use of 5G and new techniques and capacity in data visualisation and interpretation.

We face ongoing challenges in terms of coastal monitoring and data to support coastal processes science and research which can inform adaptive coastal management. These are not easy to resolve but are worth acknowledging:

- Inherent uncertainty around advance monitoring needs to support adaptation
- Capacity and expertise - to be able to identify what is needed of regional monitoring going forward, what to ask of the data and in interpretation of analyses
- Need for long-term data sets to make future projections – the national coastal monitoring programme is now enabling this, and the data record is lengthening all the time
- Data size and storage
- Non geophysical data needs and restrictions on accessibility of data
- Collation of disparate data, i.e., the wealth of data held by parties other than the NCMP and not openly accessible
- More information is available for defended than eroding sections of coast because where there are schemes, there is more monitoring and analysis.

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6. Coastal Processes Knowledge Co-development

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Identifying how knowledge is co-developed and produced is key if we are to improve on this and maximise our collective ability to learn and progress coastal change science and its application in practice. This part of the report summarises:

- Where the expertise in this field is
- How knowledge and learning is linked and shared
- Broad needs and opportunities with respect to information availability, learning and knowledge co-development.

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6.1 Who has the expertise?

'Who' is 'doing' coastal processes science and where does the expertise lie? The research-practice-policy community in this field is tight and well networked. It will certainly be expanding given the recent announcements about national investment in FCERM going forward. This section acknowledges the key role and importance of a relatively small number of extremely passionate and committed individuals in the sector, and the growing need for effective knowledge co-development mechanisms going forward.

There are many experts within consultancy, local authorities and coastal partnerships, and academia. Many of these have necessary niche expertise in particular phenomena (e.g., landslides) but it is becoming apparent that we collectively need to take a broader view to understand the challenges we face and where coastal change problems are likely to emerge.

Consultancy

Within consultancy there is a lot of advanced work in this field which contributes significantly to pushing the technical boundaries of work in the sector. Types of work range from 'bread and butter' scheme-based local studies (e.g., feasibility studies; scheme or structure design; options business cases), to interpretation of regional monitoring data and contribution to developing regional strategic coastal plans, and more national scale work (e.g., NCERM2 and the SMPR – see section 2.1). A lot of this is very advanced and at the forefront of national expertise and what is possible in this sector. There are a few consultancies with really specialist and well-established knowledge around coastal processes, including where and how the technical information we have links to emerging national policy and practice. They tend to excel at integrating expertise in civil engineering, geomorphological and sedimentology processes, modelling and knowledge of coastal governance. Consultants tend to be employed on a scheme-by-scheme basis and may not consistently be involved in projects across a frontage over time. They are usually restricted to delivering a tight scope of work which depends on a client being adequately knowledgeable and asking exactly the right question (more on this in section 3.7). Depending on the commissioning organisation, outputs may not be shared beyond the client.

Academia

Academics can sometimes be perceived to be very focussed on a niche topic and it is not always apparent as to how this links to the needs of coastal managers in practice. However there has been an observed improvement in the links between research and practice over recent years, with many more PhDs and Masters level research being integrated into what coastal local authorities need (e.g. around how to implement CCMA's, see Kirby et al. 2021[53]).

[53] Kirby, J.A., Masselink, G., Essex, S., Poate, T., Scott, T. (2021) Coastal adaptation to climate change through zonation: A review of coastal change management areas (CCMAs) in England. Ocean & Coastal Management, 215. https://doi.org/10.1016/j.ocecoaman.2021.105950

The public sector

The public sector (coastal partnerships, local authorities, the Environment Agency) have established some excellent knowledge sharing structures, for example within and across Coastal Partnerships, the LGA Coastal SIG, the network of Coastal Groups and the network of regional monitoring programmes. But there is not a structure which enables routine knowledge exchange between these groups and academic and private sector parties.

> *"Things are moving on working both ways – we know that we [coastal managers] want to apply their research and they [academia] know that the end users need to benefit and be fed the work."*
> Interview B9

This field – across policy, practice and research – is rapidly evolving. Some interviewees felt that there appears to be a lot of similar research being undertaken which overlaps. Some coastal partnerships, groups or monitoring programmes are fortuitous in their locations or proximity to academic institutions which enable natural links to develop and be sustained; for example, the Southeast Coastal Monitoring Programme runs out of the Plymouth Coastal Observatory which is part of Plymouth University so there are easily established links into innovative types of analysis, research and development. Others do not have such natural research relationships. Within practice there are some excellent mechanisms and extremely effective at enabling knowledge sharing, for example the Coastal Groups Network and through the LGA Coastal SIG.

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6.2 Coastal processes knowledge sharing and learning

Are we being as effective as we could be in sharing and learning from the research, policy and practice around coastal processes? The professional view is that science in this field is not developing as well as it could, considering what is technically possible. It is not being done in an effective or joined-up way at present and there is a particular disconnect between the academic and practitioner communities. Coastal managers are increasingly stretched with little time or other resources to keep in touch with learning in the FCERM community. In policy and practice there are some solid and effective networks which have been very valuable to the national experience of knowledge sharing and collective learning over the last few years. This section presents more detail on:

6.2.1 Important role of the Coastal Group Network, the LGA Coastal SIG and coastal partnerships
6.2.2 EA FCERM framework
6.2.3 The important role of informal networks and ad-hoc conversations
6.2.4 Conferences
6.2.5 Publications
6.2.6 The importance of being an informed/intelligent client
6.2.7 Institutional constraints to more effective knowledge sharing

6.2.1 Important roles of the Coastal Group Network, the LGA Coastal SIG and coastal partnerships

Coastal groups exist partly as a way to foster collaboration and to share knowledge and best practise. The Network of Coastal Groups is becoming increasingly cohesive and is key in enabling the local authority voice around the challenges of coastal management to be stronger and be heard. The network, and the functions of the regional groups within it play a critical role in sharing learning and information nationally. The network enables a great deal of progress to be made at national policy level and acts as a conduit for knowledge sharing, and coastal group meetings are an excellent mechanism for coastal professionals to find out what's going on regionally.

> *"We still need to get erosion risk much more front and centre in the national thinking to help us do what we are trying to do locally. The Coastal SIG is very important and is giving us a vehicle to get things done at a national level. It doesn't work at a local level without that national framework."*
> Interview B9

> *"The LGA coastal SIG has matured into a useful organisation in terms of aligning and absorbing and feeding back on the information that we share and things like that. I think it's been depoliticized a little bit over the last few years, which I think is a good thing."*
> Interview B5

Many participants also noted the growing importance and effectiveness of the Local Government Association Coastal Special Interest Group (LGA Coastal SIG), which has various sub-group for example on adaptation.

Coastal partnerships are also notable in their role nationally on the topic of knowledge sharing, co-development and learning. They have strong presence on regional coastal groups, national policy, and practice networks such as the LGA Coastal SIG and tend to reach out beyond their areas to support other partnerships and local authorities, etc. One risk is that these partnerships grow too big; limiting the size may be necessary to enable partnerships to keep pace with national policy, research, and delivery – to operate strategically, tactically and operationally in a joined-up way whilst also delivering on the ground. There is a point when organisations become naturally siloed but lacking in connectivity because of their size.

6.2.2 EA FCERM framework

The EA FCERM contractor framework is much more in tune now with what is needed and how you might be able to bring people together to solve problems. The contractor framework recognises that key expertise sits within a small number of consultancies with proven track records of quality work.

6.2.3 The important role of informal networks and ad-hoc conversations

Much knowledge sharing and progress occurs as a result of ad-hoc conversations as tangents in other projects, chance meetings at conferences (pre-Covid) and other such occasions. These unplanned opportunities are often extremely effective catalysts for knowledge sharing or collaboration.

6.2.4 Conferences

Conferences are a key source of information sharing and opportunity to catalyse knowledge co-development. Flood and Coast is the most obvious example; to date this has been very flood focussed but certainly in 2022 the agenda contains a lot more focus on coastal erosion and adaptation. It tends to look more at policy and practice as opposed to the technical science aspects of coastal processes. The Institute of Civil Engineers also have regular and well-attended conferences, but these can be prohibitively expensive. There are others too and the in-person events offer particularly kinds of networking opportunities. Online events have many benefits as they are more widely accessible but don't offer the same degree of immersion or opportunity for side discussions.

6.2.5 Publications

Key publications include journal papers though practitioners and consultants may not have access to these or the time to read them. Industry publications are important, including the CIWEM magazine and New Civil Engineer.

6.2.6 The importance of being an informed/intelligent client

In commissioning work, a buyer/client might set an interesting problem where what is really needed is a bit of innovation to solve it. The status quo means that the work tends to go to the lowest cost proposal but being innovative or trying new approaches can be more costly than sticking to tested (but predictable) tools. Coastal partnerships are already demonstrating how effective they can be at sharing expertise across local authority boundaries, and indeed between partnerships on some occasions.

There may be more scope around the idea of enabling a 'smart client' approach through national networks of coastal management professionals providing advice and support to one another in defining problem scope and key questions at an early stage in the procurement of work. There would be significant challenges here though around agreeing enabling legal and contractual bases. The model of shared service agreements that underpin the Coastal Partnership East and Coastal Partners approach is perhaps a good example. BCP Council are looking to establish a "centre of excellent" approach which evolves this further to setting up contracts with other local authority partners.

Overall there is a need here for some different thinking by the EA, Defra and Local Government about how to enable these different arrangements for informed/intelligent partnership working to deliver more effective and efficient coastal management.

6.2.7 Institutional constraints to more effective knowledge co-development

This study revealed some interesting points around barriers from different perspectives to proactive knowledge co-development and innovation.

Some examples of challenges from an **academic perspective:**

- Researchers are often distracted by the challenge of having to constantly apply for funding
- There is embedded feedback within the system around who gets research funding; if you have got substantial funding in the past, you are more able to get additional funding in the future. Despite recent initiatives through UKRI to fund innovation programmes, this can block early-stage innovative ideas.
- Business as usual means that it is easier to get funding for projects using approaches that are already proven to work, but you can't get money for ideas which might be novel and innovative but a bit risky.

- Despite pushes for research projects to prove impact and include external partners from industry or practice, a lot of academic dissemination is either through conferences that local authorities can't pay to go to, or publications which they don't have access to or time to read. Unless both academics and practitioners are engaged in targeted events and research outputs there is little effective crossover.

Some examples of challenges from a **consultancy perspective:**

- Consultants are hampered by the need to turn a profit; low profit margins give little headroom to invest in anything innovative
- The approach in the private sector tends to be to attach a high multiplier to expert work because there are few others who can do it. It is difficult to get low multipliers for contributions to research project opportunities which may develop new tools and enable fruitful engagement with other experts.
- Benefits, when this IS made possible include being able to learn from others, show leadership in the field, strategic use and other things.
- Some publicly funded organisations are able to bid for consultancy work without taking on the same degree of risk that private sector consultants would have to carry (problematic because it can distort the market/miss important sources of expertise)
- A huge amount more could be done with better links into, and collaboration with academic research in universities as well as actual users; this collaboration is the route to the cutting edge.

Some examples of challenges from a **public sector perspective:**

- Resourcing within local authorities to enable delivery of coastal management operations and maintenance is stretched meaning that there is often little opportunity for strategic thinking around adaptation planning, keeping up with research and activities elsewhere, and attending national meetings for example. Coastal partnerships have more capacity for this because they have bigger teams, pooled resources and expertise.
- Where local authorities do not have the necessary skills, depth and breadth of experience it would be helpful to have a mechanism to enable some kind of shared support across partnerships and local authorities nationally (for example before technical consultants are appointed there is a lot of work to be done to scope, secure funding and procure them – the lack of capacity in the client side is a bottleneck to getting work commissioned).
- Recruiting people with appropriate skills is problematic. This is likely due to a skills shortage across FCERM, but also because there is a limited resource pool and a lot of competition between different parts of the sector. The private sector can pay more so public sector may not be able to attract skilled people into FCERM delivery.
- There is an obvious dependence on particular individuals with key interests or skills to proactively advance the agenda around adaptation to coastal change (erosion) and to work with others regionally and nationally. It is an issue when key people retire, for example and their wealth of experience and knowledge is lost to the sector.
- Coastal partnerships can still face constraints in working across different local authority systems (e.g., separate IT systems, GIS platforms and legal / contractual arrangements, for example). So, the sharing of relevant technical information is difficult. The practice of effective partnership working can be frustrating, limiting and time-consuming for this reason.
- Nationally and locally, a lack of framework to enable the delivery of adaptation initiatives locally with any national support (this is ad-hoc and driven to date by the energy of individuals around the country committed to advancing and proactively working through their networks).

To echo Section 6.2.6, there is a need here for some different thinking by the EA, Defra and Local Government about how to enable these different arrangements for informed/intelligent partnership working to deliver more effective and efficient coastal management.

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6.3 Knowledge co-development opportunities

This research highlights some clear needs and opportunities for national knowledge co-development around how we do and use coastal processes science to support the management of coastal change. It is worth noting both a sense of frustration in the slow pace of change on delivering adaptation since the early 2000's, but also the huge progress that has been made in the last few years in regional and national governance on coastal adaptation. There is more we can collectively do to proactively drive change and these aspects or mechanisms emerged from this study as pragmatically important:

6.3.1 Collaboration is key
6.3.2 Resurrect a CoRDDi-type framework
6.3.3 Need for a widely accessible coastal information/research hub
6.3.4 Traditional channels of knowledge exchange are effective
6.3.5 An annual meeting focussing on erosion
6.3.6 Cultivate a better interface with UK Research Council (UKRI) funding

6.3.1 Collaboration is key

Collaboration is seen as critical and where the best successes are achieved in progressing knowledge in this field. It is important that projects and other initiatives draw upon a combination of academics, practitioners and expert consultants who are interested in real world application and impact. There is no single source of expertise.

Collaboration is also crucial from an adaptation delivery perspective. As explained in section 4.9.4, adaptation is more than coastal management – it is about the sustainable future of places with economies, utilities, environmental assets and other characteristics of communities that are deeply connected into whole regions. This requires cross-scale governmental and political buy-in as well as better co-ordination and integration with other actors such as utilities providers.

> *"Some of the best projects I [consultant] have been involved with have been where you have had a strong collaboration between universities and actual users. Because then you are getting the work tailored to the cutting edge; how it is going to be used as opposed to how people think it might be used."*
> Interview A3

It also requires a strong baseline understanding, and this can be better achieved with sources of expertise are well connected and where collaboration is enabled.

6.3.2 Resurrect a CoRDDi-type framework

As noted in Section 4.8, the importance of good knowledge co-development mechanisms is critical to enabling progress in impactful coastal processes science. there are some particularly effective networks around the policy-practice interface, but these do not appear to have widely established links into the coastal processes science community (both academic and consultancy)

The need for a network for the co-development of knowledge and sharing of information spanning policy, practice and scientific research is widely shared and already being discussed by the EA with other parties. A formal mechanism of this kind would enable a more robust and broad perspective to be taken of what is going on across disciplines and in different regions of the UK within the field of coastal change processes with a view to supporting robust adaptive coastal management.

A Coastal Research, Development and Dissemination framework (CoRDDi)[54] has previously existed through the Environment Agency to boost collaboration and set out research priorities for those responsible for managing flood and coastal erosion. Many interviewees talked enthusiastically about the likely value of resurrecting this framework (or something similar going forward), almost unanimously citing its usefulness and effectiveness. Discussions are underway between various parties and the EA's coastal research team on this. Such an arrangement would enable (amongst other things):

- Establishing a baseline understanding nationally around the work being done in this field, national technical capacity and areas of need and opportunity to collaborate
- More timely and co-ordinated R&D identification, and an effective point of contact between the coastal management/adaptation community and the UK Research Councils
- Ability to scope and support innovation in research and practice, sharing opportunities and prompting experimentation
- Good collaboration across institutions (public and private) at early stages of project development

How such a framework or network is funded, organised, managed and so on would need clarifying but a model for this kind of mechanism does at least exist and would complement and help to advance the work of networks that are presently active and effective – as long as it would not be an additional burden.

6.3.3 Need for a widely accessible coastal hub – tools, legislation, research

There is a clear need for a single point of reference for all the relevant interpretive tools with regard to FCERM to assist with the challenge of baselining and avoiding replication of practice (but learning instead). This should include SMP's and NCERM2 alongside flood maps in one portal so that they can be viewed together. At the moment this information is separate and spread out. The NCERM2, SMPR and SMP Explorer projects are linked and work is being done to ensure that the outputs, once live, will be linked together – there may be scope to widen what is included.

> *"Many projects have contributed something in the past but to use that information is hard because websites become defunct or links are broken, or the tech moves on...you have to really dig for information even though there is a great wealth of knowledge out there."*
> Interview A9

Other information and research pertaining to coastal change science and adaptive coastal management is disparate – a lot of work is being done nationally but there is no central hub for finding out about this, or portal for accessing the outputs. A lot of investment has been made previously by the public sector in research in this field but often this 'disappears' as websites become defunct, etc.

The field is fast-moving in practice, academia and in consultancy; it is easy to miss key items of research and learning. Often, local scheme-level studies are important in advancing our understanding of specific coastal processes (e.g. bimodal waves and extremes), but these tend not to be picked up beyond the scheme level unless they are known about by particular individuals (and when these people move on or retire from a role or organisation, this 'library' is lost). There is no overall information or research hub at present, except *within* organisations such as the EA (but of course these archives are not open to others outside of that organisation), or the CCO (website hosts information about a range of projects and the outputs where they have been partners or integrally involved as user advisers but cannot do this comprehensively for everything). It is difficult for organisations to learn from one another due to the sheer quantity of material and lack of central hub for this.

There is nowhere where research and study outputs are centrally collated and held. It is very costly when projects begin; each time there is a long process of scoping relevant work that has been done before. Some kind of digital information or research repository or portal would therefore be extremely useful for coastal researchers and practitioners to source key information (some of which may have been published quite some time ago but still be very relevant). Particularly if it was hosted alongside the SMP Explorer for example. It would

[54] https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/coastal-research-development-and-dissemination-corddi-framework

help to better link and guide research priorities, enable national learning and save time in starting up repetitive studies on the topic of coastal change. There is a lot to consider around funding, building, hosting, managing, maintaining and updating something like this.

6.3.4 Traditional channels of knowledge exchange are effective

Despite there being lots of opportunities as technology develops, to interact and exchange knowledge in new ways, traditional formats are still very effective:

- Written communications such as newsletters and coastal email lists: These are still important (e.g., CMS network and EA updates) – even if you don't always read the emails in full, the headlines are really useful and are enough to keep aware of key projects and policy activity relating to coastal change
- Conferences and other meetings: Since the Covid19 pandemic began, it has not been possible to attend conferences in person but many have migrated online and are still deemed to be really useful and effective for information sharing and for networking amongst key individuals from different sectors, organisations and areas of work (e.g. practice, academia, private sector).
- The importance of informal opportunities in seeding collaboration: Overall the community of experts on this topic (across government, academia and private sector) is relatively small and people know and have great respect for each other. Relatively informal opportunities that are available at conferences and after attendance at other types of meeting are really significant in seeding ideas and collaboration.

6.3.5 An annual meeting focussing on erosion

A coastal change [erosion] focussed annual meeting or conference is something that could facilitate linkages between organisations and individuals that are not happening. This would include opportunities for discussion and idea generation where people get together and just talk would be well placed. A huge part of advancing this field of work is creating the opportunity for discussion and presently there is a bit of a disconnect between the practitioner and academic arenas. Particular working groups could form within this network. This could spin off from CCO and coastal monitoring, or NCERM2 for example. It would need to be well organised and thought through in order to be a valuable opportunity that consultants and others can justify attending. The scope would be broader than the EA's focus (e.g. in Flood and Coast) and more about understanding the coasts of Britain. It should focus on the needs of local authorities as coastal management authorities, the EA and the relationship with universities and consultants to encourage better partnership working between all these parties.

6.3.6 Cultivate a better interface with UK Research Council (UKRI) funding

> *"This is where collaboration really comes in. If it's a local authority approaching UKRI they probably won't get very far. But if it's a collective with an agreed topic suggestion that various organisations can support then suddenly it becomes a lot more feasible and achievable."*
> Interview A8

The field would benefit from a better interface with the UK research councils, as a source of funding – which could be achieved through the resurrection of a CoRDDi framework (section 6.3.2). If some programmes could be actively pitched and funded, then there would be more university activity in this field and the opportunity for some new studies. Try to engage UKRI, to create an opportunity for funding a set of small projects coupled with and steered by organisations like CPE (to ensure they are directly relevant to the real-world problems rather than conceptual).

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Theme Summary C: Coastal Processes Knowledge Co-development

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The research-practice-policy community in this field is fairly tight, well networked and is expanding as interest in how to 'do' well-evidenced adaptation and resilience in England grows. There are a relatively small number of extremely committed expert individuals in the sector who, to date, have been critical in advancing this agenda within and across consultancy, the public sector (i.e. local authorities, coastal partnerships, the Environment Agency), and academia.

This study highlights the importance of being a well-informed and intelligent client in commissioning or guiding coastal technical studies, but coastal managers are increasingly stretched with little time or other resources to keep in touch with learning in the FCERM and academic research community. This is one of a host of institutional constraints to advancing collective learning facing consultants, academics and public sector FCERM staff.

We need more effective knowledge co-development mechanisms going forward which better link the practice-policy realm with that of the technical science around coastal processes. Across policy and practice there are some extremely effective mechanisms enabling collaborative working, knowledge sharing and collective learning nationally, particularly the Coastal Groups Network and the LGA Coastal SIG. The professional view is, however, that science in this field is not developing as well as it could do, considering what is technically possible; there is a particular disconnect between the academic and practitioner-policy communities.

There is an opportunity for more meaningful collaboration across the research-policy-practice nexus. Resurrection of the Environment Agency's CoRDDi framework would be extremely valuable and would enable a stronger link with UKRI. The SMPR and SMP Explorer process and the NCERM2 projects present a known opportunity to bring together information on coastal change into one user-hub, which is much needed. Traditional mechanisms such as conferences and routine publications remain essential, and the importance of having time and opportunities to network informally and creatively should not be underestimated.

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7. Expert Reflections

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In Summer 2021, an online workshop was held to reflect upon a draft of this report and review the key findings. This session included participant interviewees as well as some additional experts in the sector who had not been involved in the main study.

Sediment transport is an aspect we need to understand better

- There is an obvious need to better understand better how sediment moves and what sediment transport is happening. For example, identifying sinks and sources of sediment (fundamental data is needed).
- This would help to evidence the drive toward more nature based solutions in FCERM.
- Value of sediment, and sediment transfer processes in providing nearby benefits needs to be better recognised and understood. The value of current losses aren't presently being captured in our institutional processes.
- Look into expanding SCOPAC sediment transport assessments – this is deemed to be needed. EA have been approached to roll out this work (correct at time of writing). Current work includes using an acoustic tag tracer to understand sediment movement in the white ribbon zone.
- In Norfolk, a lot of work has been done as well and it could be possible soon to do some quantification on sediment transport.
- Capacity in the sector is an issue – we have better coverage in terms of hydrodynamics but very few experts are looking at geomorphology and sediment transport so there is a need to build skill and expertise in this area nationally.

National network of regional monitoring programmes is critical and effective in providing a robust data record

- Data is increasingly important given the need for accountable decision-making around coastal transitions. This relates to the need to better understand triggers for emerging adaptation processes, e.g. coastal catch-up, outflanking.
    - In some places we need more frequent monitoring as many metres of cliff can be lost in just a few months; how to do this needs exploring. Satellite data could be really key.
- We need much more understanding the impact and performance of interventions:
    - Better data and studies on the performance of coastal schemes, with longer additional monitoring and more analysis than is done presently.
    - More understanding about the vulnerability of existing defences; how they react to storm events and the condition of beaches before and after, for example.
    - What would the coast look like if it had never been defended?
- Are there opportunities to include local knowledge, public interest and experience? What are the opportunities for citizen science? Particularly useful for rapid changes, e.g. following defence removal. This kind of information about local coastal processes could inform adaptation planning timescales/thresholds.

Cross-institution FCERM research, policy development, planning and delivery is needed and could be better enabled

- The south coast's Coastal Partners (CP) is an example of success here. CP covers a frontage with many assets at risk so it is possible to attract substantial government funding. CP includes approximately 65 people (at time of writing) across three teams and takes in five local authorities. The primary goal is to support partner authorities but CP plays a strong role in supporting the EA and provides coastal

process studies for many strategies and schemes. The substantial amount of in-house research is really valuable and important in supporting broader research interests.

- This is more than a communication and dissemination challenge – it relates to institutional structures, funding arrangements and other such factors so EA and national government departments play critical roles here.

We need to focus on asking the most effective management questions

- We need to think critically about what we want and need to know from the more technical science and research to avoid generating 'knowledge for knowledge's sake'.
- In transitioning from SMP epoch 1 to epoch 2 (and beyond) there are many unresolved questions that we do not have the answers for yet.
- For example, what are the triggers for adaptation? When should we be doing 'transitions' and how? Where holding the line is not feasible, what are the options? How ready are people and places to discuss change and transition?
- What are the most appropriate types of risk projections for informing transitions?
- Looking at coasts at big scales is helpful for understanding drivers of change, and this gives potential to engage with people through simulations to build understanding of how the coast behaves. Also perhaps a way to start exploring long-term aspirations/trajectories.

Cross-collaboration and co-development of knowledge are really needed because the decisions element is so complicated

- Mechanisms like the Coastal Group Network are really important
- The recommendation for resurrecting a CoRDDi framework was strongly emphasised in this workshop.

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8. Discussion and Conclusion

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This assessment of coastal change science needs and gaps incorporated a review of national coastal monitoring and how knowledge is presently developed and shared. The findings indicate that there are some fruitful areas of opportunity for coastal change research. For example, around developing better understanding sediment transport processes through quantification and modelling, the dynamic behaviour of complex coastal features, and how to go about modelling and interactively assessing the behaviour of regional coastal systems. The National Coastal Monitoring Programme is deemed to be extremely good and is unanimously highly valued. Through this programme, the data record is improving all the time and adjusting in a timely manner to advances in monitoring technology and fluctuations in regional requirements. There are some areas of potential opportunity, particularly around data and trends analyses as well as some aspects of data coverage and collection (e.g. the 'white ribbon').

Capturing any of the technical science opportunities with respect to coastal processes fundamentally depends upon both the funding landscape and our capital reserve of skilled and qualified people – both in a technical sense and in terms of the adaptation challenge. Defining the questions we really need to ask of the science requires substantial technical expertise, and the ability to understand and interpret the outputs of coastal change assessments and models which incorporate various scenarios and assumptions. Here, it is suggested that we have a national shortage, a coastal change skills gap that needs attention at a national scale.

Whilst there is certainly room for collective knowledge development, we do not appear to have significant gaps in technical capacity to understand coastal change. The results of this study firmly suggest that bridging 'the gap' between need and capacity is less about doing further and more precise technical work (though this is often worthwhile). Rather, it is more about translation into practice as expressed in these three points and articulated in Figure 1:

- At local to national scales, asking well-informed questions of the science so that it effectively supports a robust pathways approach to delivering adaptation
- Having appropriate evidence to better understand the potential evolution and implications of long-term coastal change in order to develop timely adaptation policies, options and plans for coastal places
- Being able to integrate and incorporate new and nuanced coastal change information into transition plans and adaptation processes in the future.

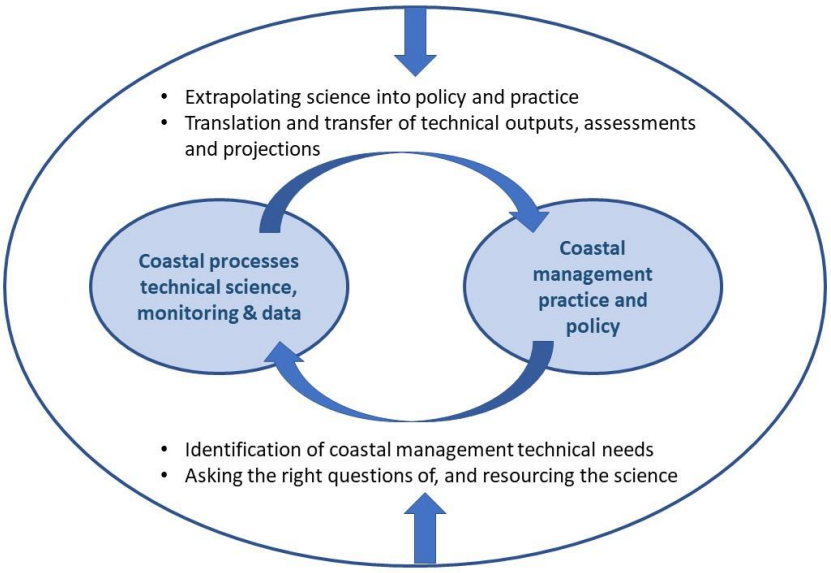

Figure 1. Relationship flows between coastal processes technical science and the policy & practice realms

There has long been a clear need to adapt, but our lack of institutional governance to enable the delivery of coastal adaptation and lack of political will across scales are the main barriers to doing so. This finding is not 'new', but in the context of a 'technical' rapid evidence review it was somewhat surprising that this outcome emerged so unanimously and strongly. Because SMP's are non-statutory and the public sector is so resource poor, strategic coastal change information is inconsistently upheld in town and country planning (except in CCMA's which are not yet mainstream and do not deal with past development). Having institutional arrangements to enable evidence-based adaptation to coastal change is really critical, including national policy and guidance on adapting to coastal change and a bespoke delivery framework which includes funding mechanisms and a guarantee of local capacity and adequate skilling (e.g. in community engagement) for implementation.

Negotiating timescales and where to focus our work and resources is also key. Coastal managers presently find that they must deal with the day-to-day challenges presented by ongoing coastal change, but are also feeling the pressure to start planning strategically for a 'resilient' future coast – but without the funding resources or tools to do this (yet). There is a sometimes a sense that we need more precision about what to expect from coastal change; precision in projections has a place perhaps for managing shorter-term schemes, but not so much the long-term picture. This, we can probably anticipate well enough given the information we have to date. Once again, this depends on our adaptation choices going forward. Investing in science to better understand rates and manifestations of future coastal erosion is almost irrelevant if we do not fundamentally incorporate coastal management/adaptation pathways into assessments and analyses of coastal change. Enabling future coastal resilience means having the resources to make adaptation plans and link these to understanding the likely evolution of the physical risk.

Coastal change information is prolific but disparate, overlapping but not always aligned and is thus difficult to identify and apply to mainstream coastal management practice (i.e. technical studies, research reports, SMP documents, etc.). This study also identified a substantial need for mechanisms for knowledge sharing and co-development of research (including opportunities for collaboration and well aligned funding) between organisations across government, private sector and academia (at the very least something akin to the CoRDDi framework).

In a nutshell, there emerged a general sense that the technical science in this area is not quite as advanced or effective in the UK as it could have been over recent years, partly because of the issue of whether we are really asking the right questions of it, and funding it adequately. Evidence based tools to explore the implications of coastal change over time (in relation to climate change scenarios and coastal management options) would be useful to local coastal risk management authorities in identifying the questions they need to ask, but are not currently within reach. Indeed, what kinds of exploratory tools are needed given that no single type of tool is appropriate for every type of coast, and is there the expertise within local government to adequately interpret the outputs?

In sum, high quality scientific evidence is a critical foundation for innovation in developing politically and economically justifiable approaches to coastal adaptation. We need this evidence to underpin strategic coastal planning for future resilience. There is a need for more effective collective knowledge development to improve translation into practice:

- At local to national scales, asking well-informed questions of the science so that it effectively supports a robust pathways approach to delivering adaptation
- Producing fit-for-purpose evidence to better understand the potential evolution and implications of long-term coastal change to develop timely adaptation policies, options and transition plans for coastal places
- Being able to integrate and incorporate new and nuanced coastal change information into adaptation and transition planning processes in the future.

In England, we have good national expertise and capability in the technical science of coastal processes and coastal change but could do more to increase capacity and skills in this sector and to more effectively extrapolate

this into policy and practice. The examples given in this report indicate that there is huge potential to accelerate progress in this field. This largely depends on two things:

c) Funding - given a pulse of strategic national investment, coastal processes science and skills development carefully tailored to the needs of those responsible for managing coastal change now and into the future would be extremely effective.
d) An enabling national coastal governance context – this does not yet encompass or enable the development of a robust delivery framework to deliver adaptive coastal transitions although great progress is being made thanks to the continuing efforts of the coastal change community across the science-policy-practice nexus in the UK.

The language of coastal adaptation, transition and resilience is becoming mainstream in FCERM in England; we must be optimistic and continue to collectively drive the emergence of an enabling policy context underpinned by high-quality science, collaboration, and meaningful knowledge co-development in this field.

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Acknowledgements and ethics information

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This work was mentored by Rob Goodliffe (Coastal Manager North for Coastal Partnership East based at North Norfolk District Council) and Professor Robert Nicholls (Director of the Tyndall Centre for Climate Change Research, University of East Anglia (UEA), Norwich).

The study proposal was reviewed and approved by the UEA Science Research Ethics Committee in summer 2021. All participants gave their consent for the content of the interviews or focus group they participated in to be anonymously used in this study.

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Appendix A - Opportunities in coastal processes science with respect to CPE activities

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Autumn 2021

A working document to develop team thinking on how might CPE proactively develop better estimates of shoreline change?

Key tools currently available

- SCAPE is still a leading example
- Coastal ME
- Tyndall Coastal Simulator approach

a. For Norfolk, explore the potential to resurrect the Tyndall Coastal Simulator approach

Bringing the TCS approach up to date and refine the approach now that the tech capacity is so much better. As a tested approach, which has already informed two strategy studies, it represents a good option. It would address the frontage from Blakeney Spit to Winterton Ness, coupling erosion with flood risk. This could act as a good demonstration of how you could bring that kind of knowledge into better future planning; of what could be achieved. Later, it may be possible to look into transferability to places such as Holderness, Isle of Wight, etc. It would be needed to secure the resources to do something properly in one place, to show the value to support applications for the resources to do it elsewhere.

<u>Who would do it and likely cost?</u>

- Using the Simulator would be quicker and less expensive since the model went through the iCOASST project
- Would probably involve Mike Walkden
- Perhaps some input via UEA and Robert Nicholls – student project?
- *As is also noted earlier in the report, cost estimates can be infinite but potentially for around £100K it may be possible to develop something like this for Norfolk here a lot of work already exists. Would need scoping with above experts and some others.*

<u>Apply only to the frontage that it was designed for or could it be adapted for Suffolk and/or other places?</u>

- Use the original stretch of coast that it was developed for (Blakeney spit to Winterton ness)
- As part of iCOASST, some SCAPE models were produced for other sections of the coast including Bawdsey in Suffolk, but results were not very revealing
- A rough model was produced for Southwold to Kessingland which started to pick up the interaction between the barrier coast and the cliffed coast. One might expect them to behave differently to SLR, yet the coastline is really quite straight along that section. That work basically showed how this straightness emerges and simulated how this system jointly responds to SLR.
- For much of Norfolk and Suffolk the system is unpredictable; sediment fluxes are very important but not well understood. See section 2.2 for more on this.

<u>Other</u>

- During the original research the user interface was never fully developed. Now software has move on so much, this would be more feasible to do within the £100K suggested budget.

b. Consult with Andres Payo on the potential application of CoastalME

CoastalME is presently being used to simulate the future evolution of the whole Andalucia coast (approx. 900km), being led by a group at Granada University who are developing the model. They developed a new object to capture sediment from the Ramblas and fixed a number of bugs. They have worked with AP to create a thickness model for the whole of that coast which is the first time this has been done. The Granada team have been trained and have been developing the skills to use Coastal ME over 2 years, so translating the work elsewhere may involve taking this kind of approach. Building on BlueCoast we know how to build the right types of model, and we have the data. Also it would be easier to build a model for the UK because we know the data extremely well. There hasn't been time to sit down and think about how much it would cost per km of coast or area but it would be likely cheaper to do in the UK. It would also be possible to have several iterations and go with whatever information is available, e.g. if you only have topo, bathy and geology, what do you get? There would also be potential to improve the model through applying it which would be a second step (based on new borehole and other sample information). *So for Norfolk and Suffolk?* A Trimingham model is already developed and the intention is at some point to run the model to see how it would behave under different scenarios. We also have one for Happisburgh and one for Covehithe. These are small models but it is AP's ambition to create a whole East Anglia model. That would be even better but at the moment we only an operational one for small chunks of our frontage.

c. Consider options for the coast south of Winterton Ness

- Consult work done by Jon French and Helene Burningham for The Crown Estate
- Focus on understanding known erosion hot-spots
- Around Great Yarmouth and south, off-shore banks are very important; we need to understand more about how these banks are developing (will require a holistic approach)
    - Consult UCL on their shoreline change work and system mapping work to understand the dependencies of the different sections of coast to on the geomorphic features around them, particularly the off-shore to understand how the banks might develop.
- Look at where we have bits of headland that are controlled by cliffs
    - A model like SCAPE is not revealing enough where you have lots of sediment movement.
    - But if you have patches where cliffs appear and form (even a minor headland that everything else follows), then it might be worth a bit of SCAPE modelling to pick up the response of those headlands. They might be quite subtle.

In the first instance, refer to the EA cliff recession with SLR work recently completed, as this might reveal key locations [consult EA national coastal research team lead on this]

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Glossary

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Bathymetry[1] Bathymetric	The study or measurement of the depth of water in an ocean, sea, or lake. Bathymetric monitoring indicates the depth of water and is used to show submarine topographic features.
Bimodal waves[7]	A bimodal sea state exists where high energy swell waves generated in the Ocean occurs alongside locally generated 'wind waves' (shorter period but higher wave height). The two interact and the result is a 'bimodal' high energy sea state that can do a lot of damage through increased overtopping of beaches and sea defences.
Cross-shore[3]	A cross-section taken perpendicular to a given beach contour; the profile may include the face of a dune or seawall, extend over the backshore, across the foreshore, and seaward underwater into the nearshore zone.
Intertidal[6]	The intertidal zone, also known as the foreshore or seashore, is the area above water level at low tide and underwater at high tide (in other words, the area within the tidal range).
Lidar data[2]	Light detection and ranging, or lidar, is a remote-sensing technology that uses pulsed laser energy from above (usually aircraft) to measure distance. Engineers and earth scientists use lidar to accurately and precisely map and measure natural and constructed features on the earth's surface
Topography[1] Topographic	The physical appearance of the natural features of an area of land (above or below water), especially the shape of its surface.
Earth Observation[4]	EO is the collection, analysis and presentation of data in order to better understand the planet Earth. Satellite EO is the use of satellites to collect information about the Earth.
Hydrodynamics[3]	The branch of science concerned with forces acting on or exerted by fluids. The dynamic processes that exist in the nearshore region are generated by various drivers. Under the influence of these external forces, the fluid motion of the water manifests itself as coastal currents, tides and tidal currents, internal and surface waves, storm surges, tsunamis, etc. The main features in coastal hydrodynamics are the wind waves, generated by the stress exerted on the ocean surface by the wind.
Metadata[1]	Information that is given to describe or help you use other data or information.
Morphology Morphodynamics[8] Coastal morphodynamics[3]	The scientific study of structure and form Morphodynamics is the process by which morphology affects hydrodynamics in such a way as to influence the further evolution of the morphology itself. The mutual interaction of coastal morphology with hydrodynamic agents (tides, currents, waves). This interaction takes place through sedimentation, erosion and sediment transport processes.
Nearshore[3]	The zone which extends from the foreshore to the lower shoreface. In another definition the nearshore zone extends to the 'offshore' zone, typically to water depths of the order of 20m.
Sub-bottom properties[5]	Physical properties of the sea floor; geological character of material a few metres below the sea floor.

[1] Definition adapted from the Cambridge Dictionary
[2] Definition adapted from esri.com
[3] Definition from or adapted from coastalwiki.org
[4] Definition given by https://www.gov.uk/government/collections/earth-observation-eo
[5] Definition adapted from https://www.ga.gov.au/scientific-topics/marine/survey-techniques/sonar/shallow-water-sub-bottom-data
[6] Definition taken from Wikipedia entry on 'Intertidal Zone'
[7] Definition adapted from Coastal Partners definition https://coastalpartners.org.uk/bimodal-summary
[8] Definition given by https://www.sciencedirect.com/topics/earth-and-planetary-sciences/morphodynamics