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Overstrand Cliffs Study Report

Part 1: Understanding the relationship between water and cliff failure

Volume 1: Report

P01

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Contents

Executive Summary xiii

1 Introduction 15

1.1 Project overview and objectives 15
1.2 Scope of this report 15
1.3 Structure of this report 16
1.4 Sources of information 16

2 Review of Site Information 17

2.1 Site location and description 17
2.2 Site history 18
2.3 Coastal defences 21
2.4 Recent coastal defence works 26
2.5 Geology and geological setting 26
2.6 Previous geotechnical investigations 31
2.7 Previous cliff stability studies 35
2.8 Hydrogeological designations 37
2.9 Water abstraction licences 37
2.10 Near-surface soil permeability 37
2.11 Groundwater interception boreholes 38
2.12 Groundwater monitoring 40
2.13 Observable water features and cliff failure locations 42
2.14 Climate change effects on cliff stability 44
2.15 Episodic (wave dominated) versus progressive (soil strength dominated) cliff retreat 46
2.16 Beach wedge area and coastal "catch up" effects on cliff recession rates 48
2.17 Effect of till properties and groundwater on strength and stability of cliffs 50
2.18 Shoreline Management Plan statements for Overstrand 53
2.19 Historical rainfall and cliff instability records 54
2.20 Potable, surface and foul water drainage systems 55
2.21 Surface water flooding 59
2.22 Community engagement 60
2.23 Ground motion from satellite InSAR monitoring 61
2.24 Unexploded Ordnance 63
2.25 Ecological conditions and sensitive land designations 63

2.26 Rates of cliff retreat 64
2.27 Ground elevation changes 2015-2024 67
2.28 Cliff slope angles 68

3 Site Visit 70
3.1 29 January 2026 70
3.2 30 January 2026 71

4 Assessment of Cliff Behaviour Units (CBUs including relationship to water) 78
4.1 CBU A - Pauls Lane Car Park (Mudslide type) 82
4.2 CBU B - Slipway/walkways (Mudslide/Rotational transition zone) 85
4.3 CBU C - Main promenade (Rotational type) 87
4.4 CBU D – Ivy Farm (composite rotational slide over rock - chalk) 90
4.5 CBU E – Clifton Way (Deep-seated landslide with failure at more than one level) 90

5 Summary (Sections 2 to 4) 93

6 Conclusions on relationship between water and cliff failure at Overstrand 99
6.1 Role of groundwater 99
6.2 Role of groundwater interception scheme 101
6.3 Sea cliff toe protection and its impact on stability 102
6.4 Specific conclusions on Cliff Behavioural Units (CBUs) extents on Figure 6-2 103

7 Next Steps 105

List of Figures

Figure 1-1: 2025 aerial image of Overstrand and inset map showing geographic location Source: NNRCMP Aerial Imagery and open map. 16

Figure 2-1: Topography of the Overstrand area. 18

Figure 2-2: OS 1886 1 Inch. Norfolk XI.NE & SE. 20

Figure 2-3: 1961 Land utilisation map (ref. TG23NE & TG24SE – Land Utilization Sheet 549 – North Walsham, 1961). Source: Scottish Library Maps. 20

Figure 2-4: 2026 Landcover classification at Overstrand. Source: CEH 21

Figure 2-5: Types of sea defences and points of interest within Overstrand. 23

Figure 2-6: Example of timber palisades and groynes at Overstrand (15/01/2024). Source: NNDC. 24

Figure 2-7: Seawall/Promenade at Overstrand with apron section (25/07/2022). Source: NNDC 24

Figure 2-8: Informal rock armour at the western end of the promenade (30/01/2026). Source: JBA 24

Figure 2-9: Rock armour at the base of Clifton Way. Source: NNDC 24

Figure 2-10: Legato blocks supporting debris boards behind along the promenade (01/12/2025). Source: NNDC 24

Figure 2-11: Gabion basket installations along the promenade (29/01/2026). Source: JBA 24

Figure 2-12: Historical photo of Overstrand dated 1907 showing a section of the original 200m long concrete seawall at the bottom of the Cliff Road/Paul's Lane cliff face with access steps to the crest. Note the tunnel/shelter through the cliff. Source: NNDC 25

Figure 2-13: The local coastal promontory at Overstrand (Map image © OpenStreetMap, 2026) 25

Figure 2-14: Map of Anglian (largest) and Devensian (most recent) glacial ice extents. Source: Evans et. al. (2011) 26

Figure 2-15: Extents of periglacial ice advance/retreat stages R1-R12 in the vicinity of Overstrand during the Devensian glaciation Source: Lee et. al. (2017) 27

Figure 2-16: Glacial reworking of North Norfolk Coast geological strata during the Devensian glaciation Source: Evans et. al. (2011) 28

Figure 2-17: Banham (1975) model of cliff geology between Weybourne and Bacton (note elevation in feet) 28

Figure 2-18: Lee et. al. (2004) model of cliff geology between Trimingham and Cromer 28

Figure 2-19: Lee et. al. (2017) geological model at Overstrand (note "?" denotes zone obscured by vegetation due to toe defences) 29

Table 2-3: Relationships between recent and older geological naming in the vicinity of Overstrand. Source BGS, 2008 29

Table 2-4: Summary table of superficial and bedrock geology likely to be present within the Overstrand frontage. Source: BGS Lexicon of Named Rock Units. 30

Figure 2-20: Superficial geology map 1:50,000 overlain on 2022 LiDAR DEM. Source: BGS geology viewer. 31

Figure 2-21: Available ground investigation locations laid over superficial geological map. 32

Figure 2-22: Topographic cross sections through selected historic boreholes (BGS 50k superficial geology map in background) 33

The relationship between surface profile and available subsurface geology is then shown Figure 2-23 33

Figure 2-23: Historic borehole data superimposed on topographic cross sections A-A' to C-C' and the radar station to W3. 34

Figure 2-24: Clifton Way topographic cross section of multiple failures. 37

Figure 2-25: Locations of known groundwater interceptor boreholes and recent and historically observed cliff face seepages/water features at Overstrand. 38

Figure 2-26: Sketch of typical Clifton Way (1994) interceptor borehole installation and not an actual one. Source: NNDC (Brian Farrow) - Refer to Appendix B in Volume 2. 39

Figure 2-27: Examples of groundwater interceptor borehole condition survey result in 2002 showing erroneous surface drainage connection and hole flooded to surface 40

Figure 2-28: Change in borehole water levels between 1998 and 2002. Source NNDC. Note 14A/B and 15 are outside of the study area but included for data set completeness. 42

Figure 2-29: Monthly rainfall totals between May 1998 and January 2002 from Cromer weather station. Source: NNDC. 42

Figure 2-30: Observable water features. Base map: NNRCMP Aerial imagery 2025. 43

Figure 2-31: Distribution of known historical failures on Overstrand Cliffs (1946 - 2025) 43

Figure 2-32: Global annual mean surface temperature 1850-2026 (NOAA, 2026) 44

Figure 2-33: Change in UK annual number of days with high-impact rainfall (Hanlon et al, 2021) 45

Figure 2-34: National Coastal Erosion Risk Map for Overstrand (DEFRA, 2026) 46

Figure 2-35: Example of an extreme storm-induced retreat event in a till cliff (Rossius et al,

2025) 47

Figure 2-36: Example of episodic cliff recession from laser scans of cliffs at Sidestrand (2005 to 2006) [red=material slippage; blue=material accumulation] (Hobbs, 2007). 47

Figure 2-37: Model of progressive-retrogressive failure in a clay till cliff (adapted from Wang et al, 2016) 48

Figure 2-38: Definition of beach wedge area (Lopez et al, 2020) [MHWS=Mean High Water Springs, a level which characterises the long-term average of high tide level] 49

Figure 2-39: Relationship between beach wedge area and cliff recession rate for North Norfolk cliffs (Lee, 2008) 49

Figure 2-41: Changes in soil strength of dense (over consolidated) and loose (normally consolidated) soil with increasing displacement during sliding/shearing (Skempton, 1970) 51

Figure 2-42: Left: Effect of clay minerology on residual strength (Lehman et al, 2021); Right: Comparison of softened and residual strength for over-consolidated clays of various plasticises (Stark & Eid, 1997) 52

Figure 2-43: Proportions of different clay minerals recorded in North Norfolk till samples at Happisburgh, Weybourne and West Runton (Kemp et al, 2009) 52

Figure 2-44: Total stress (σ), effective stress (σ') and pore water pressure (u) within a soil mass (blue=water; yellow=soil grains) (Atkinson, 2008) 53

Figure 2-45: Cromer and North Walsham daily rainfall data versus observed failures. Source: Rainfall data licenced by NNDC from Met Office and EA hydrology data portal (2026). 54

Figure 2-46: Example of foul and combined surface water sewerage within Overstrand. Adapted from Anglian Water service plan received by JBA on 11/09/2025. 56

Figure 2-47: Example of potable water supply within Overstrand. Adapted from Anglian Water service plan received by JBA on 11/09/2025. 56

Figure 2-48: Surface water drainage at the crest of the east footpath at Cliff Road leading to the promenade. Source: NNDC 58

Figure 2-49: Drainage gully for western footpath down from the Cliff Road as it discharges through the promenade to the sea. Source: JBA, 2026. 58

Figure 2-50: Overstrand surface water flooding map. Accessed 12/02/2026. Source: https://check-long-term-flood-risk.service.gov.uk/map 59

Figure 2-51: Community engagement event from 2024. Source 2024 60

Figure 2-52:Settlement monitoring sample points within Overstrand. Source: https://egms.land.copernicus.eu/ 61

Figure 2-53: Average vertical displacement of points along the promenade (red dots in Figure 2-52) 62

Figure 2-54: Average vertical displacement of points behind the cliffs (orange dots in Figure 2-52).Source: https://egms.land.copernicus.eu/ 62

Figure 2-55: Marine Special Protection Area (blue hashed area), SSSI sites (bright green and red areas) and zone o Japanese knotweed infestation at Overstrand 63

Figure 2-56: Cliff retreat rates 1880 – 1967 (Cambers 1976). 64

Figure 2-57: Cumulative cliff retreat 1880-1966 (Clayton and Coventry 1986). 64

Figure 2-58: Cliff recession rate 1966-1985 (Data from Clayton and Coventry 1986 presented in Frew, 2009, NNDC). 64

Figure 2-59: Cliff top lines derived from historical mapping and recent LiDAR-derived ground surface elevation data at Overstrand study area. Base map and LiDAR data: NNRCMP, 2026. 66

Figure 2-60: Comparison of 2024 and 2015 DEM models. Positive (red) = Accumulation of material, Negative (Blue) = Loss. 67

Figure 2-61: Topographic slope angles (degrees) within Overstrand based on 2024 LiDAR. 68

Figure 2-62 Cross sections of cliff face locations showing local slope angles 69

Figure 3-1: Locations of referenced JBA site visit photos. Base map from NNRCMP Aerial Imagery (2025). 74

Figure 3-2: PLCP failure (photo 1) 75

Figure 3-3: Shallow translation slides off promenade slipway being retained by boards (photo 2) 75

Figure 3-4: Gabion baskets retaining failure above. Creep is still occurring and overwriting the upper gabions in places, the condition of the steelwork on the lower gabions is poor (photo 3). 75

Figure 3-5: Legato blocks supporting debris boards behind containing Giant Hogweed infested earth. Note seepage from multiple faces, water is also accumulating behind the seawall. (Photo 4) 75

Figure 3-6: Previous failure creeping over promenade wall. Note the level of saturation within the material and giant hogweed in the background. (Photo 5) 76

Figure 3-7: The Sea Marge Hotel cliff failure exposed back scarp. Approximate height 4m with no ground water noted. (Photo 6) 76

Figure 3-8: Water accumulation and seepage egress from creeping failure behind the beach huts at the central promenade (Photo 7). 76

Figure 3-9: Clifton Way promenade access road. Notable amount of seepage from the

previous failure. (Photo 8). 76

Figure 4-1: Summary of CBUs, identified cliff failures/toe slips, chalk exposures and cliff/promenade seepage locations at Overstrand between 1946 and 2026. 79

Figure 4-2: CBU-A: Chalk and stiff till headlands and embayments with mudslide-type failures at Pauls Lane Car Park. Background image: YouTube video “Overstrand Cliff Slip” dated 18 Jan 2025 by The Content Creator Shaun Button. 83

Figure 4-3: CBA-A: Seepage egress within an embayment in a) 2008 (Source: Brian Farrow NNDC), and b to d) January 2026 JBA site visit. 84

Figure 4-4: Overstrand 1953 showing CBU-B mudslide-type to rotational-type transition zone. At this time, the promenade had been recently rebuilt and slopes reprofiled . Source: Britain from Above archive (licenced) . 86

Figure 4-5: Central promenade cliff (CBU – C) observations and suspected failure mechanisms. Background image: YouTube – “Overstrand Cliff Slip” by The Content Creator Shaun Button. 88

Figure 4-6: Progressive-retrogressive rotational failure mechanism for CBU-C 89

Figure 4-7: Composite rotational slides over chalk at Ivy Farm (CBU-D) and the remediated multi-level landslip complex at Clifton Way (CBU-E) shown in 1998 aerial photograph (NNDC, 1998) 91

Figure 4-8 East promenade standing area (CBU - D) and Clifton Way remediated failure (CBU – E) observations and proposed failure mechanisms. Background image NNDC. 92

List of Tables

Table 2-1: Summary table of historical OS maps and 2025 satellite observations. Sources: National Library maps of Scotland and Google Earth. 19

Table 2-5: Definition table of cliff stability based on HR Wallingford (2003). 35

Table 2-6: Cliff recession models. Source HR Wallingford (2003) 35

Table 2-7: Summary table of Cliff stability assessments and potential recession models at Overstrand locations. Source: HR Wallingford, 2003. 36

Table 2-8: Generalised ground investigation data from Clifton Way. Adapted from Frew and Guest (2009). 36

Table 2-9: Borehole/interceptor well identifier and locations 41

Table 2-10: Summary of Shoreline Management Plan policy statements at Overstrand 54

Table 2-11: Summary table of rates of Overstrand cliff retreat rates based on Cambers (1976) and by Clayton and Coventry (1986)* 65

Table 2-12: Cliff regression rates at specific locations at Overstrand. 66

Table 4-1: Summary table of CBUs location 78

Table 4-2: Cliff Behaviour Unit characteristics and significance of water on cliff stability 80

Abbreviations

AONB	Area of natural beauty
bgl	Below Ground Level
BGS	British Geological Survey
BH	Borehole
BRLSG	Briton's Lane Sand and Gravel
CBU	Cliff Behavioural Units
CI	Cast Iron
CRF	Cromer Forest-bed Formation
LiDAR	Light detection and ranging
mAOD	Metres above ordnance datum
NCP	Norfolk Coast Partnership
NNDC	North Norfolk District Council
NNRCMP	National Network of Regional Coastal Monitoring Programmes
OS	Ordnance Survey
PLCP	Pauls Lane Car Park
PE	Polyethylene
SMCL	Sheringham Cliffs Formation
SSSI	Site of special scientific interest
UXO	Unexploded Ordinance
WHCK	White Chalk Subgroup
WRCG	Wroxham Crag Formation

Definitions

Colluvium	Geological material that accumulates at the base of a slope as a result of weathering and erosion
Detrital	Particles of rock derived from pre-existing rock through weathering and erosion
Glaciogenic	Sediments laid down within or under glacier ice or deposited by an ice sheet
Lithofacies	The visible physical and compositional characteristics of a rock unit that reflect its depositional environment.
Subaerial	Formed in the open air or on the earth's surface, not underwater or underground

Executive Summary

JBA Consulting has been appointed by North Norfolk District Council (NNDC) to undertake a focused investigation into understanding the relationship between water and cliff failure at Overstrand on the North Norfolk coast and to identify realistic practical approaches to mitigate the rate of cliff failures. **Section 1** of this report establishes the scope of work, extents of the study area, structure of the report and sources of information. **Section 2** covers the various information reviews; **Section 3** presents observations from JBA site visit and **Section 4** aims to classify location specific extents within the overall site into Cliff Behaviour Units (CBUs) based on observable features and using industry guidance. **Section 5** of this report presents a summary of the preceding sections, whilst **Section 6** interprets the specific conclusions for each of the cliff behavioural units (CBUs) within the overall site.

Sections 2–4 establish that **water is the dominant control on cliff stability at Overstrand**, acting in combination with complex geology, historic coastal management, and evolving climate pressures. The cliffs at the Overstrand site have been divided into **five Cliff Behaviour Units (CBUs A to E –** refer to **Figure 4-1 in Section 4)** or location specific sub-sections, each with distinct interactions between geology, water, and failure mechanisms.

Site context and evolution (Section 2.1–2.4) - Overstrand's **~30 m high cliffs** are part of a naturally eroding coastline shaped since the last glaciation**.** However, **over 140 years of coastal defences** have significantly altered this natural behaviour—holding the coastline artificially seaward (by ~350 m compared to undefended areas) and shifting instability mechanisms away from rapid marine erosion toward slower, water-driven processes within the cliffs. Recent works (2025–2026) mark a transition from "Hold the Line" to "Managed Realignment," meaning future large-scale hard defences are unlikely.

Geological and hydrogeological controls (Sections 2.5–2.12) - The cliffs comprise **highly variable glacial tills**, with unpredictable layering of sands, clays, and chalk. This variability strongly governs how water moves through the slope:

- Groundwater flow is **heterogeneous and locally concentrated**, often controlled by thin permeable layers.
- Perched water tables and pressure build-ups are common due to discontinuous impermeable layers.
- Historical groundwater interception boreholes show **mixed and often ineffective performance**, with some now potentially worsening conditions due to blockage or poor decommissioning.

Overall, the geology makes **precise prediction difficult** but confirms that **small-scale variations in permeability can have large impacts on stability**.

Water sources and pathways (Sections 2.10, 2.13, 2.19–2.21) - Multiple water inputs influence the cliffs:

- **Groundwater** (primarily from surrounding permeable sands and gravels)
- **Rainfall infiltration**, increasingly intense since ~2008
- **Localised surface water flows and drainage systems**

Water does not emerge uniformly; instead, it forms **discrete seepage points**, which strongly correlate with observed failure locations (e.g., backscarps and embayments).

These focused flows elevate pore water pressures and weaken materials locally, making them key triggers for instability.

Processes linking water to cliff failure (Sections 2.15–2.17) - The relationship between water and cliff behaviour depends on whether the cliff toe is protected:

- With **active wave attack** → rapid, episodic erosion (toe undercutting)
- With **defended toes** (as at Overstrand) → slower, progressive failures dominated by:
  - Groundwater pressure
  - Seepage erosion
  - Rainfall-driven saturation

Tills are particularly sensitive: they can remain steep until failure, but **lose strength rapidly when saturated or disturbed**, leading to mudslides, rotational slips, and long-term slope adjustment.

Role of coastal defences and sediment dynamics (Sections 2.3, 2.16, 2.26–2.27) - Coastal defences are the **primary control on erosion rates**, having reduced retreat from ~1.2–1.9 m/yr historically to ~0.2–0.3 m/yr today. However:

- They **trap the system in a non-natural state**, with risk of accelerated "catch-up" erosion if removed.
- Cliff stability increasingly depends on **internal drainage and groundwater conditions**, rather than marine processes alone.
- Beach levels and "beach wedge area" strongly influence future erosion rates.

Climate change impacts (Section 2.14) - Future conditions will intensify water-related instability:

- **2–4 times increase in extreme rainfall and storms**; and **0.3–0.4 m sea-level rise**
- Increased groundwater recharge and more frequent saturation events

This will **amplify both groundwater-driven failures and the likelihood of defence overtopping or degradation**, requiring adaptive, time-limited management strategies.

Cliff Behaviour Units (Section 4 - Figure 4-1 shows extents of these on Site Plan**) -** The cliffs have been divided into **five Cliff Behaviour Units (CBUs)**, each with distinct interactions between geology, water, and failure mechanisms. Across all units:

- **Groundwater is a primary driver of instability,** except for CBU-A being coastal erosion driven
- Failures are typically associated with **localised seepage, elevated pore pressures, and saturation of colluvial deposits**
- Variations in geology (e.g., presence of chalk rafts) create **spatially variable stability conditions**
- **Photos showing annotated elevations** are in Figures(4-2 to 4-6) in Section 4.

Key Overall Insight - Across Sections 2–4, the evidence consistently shows that while coastal defences control **whether erosion occurs**, it is **water (groundwater, rainfall, and seepage) that controls how and where the cliffs fail**. As a result, future stability at Overstrand will need to be based on **understanding, managing, and adapting to water within the cliff system itself,** with additional benefit gained in certain areas of the site using toe protection or erosion control features /defending the sea approach. **The mitigation strategies and measures are covered in the Part II report.**

1 Introduction

1.1 Project overview and objectives

JBA Consulting has been appointed by North Norfolk District Council (NNDC) to undertake a focused investigation into understanding the relationship between water and cliff failure at Overstrand on the North Norfolk coast, approximately 2 miles (3.2km) southeast of Cromer.

This work is part of the Coastwise initiative being delivered by NNDC, with funding support from DEFRA and the Environment Agency via the Coastal Transition Acceleration Programme.

The objectives of the project are:

1. To draw together existing technical and local knowledge to inform understanding of the relationship between water and cliff failures specifically at Overstrand.
2. To summarise and present this knowledge in a clear accessible way.
3. To identify realistic practical approaches that may assist with managing water locally to mitigate the rate of cliff failures, including consideration of engineering techniques whereby groundwater flows can be controlled, managed or eliminated.

1.2 Scope of this report

This Part 1 report (comprised of Volume 1 Study Report & Volume 2 Appendix) addresses the project Objectives 1 and 2 listed above. Objective 3 is addressed separately in a companion Options Report (Part 2).

The geographical scope of the study area considered is shown in Figure 1-1, which spans approximately 950m of coastal frontage from the beach area below Beach Close to the rock armour below the Clifton Way.

This study area is entirely within Shoreline Management Plan (SMP) Unit SMP6-6.06 which has recently transitioned from SMP designation “HL1 - Hold The Line”, which applied from 2005-2025, to “MR5 – Managed Realignment – Repair not replace”, applicable 2025-2055. Post-2055 the designation will become “MR2 – Managed Realignment – Slow erosion”. Under the current technical definitions of these designations, it is understood that, in principle, neither MR5 or MR2 preclude the introduction of cliff retreat mitigation measures set back from the shoreline, provided these are designed only to slow, but not stop, cliff erosion, and that this forms a technical and policy basis for the study.

The technical scope of the study includes consideration and review of the sources of information listed in Section 1.4, which includes information relating to cliff geology, hydrogeology and geomorphology, historical and current land use and designations, drainage and flooding, academic and government specialist research, historical and current coastal/cliff protection measures, cliff failure mechanisms and weather/climate effects.

This pre-existing reference information was further supplemented by JBA's own on-site observations made during a site visit undertaken between 29-30 January 2026.



Figure 1-1: 2025 aerial image of Overstrand and inset map showing geographic location Source: NNRCMP Aerial Imagery and open map.

1.3 Structure of this report

The structure of this report is as follows:

- Section 2 presents a review of information of site-wide relevance to all structures/locations listed above, to be read together with Appendix A.
- Section 3 provides an overview of the site visit conducted for this assessment.
- Section 4 presents an assessment of Overstrand cliffs into Cliff Behaviour Units based on the information presented in Sections 2 and 3 and including assessment of the relationship between cliff stability and water.
- Section 5 presents a summary of findings from the study.

1.4 Sources of information

Given the long list of references used, the references within sub-sections 1.4.1 and 1.4.4 have been added to Appendix A.

1.4.1 Publicly available information online sources

Refer to Appendix A (Volume 2) for the list under this section.

1.4.2 Information provided/sourced by JBA

Name	Purpose	Link
Utility survey drawings	Review of potable, stormwater and foul water drainage	Included in Volume 2
Zetica UXO Pre Desk Study Assessment	Preliminary assessment of possible UXOs within Overstrand and the cliffs.	Included in Volume 2

1.4.3 Information provided by NNDC (Client)

Name	Purpose	Link
Historical Photos	Dating of previous cliff failures, evidence of previous works to combat coastal erosion	Included in Volume 2
Clifton Way Borehole Logs	Information on ground condition adjacent to site	Included in Volume 2
Interceptor Borehole Logs	Information on ground conditions within and surrounding the site area	Included in Volume 2

1.4.4 Academic and industry research, guidance and technical literature

Refer to Appendix A (Volume 2) for the list under this section.

2 Review of Site Information

2.1 Site location and description

Overstrand is located on the North Norfolk coast, approximately 2 miles (3.2km) southeast of Cromer. The village is home to approximately 1000 residents and is situated above cliffs typically around 30m high overlooking the North Sea. Ground surface elevations are indicated in Figure 2-1.

The beaches at Overstrand are low and sandy, with high water reaching the foreshore promenade at the base of the cliffs each day. Low water mark is approximately 80-100m seaward from the cliffs.

In common with much of the North Norfolk coast, coastal erosion at Overstand has been a growing concern since the dawn of the 20th Century. However, it is important to remember that the natural coastal processes and causal factors behind the erosion of Overstrand's

cliffs have been ongoing for around 10,000 years since the end of the last ice age (NNDC, 2009).

Domesday Book records record many North Norfolk villages formerly situated on land that existed north of the current coastline but that has since been overtaken by coastal erosion, for example Shipley, which was located around 150m seaward of what is now Cromer Pier, which was lost by around 1400.

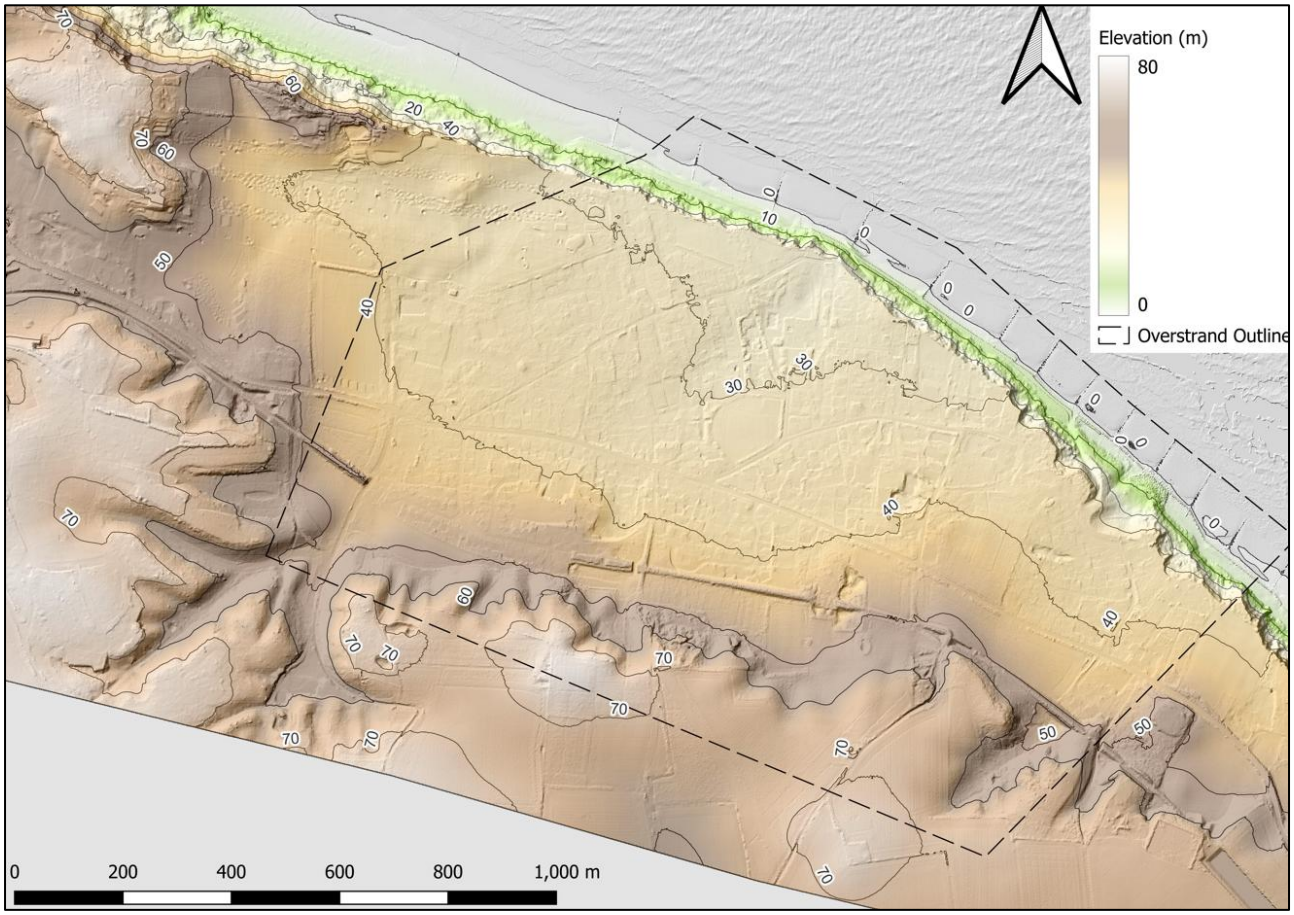


Figure 2-1: Topography of the Overstrand area.

2.2 Site history

Information from National Library of Scotland (2026), Britain from Above (2026), HR Wallingford (2002), NNRCMP (2026), NNDC (2026), Google Earth (2026) and JBA's own site observations has been used to relate Overstrand's development to its coastal setting.

Historically, Overstrand was a small fishing hamlet until the late 19th Century when it became increasingly popular as a seaside resort, growing rapidly and substantially following the opening of a railway station at Overstrand in 1906. Table 2-1 summarises key developments within the general vicinity of Overstrand from 1885 to the present day (2026).

Table 2-1: Summary table of historical OS maps and 2025 satellite observations. Sources: National Library maps of Scotland and Google Earth.

OS Map	Overview
1885 OS 6 Inch	Overstrand is a collection of small cottages and the larger Overstrand Hall. Cliffs have no development upon. Breakwater noted at the end of Paul's Lane (Steps down to promenade from NW of site). Surrounding area agricultural. Numerous clay and Marl pits. Kiln holes present to the south of the village.
1907 2nd Edition. Sheet XII	Significant increase in development of the village with addition of the Overstrand Hotel set back from the cliff but no development on the cliffs. The map appears to show the construction of a small seawall (approximately 200m long) at the current location of the access steps leading down to the beach at Pauls Lane and Cliff Road confluence. Most of the village still consists of mainly large gardens but there is the construction of the Overstrand Railway to the south the village with a mixture of embankment and cuttings. The Railway has now dissected now defunct Lime Klins. Subway built underneath The Pleasaunce Estate to the public footpath on the NW tip of the study area. Importantly, geologically, there is a gravel pit noted south of the railway cutting immediately south of the current day allotments. This feature confirms the presence of the Briton Sand and Gravel Formation (to be discussed in the next section) at this location, providing confidence in the superficial deposits map.
19x8 OS 25Inch Norfolk XI.16	Railway now present with Station on southern outskirts of the village. Additional buildings to the SE of Overstrand Hotel ~30m away from cliffs. Cliffs reprofiled around Overstrand Hotel itself with walkway down to the beach. Gravel pit now gone.
1956 OS 1:25k TG14	Noted that footpath has been built at the base of the cliffs with the addition of Groynes. Overstrand Hotel and SE building now missing (local research determined this was due to a fire in 1947). Cliff regression in this area noted. Railway and subway still present.
1969 OS 1:1250 TG2440	Footpath at base of cliffs now noted as Promenade with Groynes clearly defined. Cliff reprofiled to accommodate footpath from Pauls Lane. Railway now dismantled with new estate formed (Bracken Avenue), approaching the former station (Bracken Avenue). Second estate created SE of site south of former Overstrand Hotel (Grane Avenue). Subway now likely infilled at The Pleasaunce.
Current Day (2026)	Additional housing east of The Pleasaunce. Expansion of the estate east of old Station Farm (Lutyens Drive). Caravan Park and additional housing along Clifton Way. Majoy landslip on Coast Road has been repaired but loss of housing has been noted.

A comparison of land use in 1886, 1961 and 2026 is shown in Figure 2-2, Figure 2-3 and Figure 2-4, showing the significant growth between 1886 and 1961, and primary usage changing from agricultural to suburban. Development after 1961 was primarily infill housing estates, including those at Church Close (historic railway development), the Danish House Gardens and the Caravan park at Ivy Farm.

Current land cover is approximately 60% suburban, less than 5% urban and the remaining 35% as woods and grasslands. Suburban and urban definitions are not provided by UKCEH but are assumed based building density and property type.

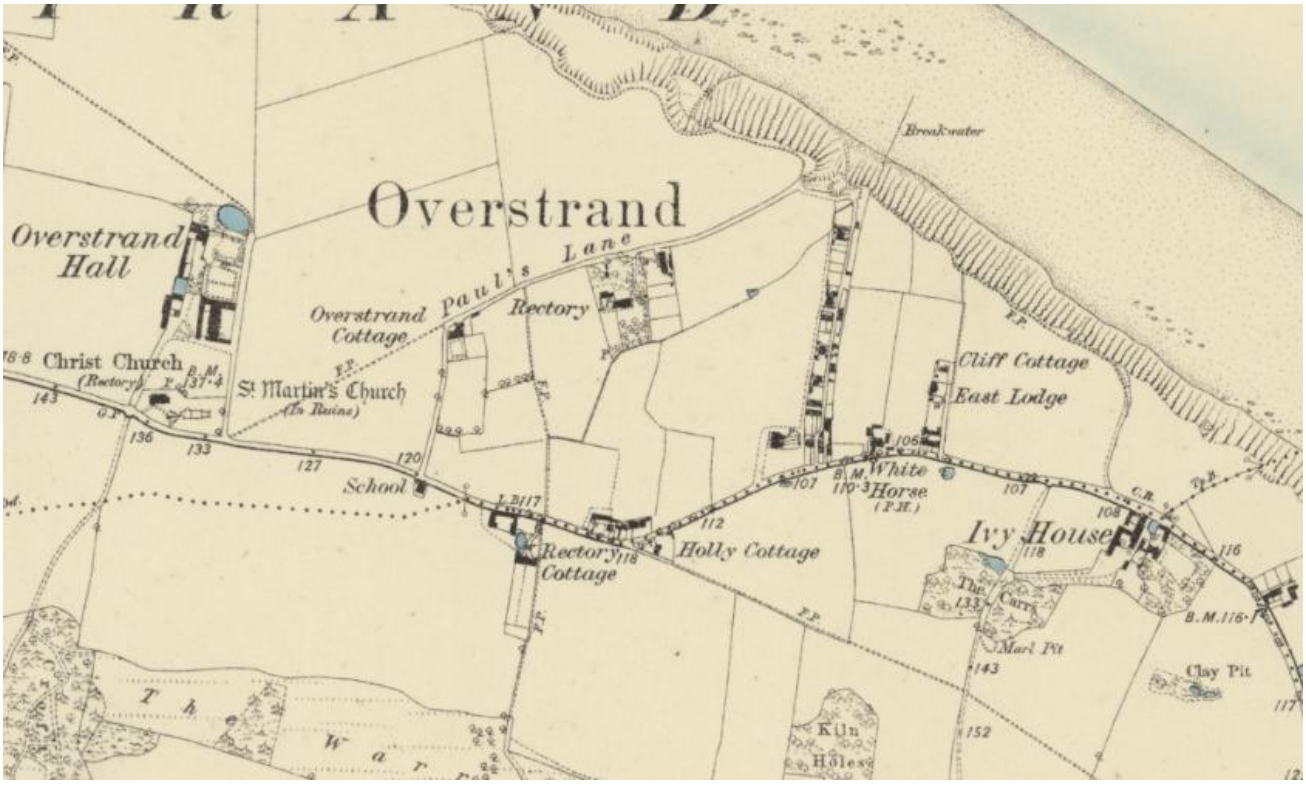


Figure 2-2: OS 1886 1 Inch. Norfolk XI.NE & SE.



Figure 2-3: 1961 Land utilisation map (ref. TG23NE & TG24SE – Land Utilization Sheet 549 – North Walsham, 1961). Source: Scottish Library Maps.

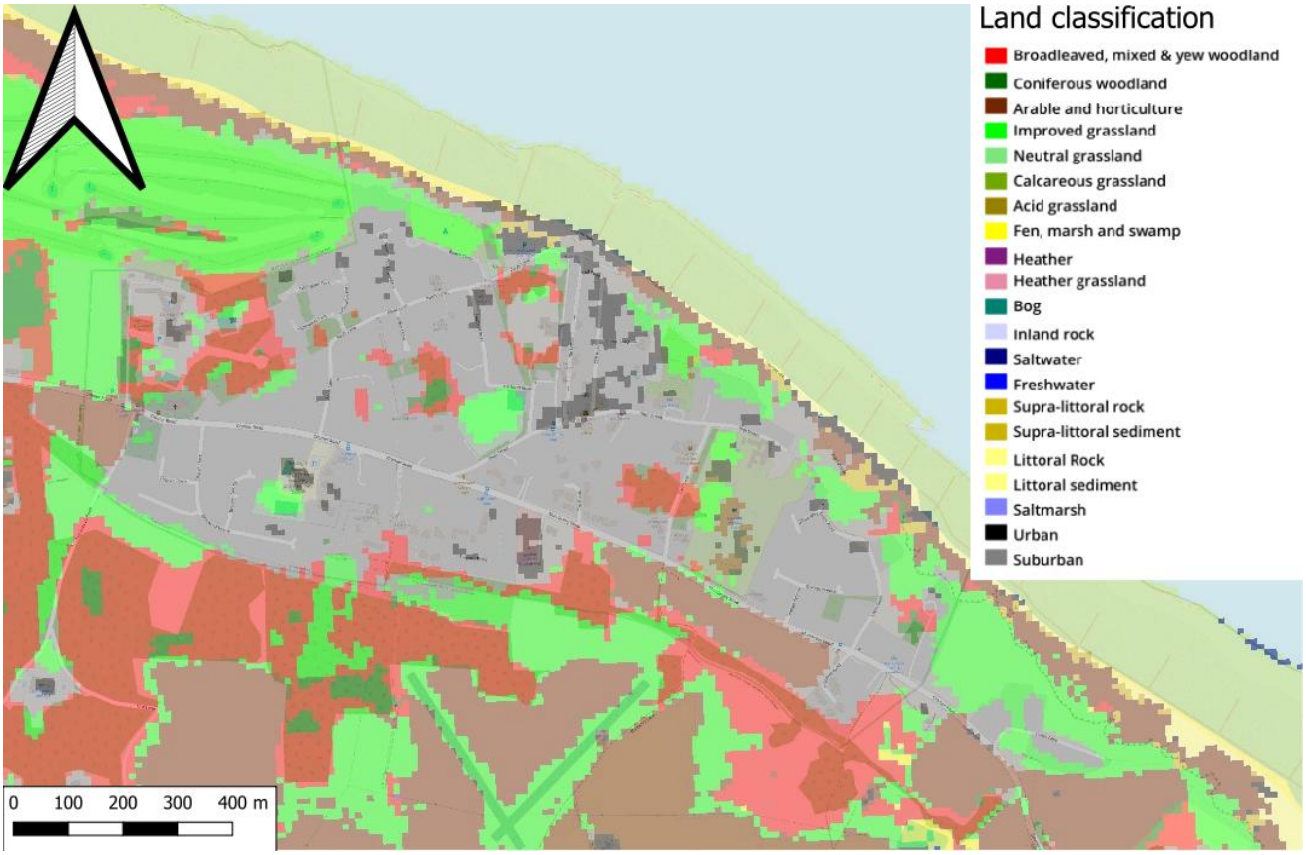


Figure 2-4: 2026 Landcover classification at Overstrand. Source: CEH

2.3 Coastal defences

From the 1890s onwards, development of new clifftop properties including large hotels and tourist demand for easy and reliable beach access prompted construction of coastal defences to mitigate the cliff erosion that had been occurring naturally for millennia prior.

The information sources listed in Section 2.2 have been used to determine the timeline, types and locations of coastal defences developed between the 1890s and the present day, as summarised in Table 2-2 and Figure 2-5, the latter also showing locations of present-day landmarks in Overstrand for reference.

Figure 2-6 to Figure 2-11 provide photographic examples of historical and current defences (further examples are included in Volume 2 of this report).

Table 2-2: Summary of sea defence types, construction and other dates of importance.

Defence type	Dates	Descriptions
Groynes	1886	Initial construction date with varying additions over time.
Seawall	1890	Pauls Lane/Cliff Road and The Sea Marge private seawalls constructed
	1901	Old Overstrand Hotel seawall constructed
	1920	Empingham Council unified private seawalls along Overstrand beach (except at former Overstrand Hotel).
	1946	Major storm damage across the existing seawall
	1953-1955	Refurbishment of Pauls Lane/Cliff Road seawall (1953). Construction of new seawall and promenade in front of the 1920s structure (except at former Overstrand Hotel).
	1980	Final extension of the promenade to its current day configuration. Old Overstrand Hotel Seawall removed in process.
Rock armour	1949	Ad hoc rock armour installed western edge of Promenade.
	1967	Ad hoc rock armour placement seaward of Old Overstrand Hotel seawall.
	1995	Large rock armour revetment constructed to reinstate the cliff toe following a large failure at Clifton Way in 1994
Sheet piles with rock infill	1965	Continuation from Ad hoc rock armour into chalk cliffs at western end of promenade
Palisades	1967	Constructed where no existing defences were present. Palisade structures include supporting sheet piles embedded in the underlying beach.
Gabion baskets	1982	Constructed close to Cliff Road access paths to protect the cliff toe behind the promenade from overtopping waves during high tides
Legato blocks	2025	Constructed close to Cliff Road access paths to protect the cliff toe behind the promenade from overtopping waves during high tides

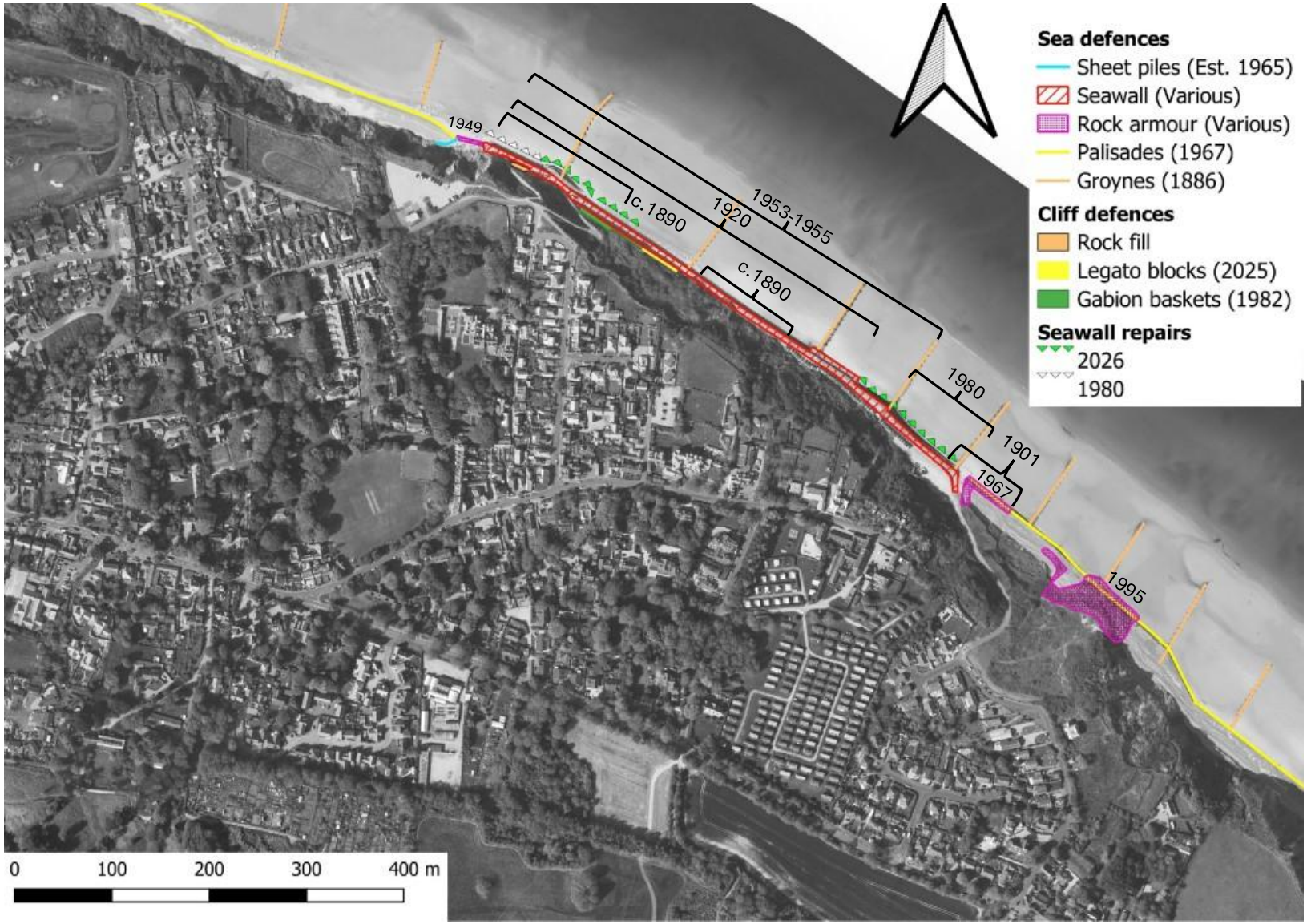


Figure 2-5: Types of sea defences and points of interest within Overstrand.

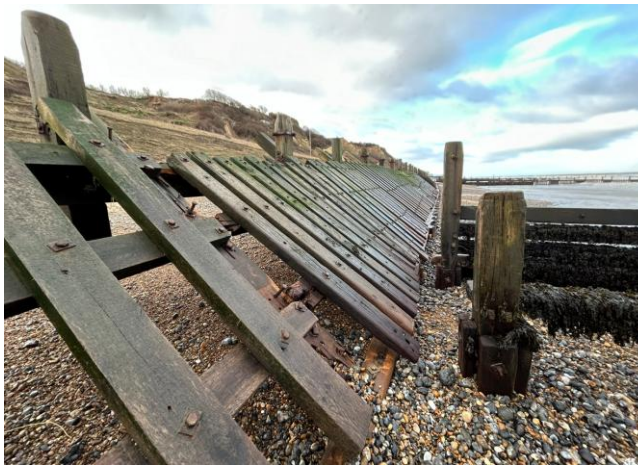


Figure 2-6: Example of timber palisades and groynes at Overstrand (15/01/2024). Source: NNDC.



Figure 2-7: Seawall/Promenade at Overstrand with apron section (25/07/2022). Source: NNDC

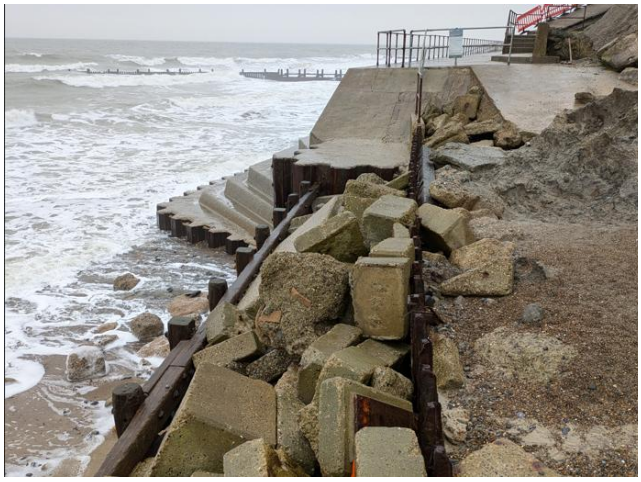


Figure 2-8: Informal rock armour at the western end of the promenade (30/01/2026). Source: JBA



Figure 2-9: Rock armour at the base of Clifton Way. Source: NNDC



Figure 2-10: Legato blocks supporting debris boards behind along the promenade (01/12/2025). Source: NNDC



Figure 2-11: Gabion basket installations along the promenade (29/01/2026). Source: JBA

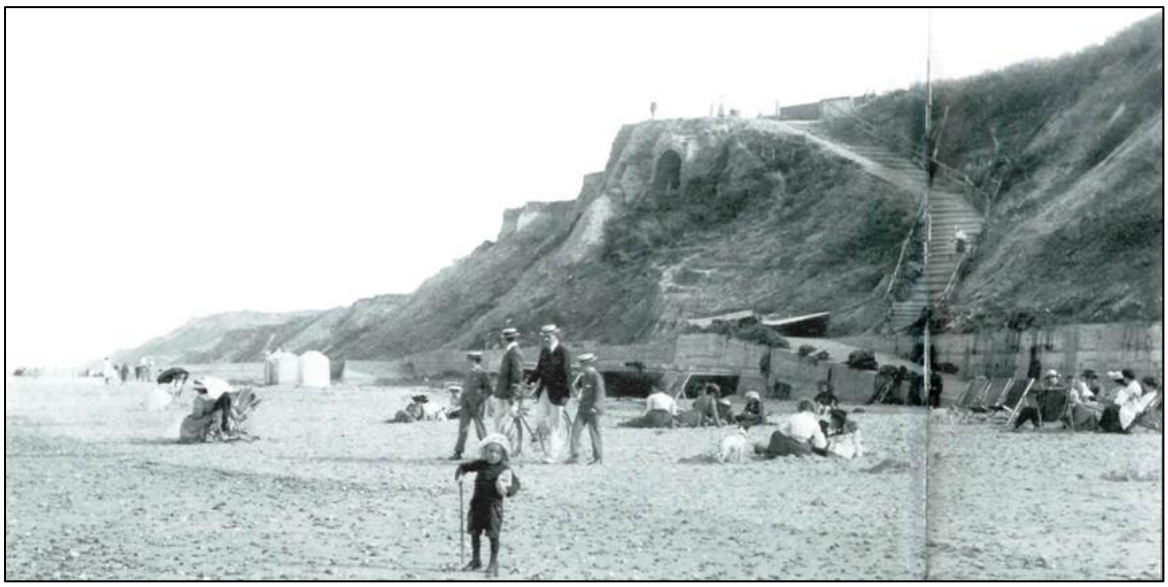


Figure 2-12: Historical photo of Overstrand dated 1907 showing a section of the original 200m long concrete seawall at the bottom of the Cliff Road/Paul's Lane cliff face with access steps to the crest. Note the tunnel/shelter through the cliff. Source: NNDC

Figure 2-13 provides an illustration of the wider effect that circa 140 years of coastal defence works at Overstrand have had on the local coastline. Overstrand sits on a coastal promontory where the clifftop position (which has been artificially held in place by coastal defences) is now up to 350m seaward of equivalent cliff tops at Cromer and Sidestrand. This is around double the distance that existed in 1886 when the first evidence of beach groynes appears on historic maps, and implies that, had hard defences never been built at Overstrand, that much of the land currently north of Cromer Road / Mundsley Road would by now have been eroded.

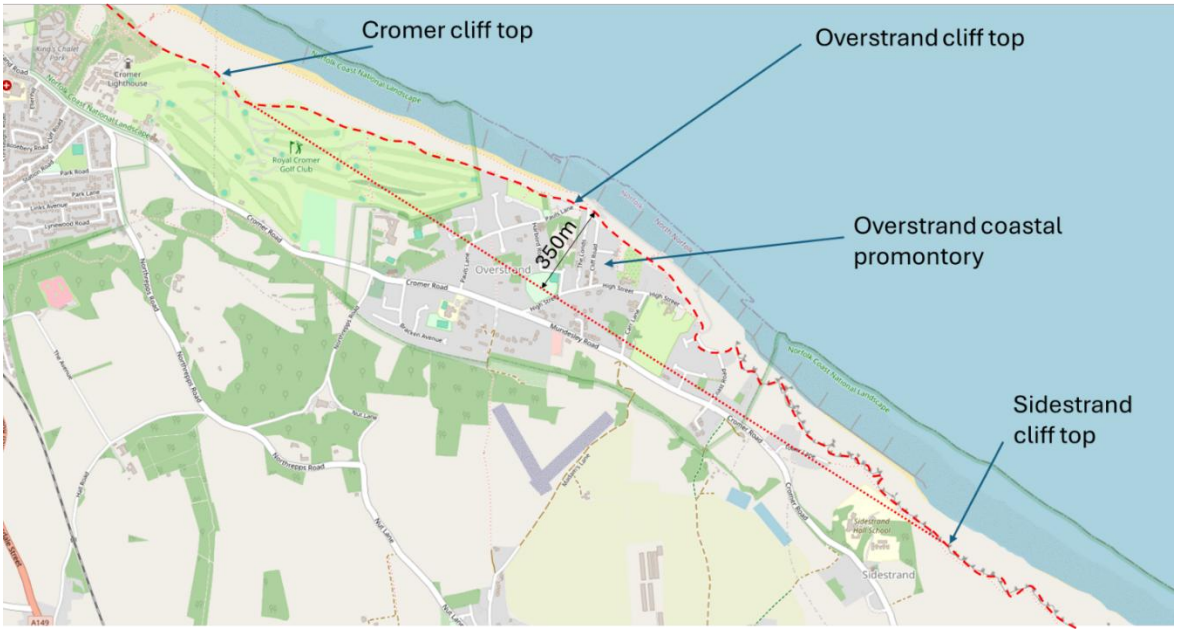


Figure 2-13: The local coastal promontory at Overstrand (Map image © OpenStreetMap, 2026)

2.4 Recent coastal defence works

In 2025-2026, the seawalls/promenade fronts in the vicinity of Cliff Road and Clifton Way beach access ramps were refurbished by installing two new sections, 120m and 140m long respectively, of new sheet piles and concrete infill just seaward of the existing life-expired piles (installed between the late 1980s and 1997). NNDC (2026) works were stated to cost £1.28M and have a design life of 20 years (i.e. until about 2051).

2.5 Geology and geological setting

The geological setting at Overstrand is highly complex, due to the North Norfolk Coast being located in a geographical zone that has been subject to multiple glaciations beginning in the Anglian (circa 400,000 years ago) and ending in the Devensian (circa 20,000 years ago), as indicated in Figure 2-14.

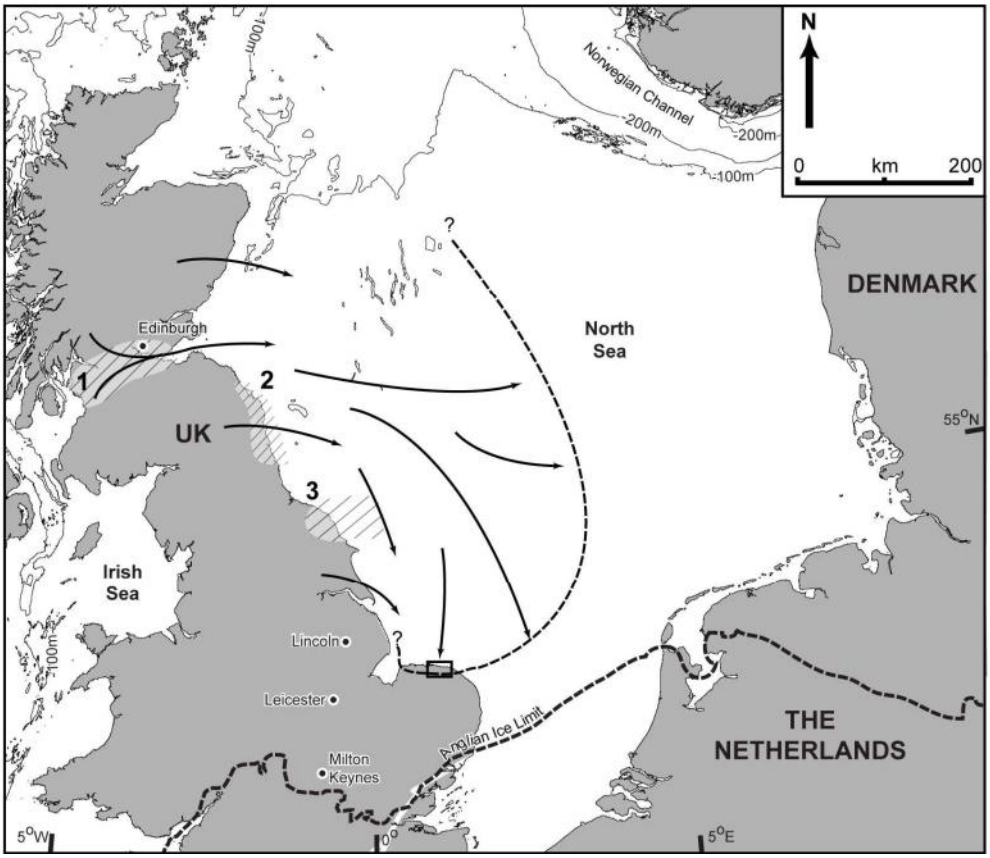


Figure 2-14: Map of Anglian (largest) and Devensian (most recent) glacial ice extents. Source: Evans et. al. (2011)

Each broad period of glaciation included multiple internal, shorter periods of localised ice advance and retreat in the periglacial zone close to the edge of the ice sheet with Overstrand's location coinciding with the most recent (Devensian) glaciation. This has cause laid down ground to be massively reworked in this period (Lee et al. 2017; see Figure 2-15 and Figure 2-16), resulting in the complex, highly heterogeneous and localised stratigraphic sequences with the cliff faces at Overstrand.

This heterogeneity means that the physical properties of the soil that are important for cliff stability (such as a tendency to reduce in strength when subject to gradual movements, or being permeable to flowing groundwater) and can vary significantly between different layers of materials.

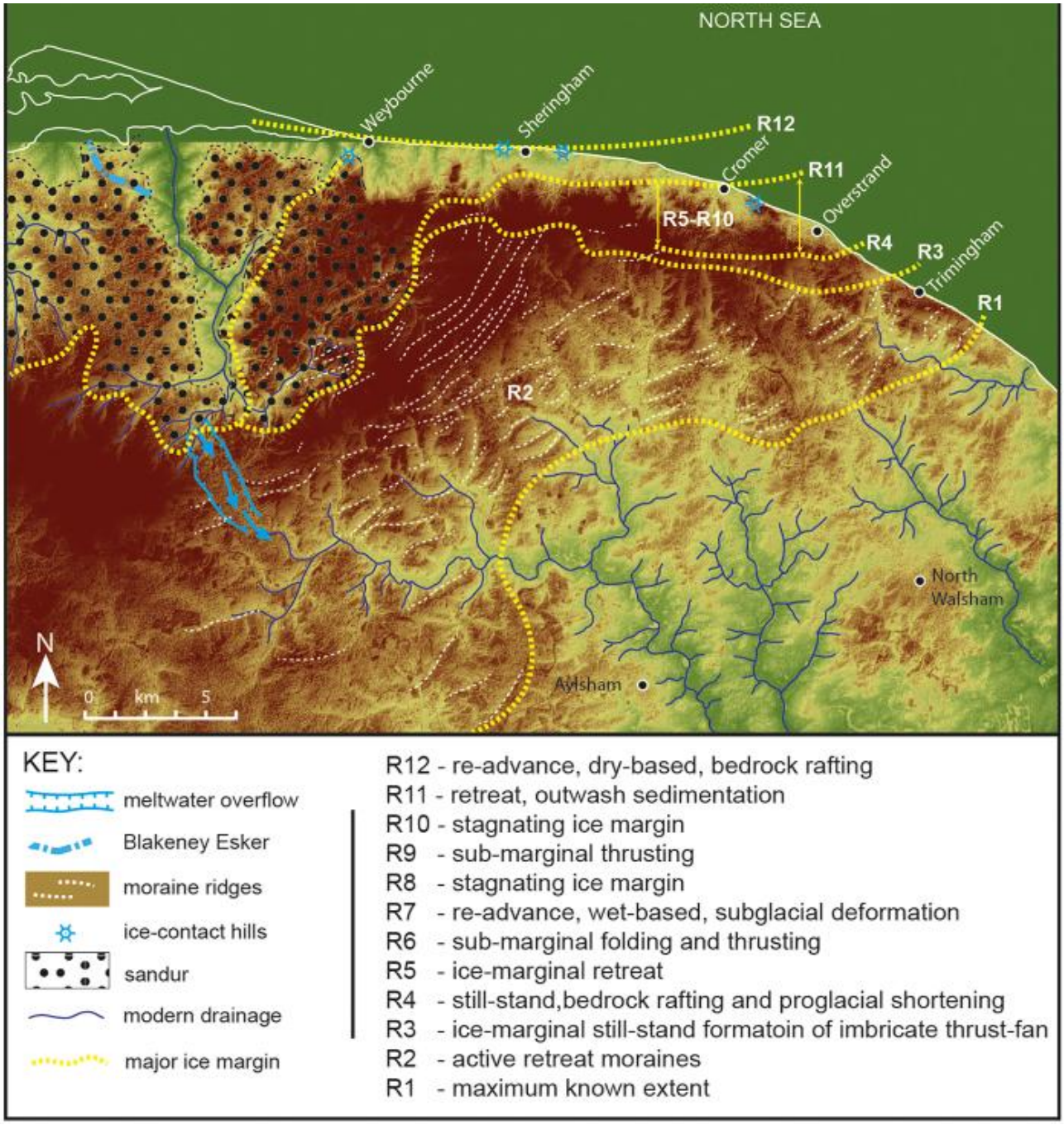


Figure 2-15: Extents of periglacial ice advance/retreat stages R1-R12 in the vicinity of Overstrand during the Devensian glaciation Source: Lee et. al. (2017)

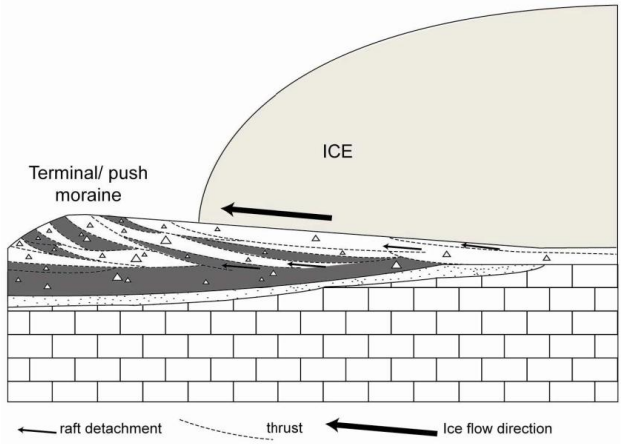


Figure 2-16: Glacial reworking of North Norfolk Coast geological strata during the Devensian glaciation Source: Evans et. al. (2011)

Understanding of Overstrand's complex geology has developed over time (Figure 2-17 to Figure 2-19), demonstrate how the level of detail in naming, characterising and spatially arranging of geological units has improved. However, a knowledge gap still exists due to Overstrand's coastal defences allowing vegetation and colluvial slopes to establish and obscure the geology.

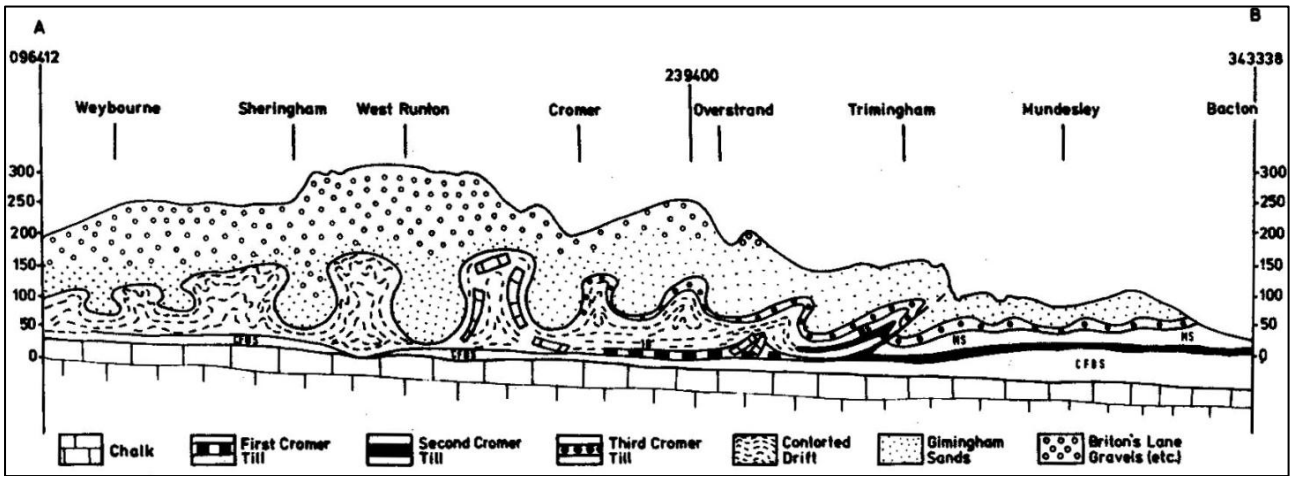


Figure 2-17: Banham (1975) model of cliff geology between Weybourne and Bacton (note elevation in feet)

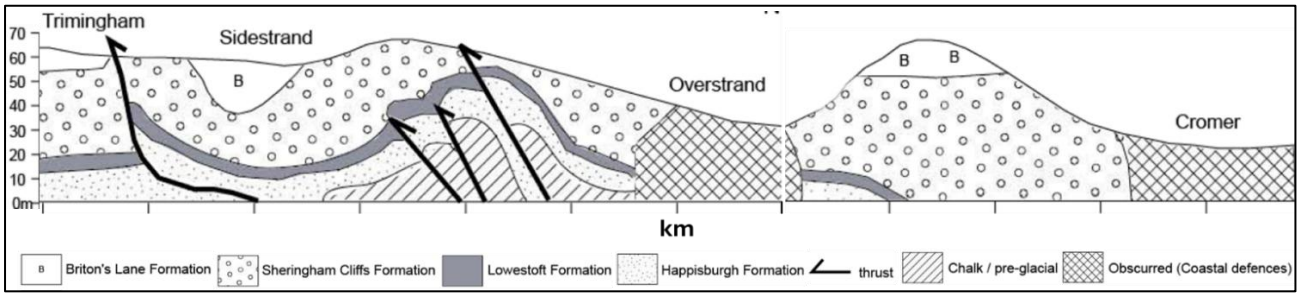


Figure 2-18: Lee et. al. (2004) model of cliff geology between Trimingham and Cromer

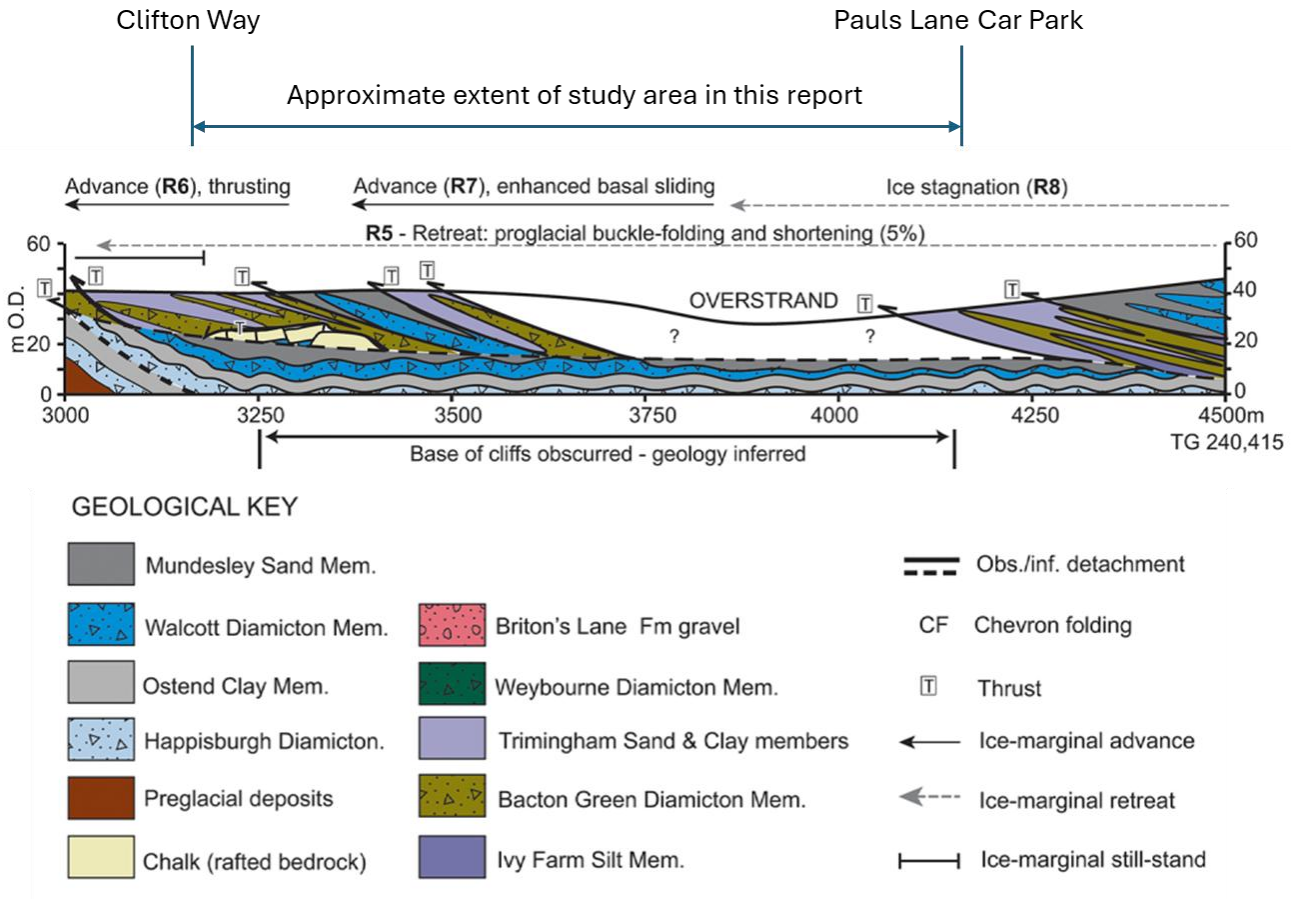


Figure 2-19: Lee et. al. (2017) geological model at Overstrand (note "?" denotes zone obscured by vegetation due to toe defences)

An indication of the relationships between recent and older geological naming and characterisation at Overstrand and historical characterisations is shown in Table 2-3.

Table 2-3: Relationships between recent and older geological naming in the vicinity of Overstrand. Source BGS, 2008

(Hamblin, 2000)		(Banham, 1988)	(Lee *et al.*, 2004a)	
Overstrand Formation		Gimingham Sands	Briton's Lane Formation	Stow Hill Sand & Gravel Member
Beeston Regis Formation	Hanworth Till Member	3rd Cromer Till	Sheringham Cliffs Formation	Weybourne Town Till Member Trimingham Sand Member Trimingham Clay Member Bacton Green Till Member Ivy Farm Laminated Silt Member Mundesley Sand Member
		2nd Cromer Till		
Lowestoft Formation	Walcott Till Member Walcot Diamicton #		Lowestoft Formation	Walcott Till Member
Corton Formation	Happisburgh Clays # Happisburgh Till Member	1st Cromer Till	Happisburgh Formation	Ostend Clay Member Happisburgh Till Member

Table 2-4 provides a summary description of the key geological units, based current BGS Lexicon entries. For full descriptions please refer for the BGS lexicon itself.

Table 2-4: Summary table of superficial and bedrock geology likely to be present within the Overstrand frontage. Source: BGS Lexicon of Named Rock Units.

	Name	BGS Lexicon Description (BGS, 2026)
Superficial geology	Head – Gravel [variable thickness]	Sedimentary deposits are subaerial in origin and are detrital, comprising coarse to fine-grained materials, forming down-slope layers and fans of accumulated material.
	Head – Clay [variable thickness]	As above with a greater clay content.
	Briton's Lane Sand and Gravel Member (BRLSG) [up to 40m thick]	Consist of horizontal, massive and low angle planar cross-bedded gravels and cobble gravels with thin seams of horizontal and rippled sand. It is commonly exposed at the surface, although in places it has a thick palaeosol (ancient soil) developed within the upper 2-3m. Note: Deposited in the same depositional environment as the Sheringham Cliff Formation.
	Sheringham Cliff Formation (SMCL) [up to 40m thick]	There are numerous members within the SMCL formation (Table 2-3,) but to summarise, these are sequences of glaciogenic sedimentary deposits characterised by a mixture of laminated clays, silts and sands of various thicknesses. created by the action of ice and meltwater.
	Lowestoft Formation (LOFT) [extremely variable in thickness, up to 60m]	Forms an extensive sheet of chalky till, together with outwash sands and gravels, silts and clays. The till is characterised by its chalk and flint content.
	Cromer Forest-bed Formation (CRF) [~6m thick]	The formation encompasses the fluvial, lacustrine and organic deposits of the postulated 'Ancaster River'. Essentially, consisting of clays, silts and sands. Refer to BGS lexicon for further information.
Bedrock geology	Wroxham Crag Formation (WRCG) [~20m thick]	Sand and gravels of fluvial, palustrine and shallow-marine origin. They are detrital, forming deposits reflecting the channels, floodplains and deltas of a river in a coastal setting (with periodic inundation from the sea).
	White Chalk Subgroup (WHCK) (Lewes Nodular/ Seaford etc.) [~350m thick]	Chalk – Shallow, biogenic, detrital and marine in origin with flint bands present within the chalk. Refer to BGS lexicon for full description

Figure 2-20 illustrates the relationship between geological units and surface elevation in the vicinity of Overstrand by overlaying BGS 50k superficial geology map onto a recent LiDAR-based surface elevation model. This shows that the high ground surrounding Overstrand is comprised of the Brition's Lane Sand and Gravel Member (BRLSG), incised by shallow valleys of clay and gravel head deposits, indicating the potential for surface water and shallow groundwater flows towards the cliffs.

Overstrand village and its coastal cliffs are shown as formed on/within the Sheringham Cliffs Formation, though as Figure 2-19 indicates, this is a broad generalisation, as glacial processes have reworked the various strata into highly localised sequences. These include:

- glaciotectonic uplift of “rafts” or “erratics” derived from deep till and chalk layers
- strata that can be strongly dipping or folded
- highly irregular contacts between geological units
- rapid changes in material composition (e.g. clay, silt and sand) causing rapid changes in permeability, strength and ductility

Rafts derived from deeper layers of stiff till or chalk have important effects for cliff failure behaviour and relationships with groundwater (see Section 4 for further discussion).

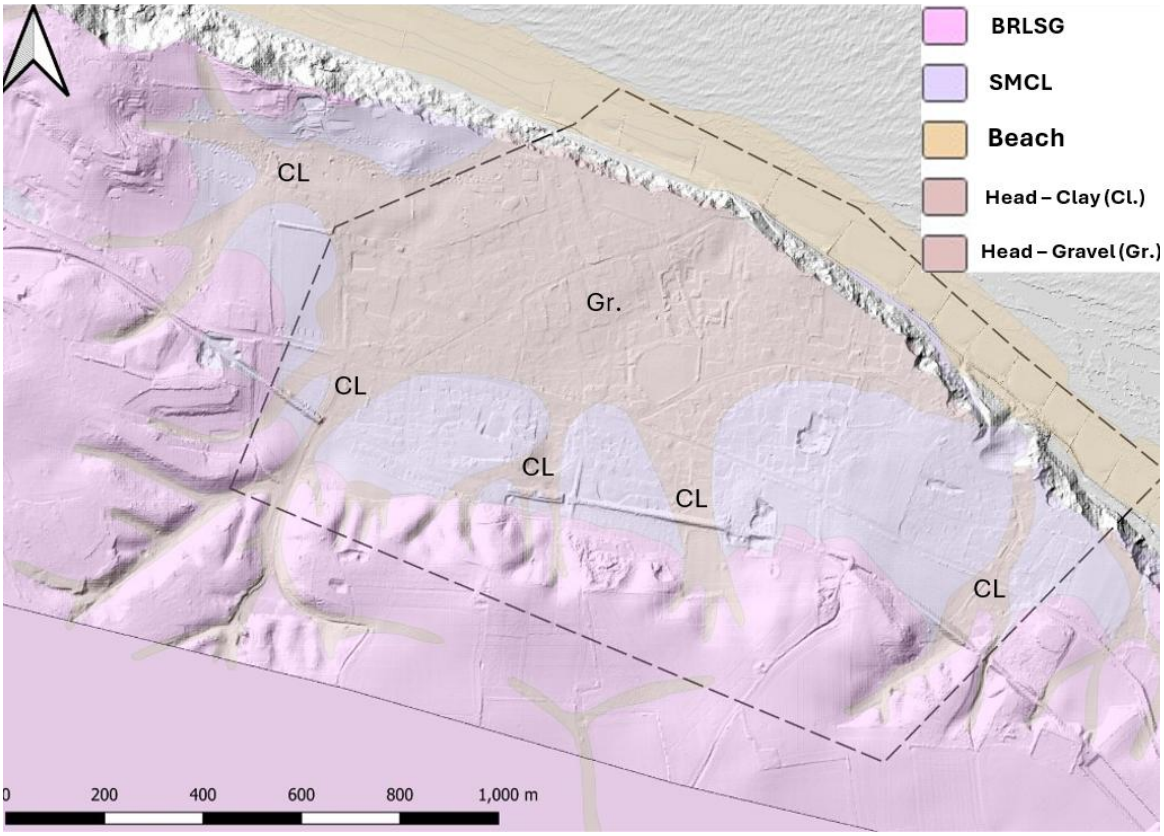


Figure 2-20: Superficial geology map 1:50,000 overlain on 2022 LiDAR DEM. Source: BGS geology viewer.

2.6 Previous geotechnical investigations

A concerted effort to retrieve all available records from historical intrusive ground investigations has been made for this report. Relevant original records have been included in Volume 2 of this report. The following section presents a short summary of that information.

Figure 2-21 presents the locations of all logged holes obtained from NNDC and the BGS GeoIndex, comprising:

- 1No. groundwater control well (W3) dug in 1982 as parr of a groundwater interception system (see Section 2.11 for further discussion)

- 12No. boreholes dug January and July 1994 during investigation and remediation of a major cliff failure at Cliffton Way (see Sections 2.6 and 2.7 for further discussion)
- 1No. borehole dug at the Radar Tower south of Overstrand, sunk in 2004.

Various historic ground investigation plans (included in Volume 2) indicate that other intrusive geological investigations have been made within Overstrand, particularly in relation to groundwater management efforts in the 1960s and 1970s (see Section 2.11) and cone penetration tests made during landslide remediation works at Clifton Way in 1994-5 (see Section 2.7), but these logs were unfortunately not available and are believed lost. The logs that remain available generally demonstrate, in broad accordance with the geological model presented in Figure 2-19:

- Strong geological heterogeneity in general, with highly localised variation in dominant material type (e.g. clay, silt, sand), often interbedded, and with variations in peak and residual strength of materials
- Highly localised variation in observed groundwater levels, indicating one or more perched water tables in the Sheringham Cliff Formation (and related reworked strata) above that in the deep basal chalk aquifer
- The sandy, gravelly high ground to the south of Overstand is a likely source of surface and subsurface water flows towards the cliffs

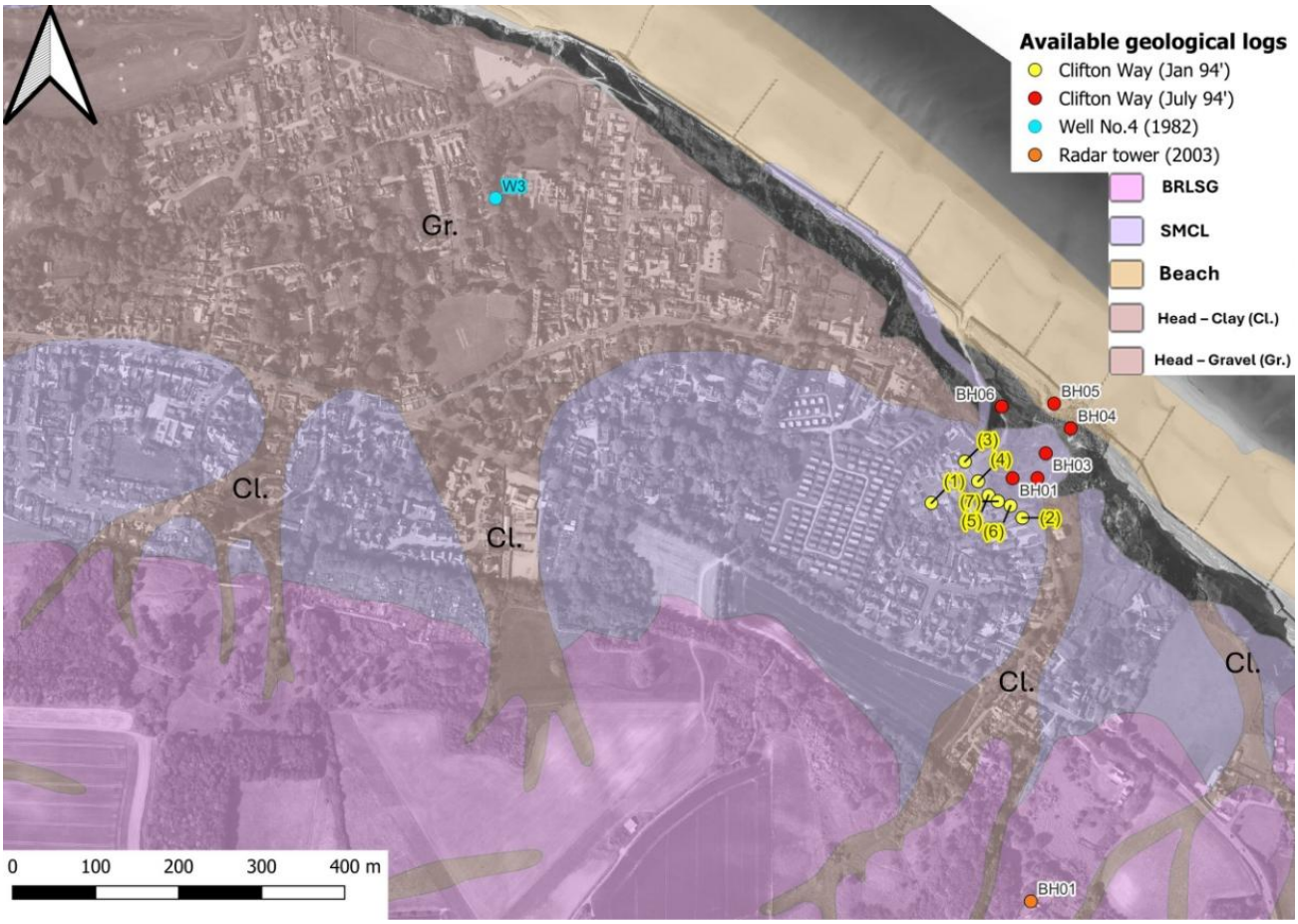


Figure 2-21: Available ground investigation locations laid over superficial geological map.

Figure 2-22 presents topographic section lines intercepting selected boreholes from Figure 2-21 (i.e. W3, Clifton way holes (1), (3) and BH6 and BH01/Radar Tower)..

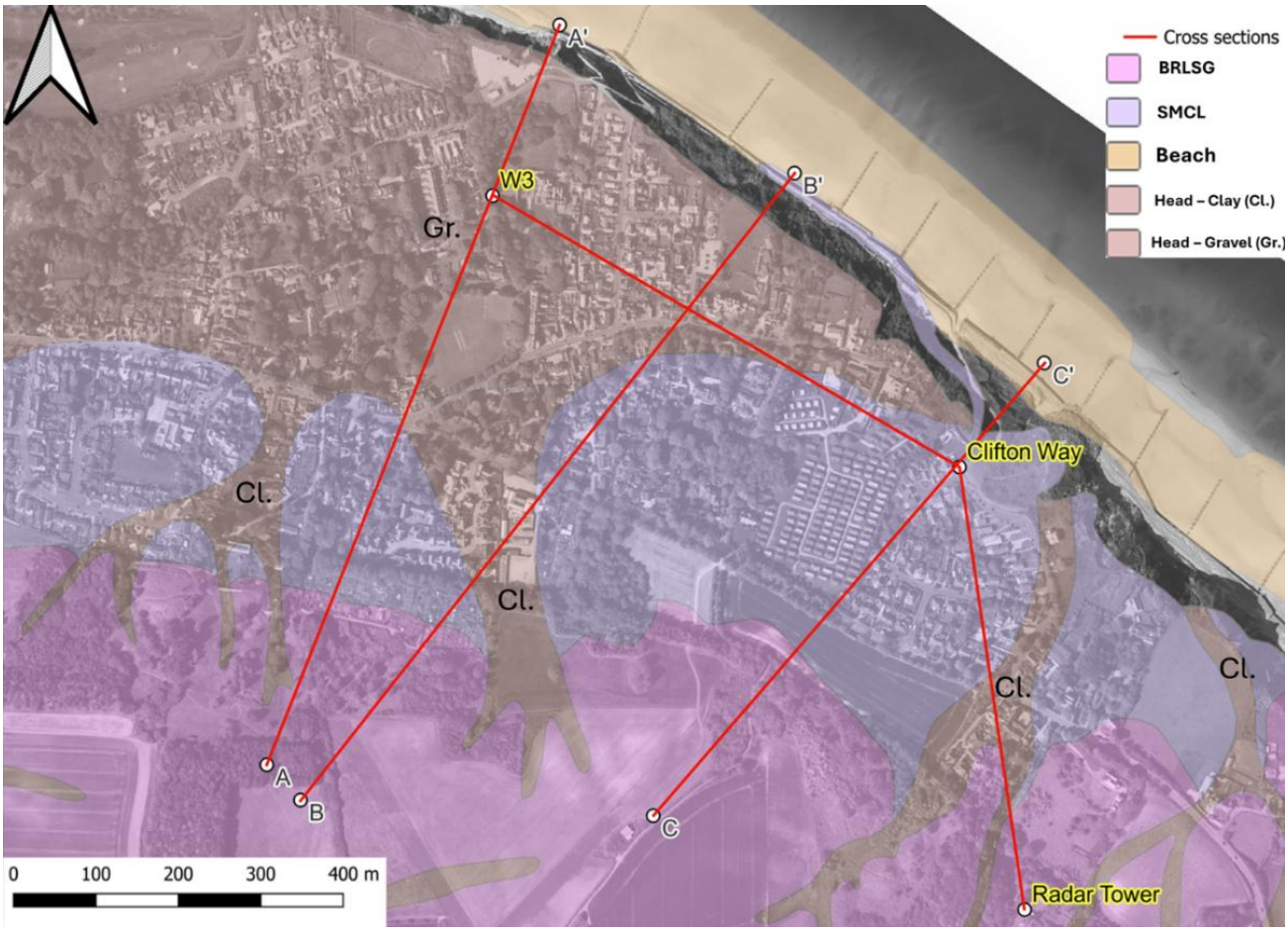


Figure 2-22: Topographic cross sections through selected historic boreholes (BGS 50k superficial geology map in background)

The relationship between surface profile and available subsurface geology is then shown Figure 2-23

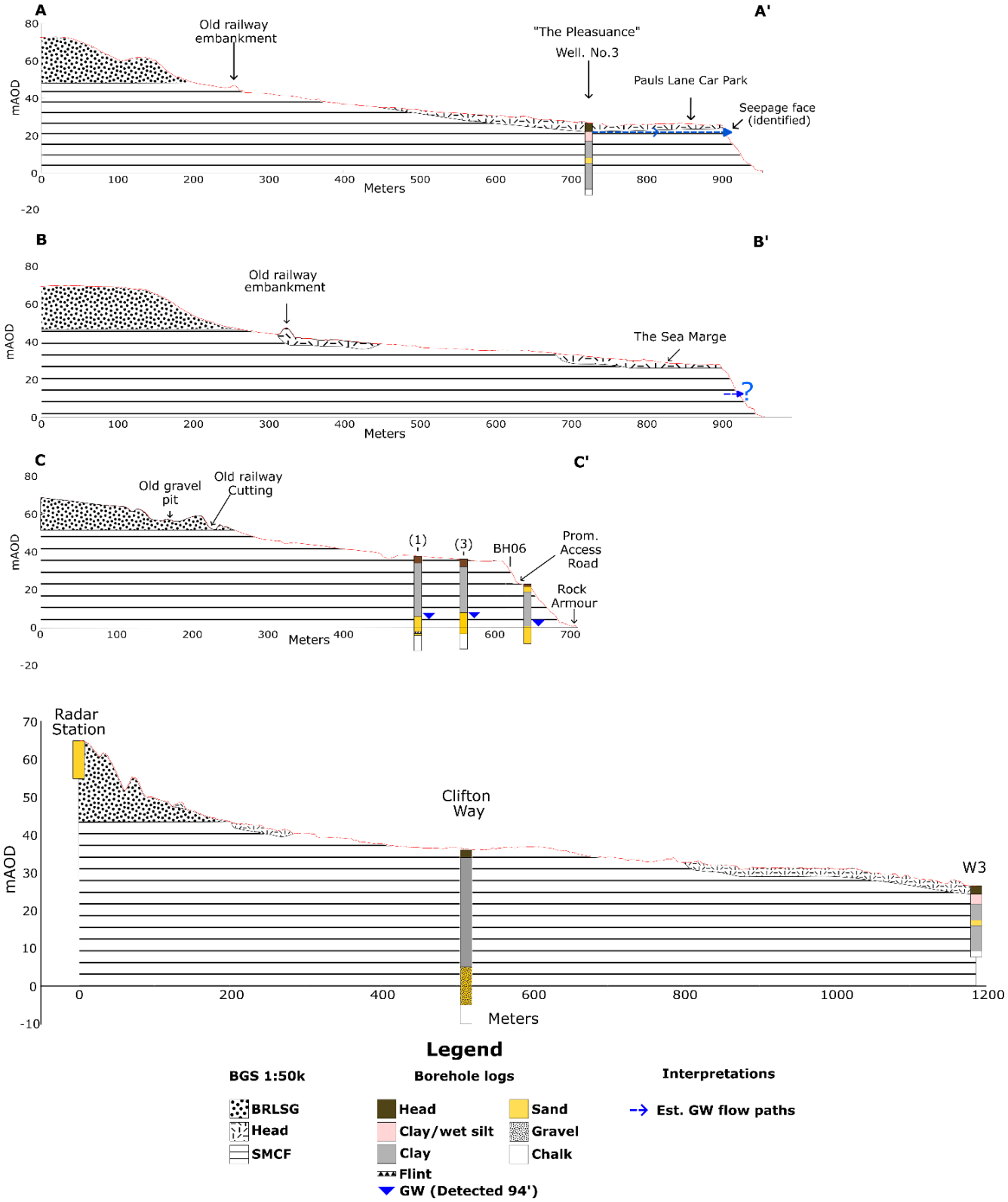


Figure 2-23: Historic borehole data superimposed on topographic cross sections A-A' to C-C' and the radar station to W3.

2.7 Previous cliff stability studies

HR Wallingford (2003) produced a comprehensive strategy study between Overstrand and Walcott which provides a cliff condition and regression assessment for Overstrand. This divided the Overstrand frontage into several sections based on their geometry and other characteristics to provide a basis for the assessment.

The definitions used within the stability assessment and cliff regression models are Table 2-5 and Table 2-6 respectively. The assessment results for Overstrand are summarised in Table 2-7 with locations referenceable to Figure 2-59.

Table 2-5: Definition table of cliff stability based on HR Wallingford (2003).

Stability assessment	Definition
Actively retreating	On-going cliff recession, through a combination of regular cliff failures (often falls, mudslides and mudflows) and rare large landslide event.
Actively unstable	On-going slope instability and loss of cliff top land despite the presence of coastal defences. Failures are generally small-scale mudslides and debris slides, although large events can and do occur.
Marginally stable	Localised small-scale instability, largely confined to the cliff face, although some loss of cliff top land may occur. Problems of this nature are often associated with the build-up of pore pressures along blocked or failed drainage lines.
Relatively stable	Cliffs show very few signs of instability other than minor small slips or creep.

Table 2-6: Cliff recession models. Source HR Wallingford (2003)

Recession model	Definition
Type A	Cliffs prone to repeated high-angled debris slides and lobate mudslides within distinct, narrow gully channels. These cliffs are affected by regular, small-scale recession events, with cliff top losses of probably in the order 1-5m/failure event.
Type B	Cliffs prone to large, episodic landslide events, usually deep-seated rotational slides or compound style failures. Significant cliff top losses can occur during landslide events, probably up to 25-30m in width
Type C	Cliffs prone to large, episodic landslide events, usually major elongate mudslides and multiple rotational failures. These cliffs appear to be associated with periglacial lake clays. At Clifton Way, for example, 85-110m of cliff top was lost due to mudslide activity between 1990 and 1995 (Frew and Guest 1997). Note: Applicable to Frew and Guest (2009)

Table 2-7: Summary table of Cliff stability assessments and potential recession models at Overstrand locations. Source: HR Wallingford, 2003.

			Slope Angles		
Location	**Foreshore Defences**	**Stability assessment**	**'Stage 1' Headlands**	**'Stage 2' Landslides / embayments**	**Potential Recession Model**
Pauls Lane Car Park	Rock amour/Timber palissades/Groynes	Activity unstable	40	37	A
Slipway	Seawall/groynes	Marginally stable	30	37	A
Main promenade *Sea Marge	Seawall/groynes	Marginally stable-actively unstable	30	25	B
Clifton Way	Rock armour	Stable - Remediated	30	15-20	C

The relationship of toe defences and the cliff stability assessment results were discussed. Where an assessment of "Stable" or "Marginally Stable" was made, this was relative to the ongoing retention of defences.

Separately, Frew & Guest (2009) presented a study of the remediated landslip at Clifton Way. The failure developed from around 1990, underwent large mass movements in 1994 and was remediated in 1995, including a large rock armour toe revetment, material replacement and an extensive system of surface and subsurface drainage. The root causes of the failure were noted to be toe erosion combined with groundwater seepage causing development of residual strength at the base of a thick laminated clay layer overlying a thin sandy layer.

Table 2-8 summaries the geotechnical properties of the materials in the failure area.

Table 2-8: Generalised ground investigation data from Clifton Way. Adapted from Frew and Guest (2009).

Material unit	Ground level (mAOD)	Thickness (m)	Bulk Density(Mg/m^3)	Friction angle (°)	Cohesion (kN/m^2)
Slip material		-	1.8	25	0
Brown Clay	36 - 32	4	2	29	0
Laminated Clay	32 - 5	27	2	20	0
Sand/Sand Gravel	+5 to -5	10	2	35	0

Figure 2-24 shows a cross section of the series of mass movements that occurred, showing how each movement caused the average cliff slope angle to approach 20° (i.e. the residual friction angle of the laminated clay).

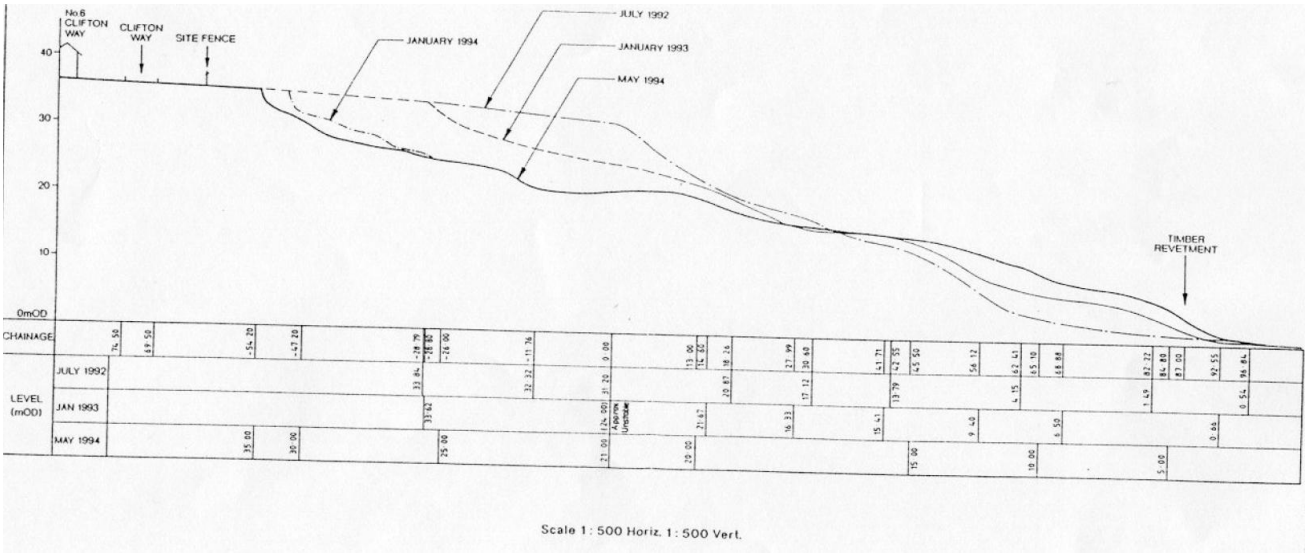


Figure 2-24: Clifton Way topographic cross section of multiple failures.

2.8 Hydrogeological designations

The DEFRA Magic Map (DEFRA, 2026) indicates the chalk bedrock geology at Overstrand is designated as a Principal Aquifer, but not a Source Protection Zone. The superficial deposits are a Secondary A aquifer for the main village with Secondary B and Secondary undifferentiated on the outskirts.

Groundwater Vulnerability, which indicates the vulnerability of groundwater to a pollutant discharged at ground level, is designated as Medium to High, indicating that any proposed development with a potential to affect groundwater will require specialist risk assessment and appropriate design mitigations to protect groundwater quality.

2.9 Water abstraction licences

Environment Agency (2026) water abstraction licence mapping indicates no active licences exist within the immediate vicinity of Overstrand, thus in principle any future effort to abstract or drain groundwater for the purposes of slowing cliff erosion would be unlikely to interfere with any existing licence.

2.10 Near-surface soil permeability

The SoilScapes Map (2026) indicates the uppermost soil type within Overstrand itself as free-draining and sandy, while the outskirts are considered free draining and loamy, indicating in relatively unimpeded surface infiltration into the uppermost soil layers, until a low-permeability (clayey) layer is encountered. This is consistent with observations of localised perched water tables on historic borehole logs (see Section 2.6) and cliff observations (see Section 3).

2.11 Groundwater interception boreholes

In the early 1960s, likely in response to improved understanding of the physical mechanisms affecting slope stability, authorities identified the significance of groundwater seeping from the cliff face, leading to the concept of boreholes or wells intended to intercept shallow, perched groundwater and discharge this into the basal chalk aquifer.

Information provided by NNDC states certain pre-existing water supply wells were modified starting in 1966 by increasing their depth by boring deeper into the chalk bedrock. This did not appear entirely successful (they were not deliberately located to intercept groundwater at the cliff face). This resulted in further investigations, including so-called “water divining”, to locate areas of high ground water and subsequent flows towards the cliffs. This method was the basis of the additional boreholes dug between 1972 to 1983. In 1980, the Council was tasked with providing maintenance on the existing boreholes and chambers through ‘jetting’ to remove accumulated fines.

Further drainage boreholes were constructed between 1993 to 1995 at Clifton Way, due to the large-scale failure of the slope, and at Pauls Lane Car Park (PLCR). Historical information provided by NNDC is summarised in Figure 2-25 showing the scope of recorded drainage/groundwater interception schemes within Overstrand.

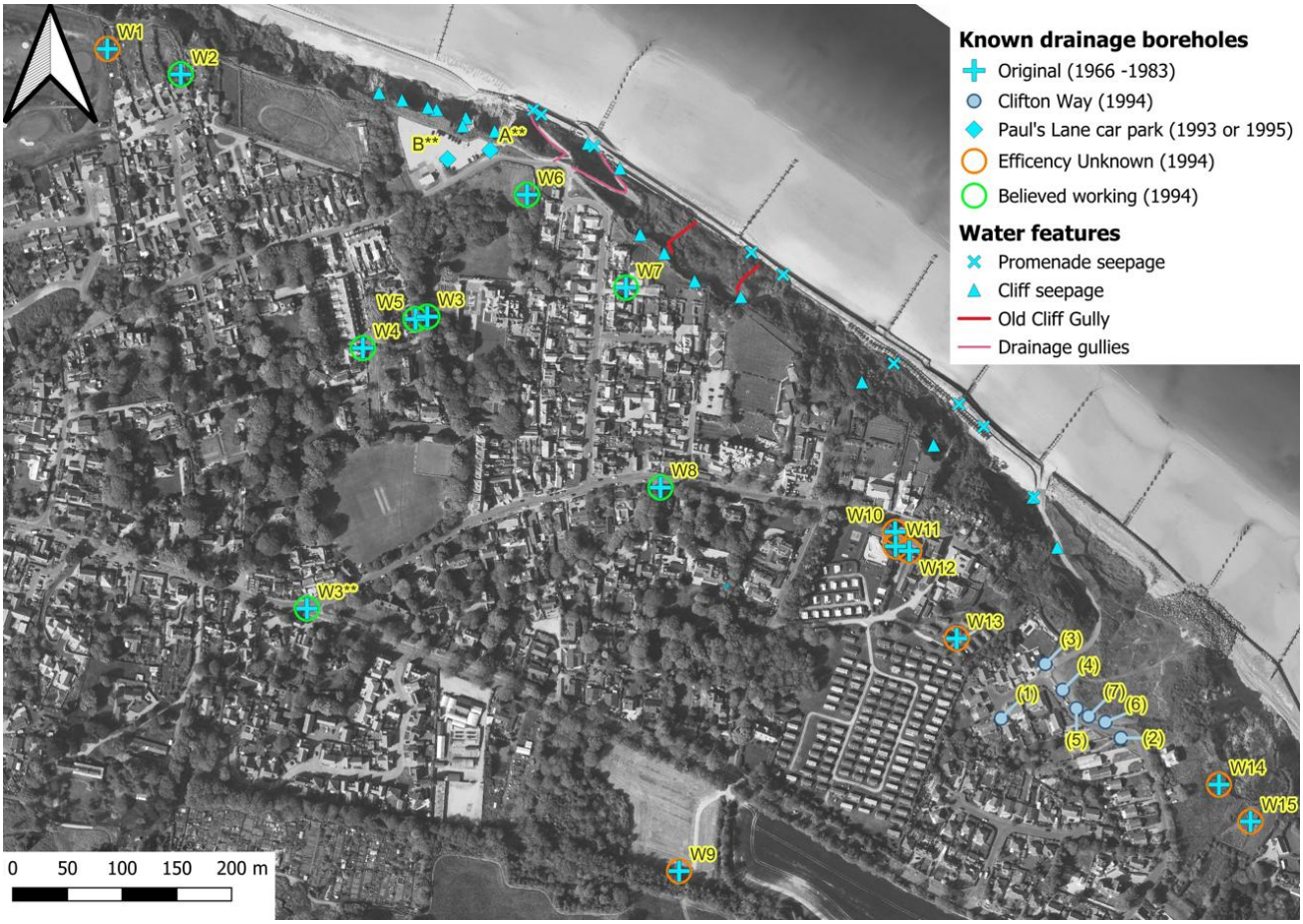


Figure 2-25: Locations of known groundwater interceptor boreholes and recent and historically observed cliff face seepages/water features at Overstrand.

An example of the general form of the drainage boreholes installed at Clifton Way in 1994 is shown in Figure 2-26, a zoomed in sketch is presented in Appendix B within Volume 2 along with supporting information on logs. These differed significantly in design from earlier boreholes in that:

- Engineering knowledge had advanced significantly since the 1960s, meaning they could be much better designed to target perched water tables
- Their design and location was supported by a comprehensive ground investigation
- they were designed to discharge into a specialised piped and subsurface drainage system, down the face of the reinstated failure at Clifton Way

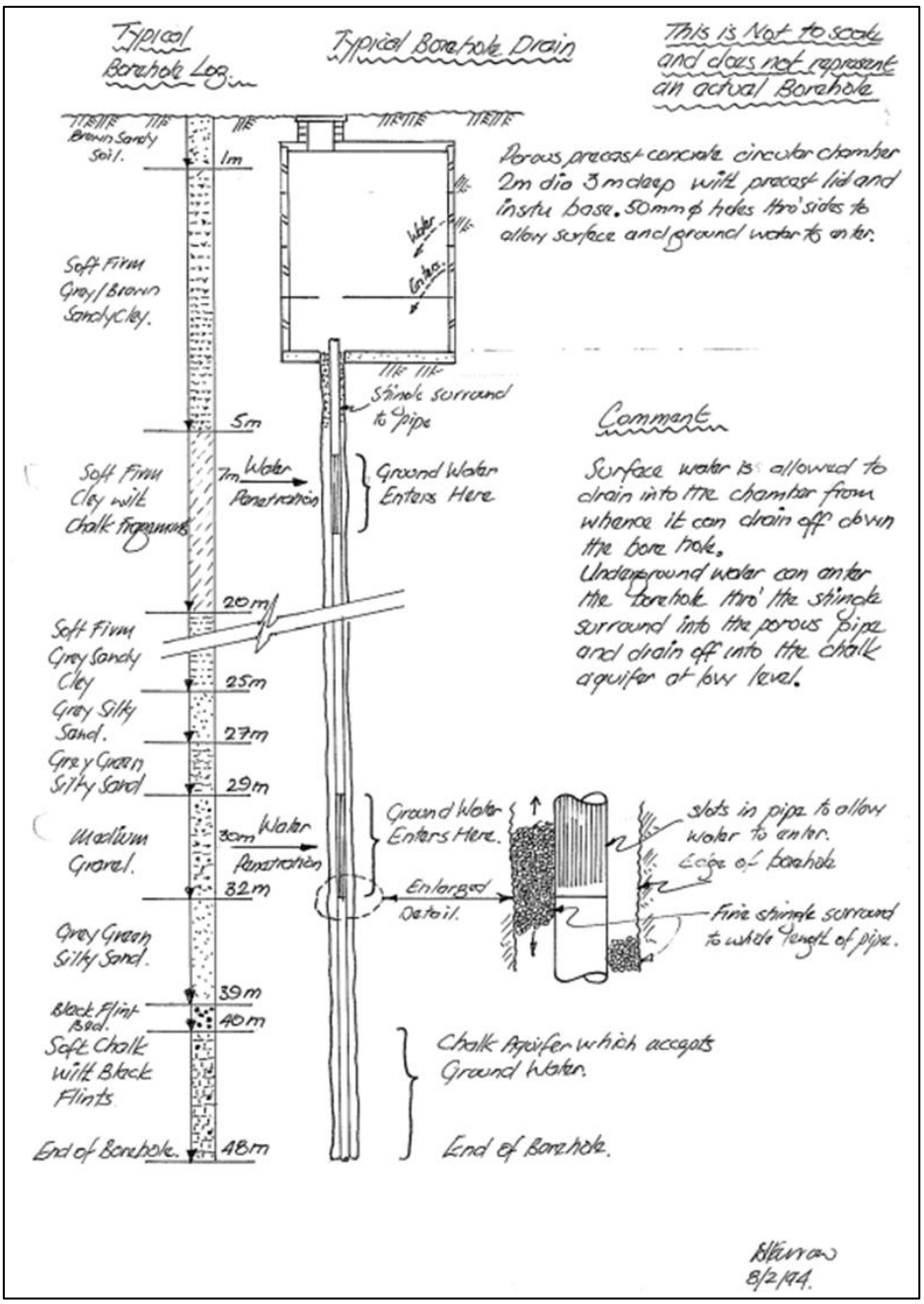


Figure 2-26: Sketch of typical Clifton Way (1994) interceptor borehole installation and not an actual one. Source: NNDC (Brian Farrow) - Refer to Appendix B in Volume 2.

NNDC have stated that all previously operated groundwater interception wells built prior to 1995 became effectively non-functional in about 2014 due to fines clogging the outfalls (to the basal chalk Principal Aquifer) and further jetting attempts to clean then being unsuccessful.

The current physical state of the disused/clogged wells is generally unknown, but some photos taken during monitoring works in 2002 (Figure 2-27) indicate that:

- Disused groundwater interception holes have in some cases been mistaken for storm drains and have had piped surface drainage erroneously connected to them.
- Where their lower outlets are now clogged but surface water entry remains possible (i.e. if full decommissioning is incomplete), interceptor wells may be increasing (rather than decreasing) destabilising water pressures within the ground behind the cliffs.



Figure 2-27: Examples of groundwater interceptor borehole condition survey result in 2002 showing erroneous surface drainage connection and hole flooded to surface

2.12 Groundwater monitoring

Groundwater monitoring Information provided was provided by NNDC between 1998 and 2002 for various groundwater interceptor boreholes (See Volume 2). Table 2-9 provides the names each of the borehole numbers used to generate Figure 2-28, showing the monitoring information.

Gaps within the plotted data at certain locations correspond to missing data, with no explanation.

The construction/design of the interceptor boreholes, elevations of perched groundwater tables and elevations of basal aquifer units are not known, except for Clifton Way (Figure 2-26). Therefore, the effectiveness of each well is uncertain, but our interpretation is included in Table 2-9 based on the depth and trends recorded within Figure 2-28 when compared to monthly rainfall (Figure 2-29).

Table 2-9: Borehole/interceptor well identifier and locations

Borehole	Location	Comments	Assessed effect on perched groundwater during (1998-2002)
1	Danish House west	Static water level – above basal aquifer.	Probably not effective
2	Danish House east	Variable water level (downward trend)	Possibly some effect
3	Old Town Sign	Static water level within basal aquifer	Possibly some effect
4	Harbord Road	Variable water level (downward trend)	Effective
5	The Pleasaunce west	Variable water level (downward trend) but not in basal aquifer	Possibly some effect
6	The Pleasaunce east	Variable water level (upward trend)	Not effective
7	Off Cliff Road	Variable water level (downward trend)	Possibly some effect
8	Pump Cottage High St	Variable water level (weak downward trend)	Possibly some effect
9	Old Railway Line	No data	No data
10	Ivy Farm	Static high-water level	Not effective
11	Ivy Farm	Variable water level down to basal aquifer	Effective
12	Ivy Farm	Variable water level down to basal aquifer	Effective
13	Ivy Farm new	Static high-water level	Not effective
14A	Strand Cottage (west), Clifton Way	Variable water level (upward trend)	Not effective
14B	Strand Cottage (west), Clifton Way	Variable water level (upward trend)	Not effective
15	Strand Cottage (east), Clifton Way	Variable water level (weak downward trend)	Possibly some effect
A**	Pauls Lane Car Park (east)	Variable water level (upward trend)	Effective
B**	Pauls Lane Car Park (west)	Variable water level (weak downward trend) but not in basal aquifer	Probably not effective
A	Clifton Way (east)	Variable water level to known elevation of deep drainage system	Effective
B	Clifton Way (east)	Variable water level to known elevation of deep drainage system	Effective
C	Clifton Way (east)	Variable water level to known elevation of deep drainage system	Effective

Note: 14A/B are replacements for the destroyed original. A-C are assumed to be part of the Clifton Way interceptor boreholes 1-7 but are unspecified. W3 is assumed to be within Pleasaunce Estate, while W3** does not appear to be a monitored location.

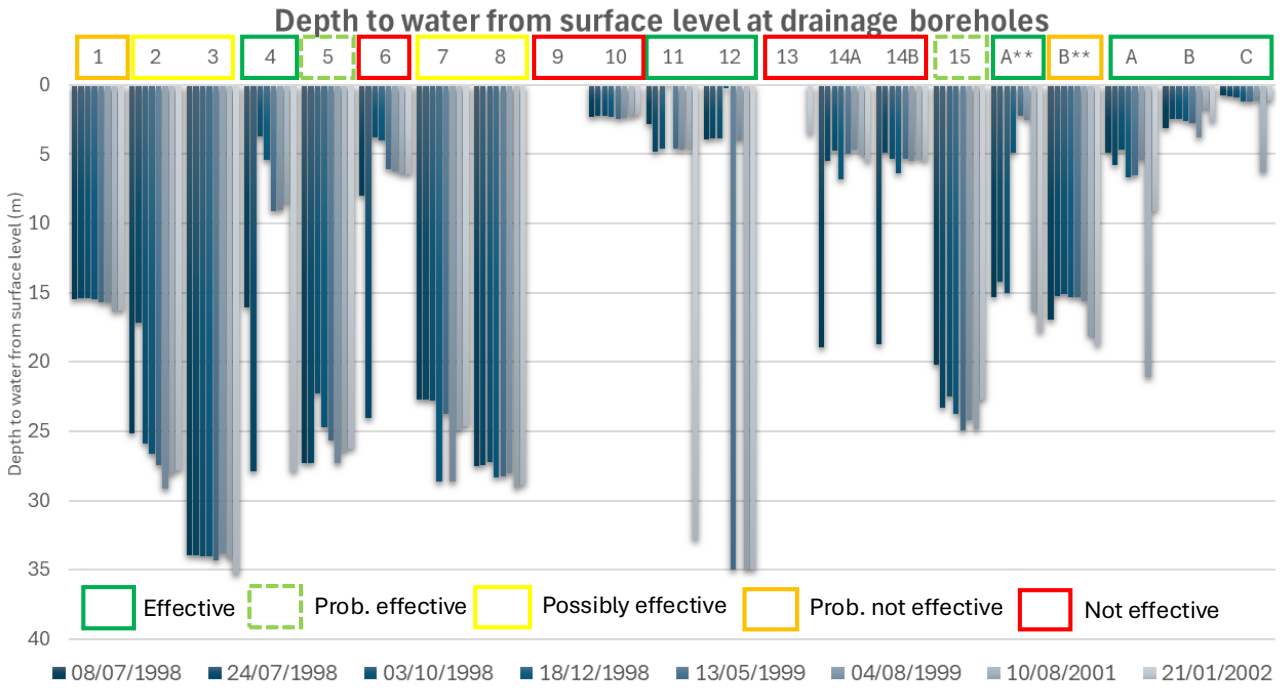


Figure 2-28: Change in borehole water levels between 1998 and 2002. Source NNDC. Note 14A/B and 15 are outside of the study area but included for data set completeness.

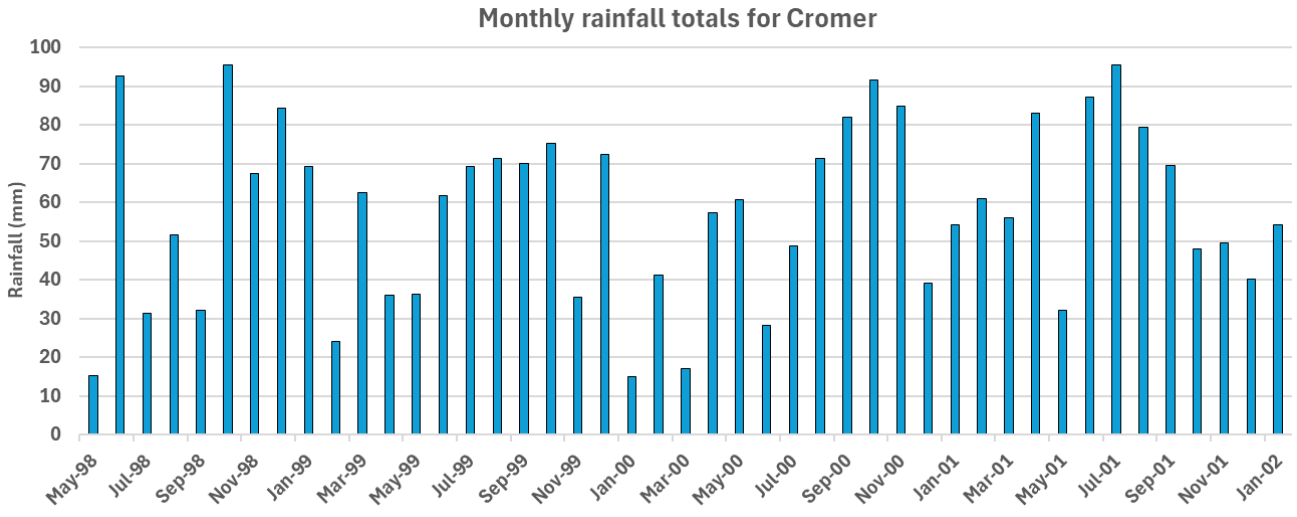


Figure 2-29: Monthly rainfall totals between May 1998 and January 2002 from Cromer weather station. Source: NNDC.

2.13 Observable water features and cliff failure locations

Historical water features from the cliff and promenade (including chalk/stiff grey till exposures) have been identified through the examination of historical photography, satellite and NNDC images, and observations during the site walk over study to create Figure 2-30. The figure shows where groundwater egress is known to have appeared from the cliff and areas of seepage concentration along the promenade indicative of toe seepage of the colluvial fans.

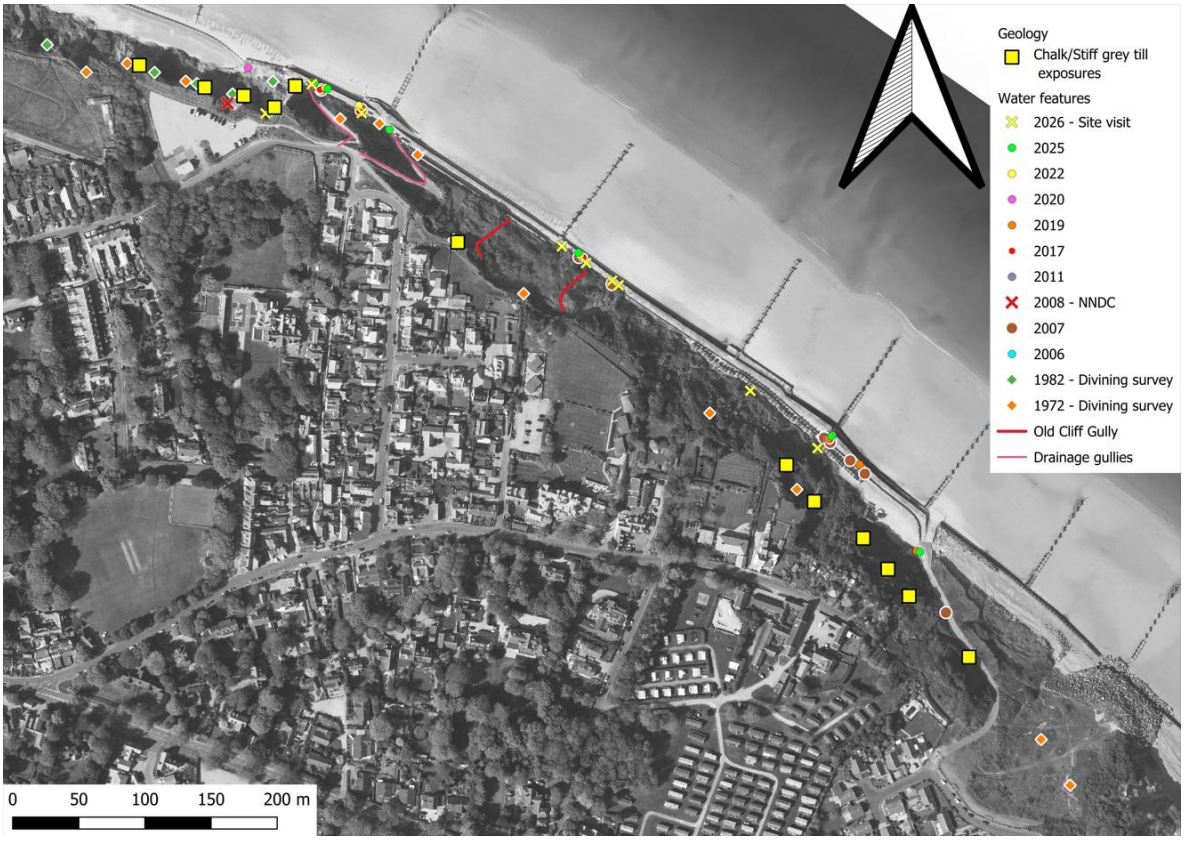


Figure 2-30: Observable water features. Base map: NNRCMP Aerial imagery 2025.

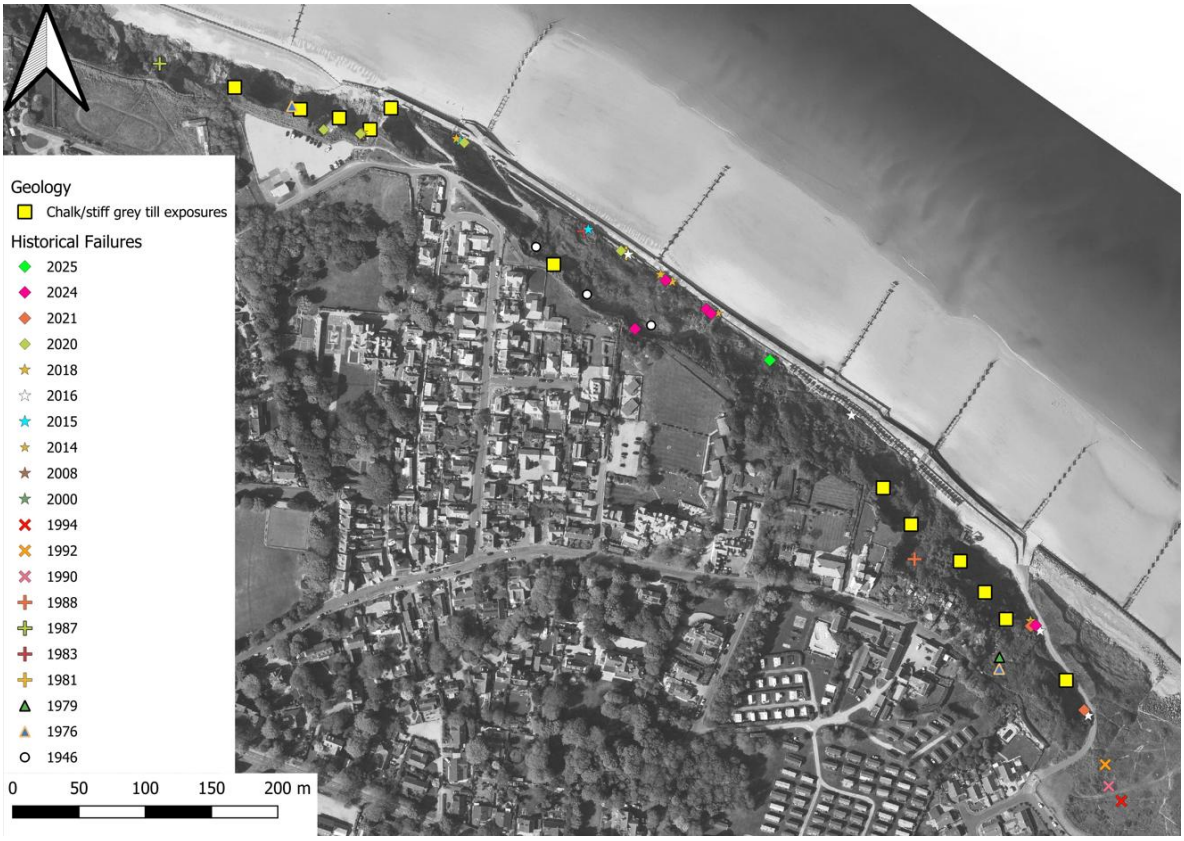


Figure 2-31: Distribution of known historical failures on Overstrand Cliffs (1946 - 2025)

Historical cliff failures and areas of instability are shown in Figure 2-31 and are inclusive of any failure type i.e. large deep rotational failures or smaller mudslides/creep.

The information is compiled from aerial photography, divining surveys (marked slip locations) and from photographs of historical failures between 1980-2025 received from Brian Farrow of NNDC . The data set is not continuous, as information for 1989, 2004-2006 and 2011 are missing, therefore it cannot be established whether failures occurred during these periods. It is assumed that each failure was catalogued with the same the rigor over the data set period. Regardless, it has provided a source of information that would not have been replicated by other known means.

2.14 Climate change effects on cliff stability

Global mean temperature data regularly published by NOAA (2026) shows that current warming in 2026 is around 1.25°C above the pre-industrial baseline (Figure 2-32), and that peak warming of between 2.7 and 3.5°C is now considered likely before 2100, depending on global greenhouse gas emission reduction rates in the near future.

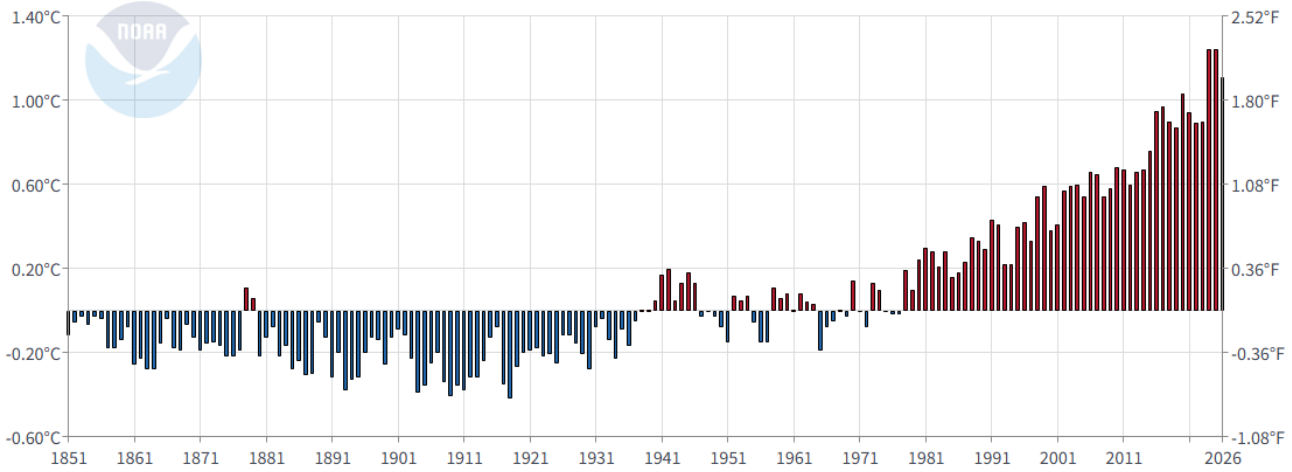


Figure 2-32: Global annual mean surface temperature 1850-2026 (NOAA, 2026)

For the currently most likely expected level of warming, the following effects on marine, pluvial and ground borne water (of direct relevance to cliff stability) are likely to occur between 2055 and 2100:

- The frequency of high-impact or extreme rainfall events in East Anglia is expected to increase by a factor of about 2 to 4 (Figure 2-33) and intensity (rainfall rate) of extreme downpours is likely to increase by circa 5-15% with every degree of mean warming (Met Office, 2010; Hanlon et al, 2021; Kendon et al., 2023)
- Mean sea level is expected to rise by about 30 to 40cm (Met Office, 2026)
- Cliff retreat rates may increase by a factor of 2 to 5 due to more energetic storms and deeper coastal waters (Shadrick et al, 2022), though such findings are currently very uncertain and likely to be highly location-specific (Dickson at al., 2023).

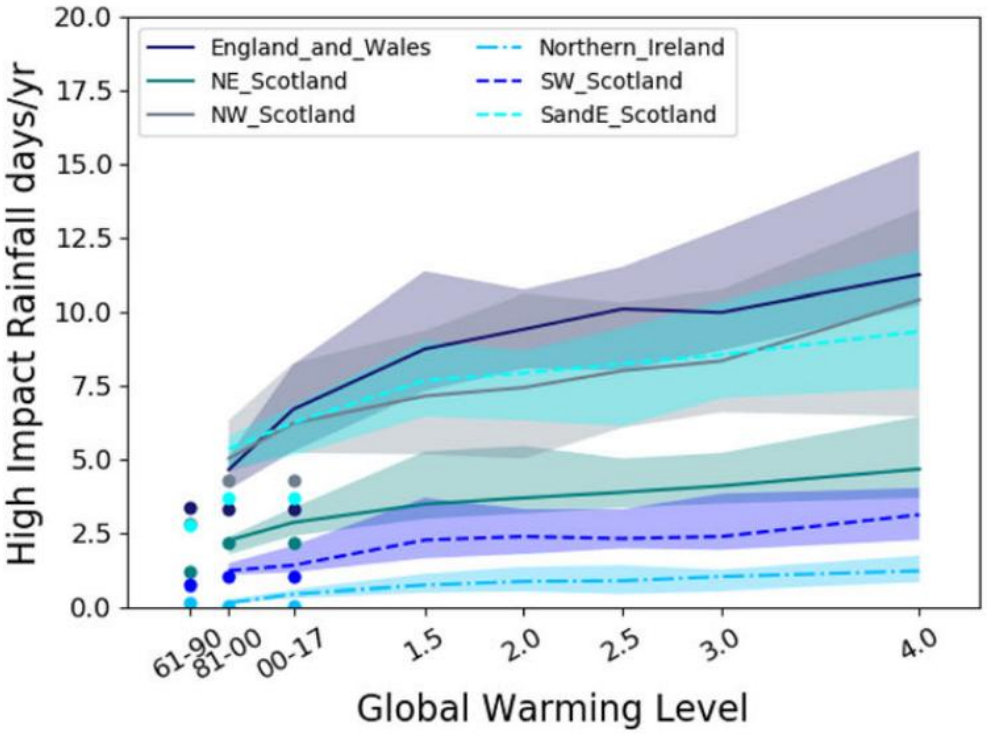


Figure 2-33: Change in UK annual number of days with high-impact rainfall (Hanlon et al, 2021)

Current estimates of cliff retreat extents assuming a more pessimistic peak global warming scenario of 8°C are shown on the National Coastal Erosion Risk Map for Overstrand (DEFRA, 2026), reproduced in Figure 2-34. This shows:

- The zone considered at risk within 2025-2055 extends around 60m landward of the current cliff top, implying an average 2.4m/yr retreat rate over a 25-year period.
- Current erosion risk modelling does not predict large differences between "central" and "upper end" estimates within the modelled 8°C warming scenario.
- Any notional set-back measures intended to slow cliff erosion located within 60m of the current cliff top will be at risk of being overrun by cliff retreat by 2055.
- The design life of any set-back measures designed to slow erosions must take this into account, potentially using an adaptive approach that would also allow for relocation or safe decommissioning prior to overrun.

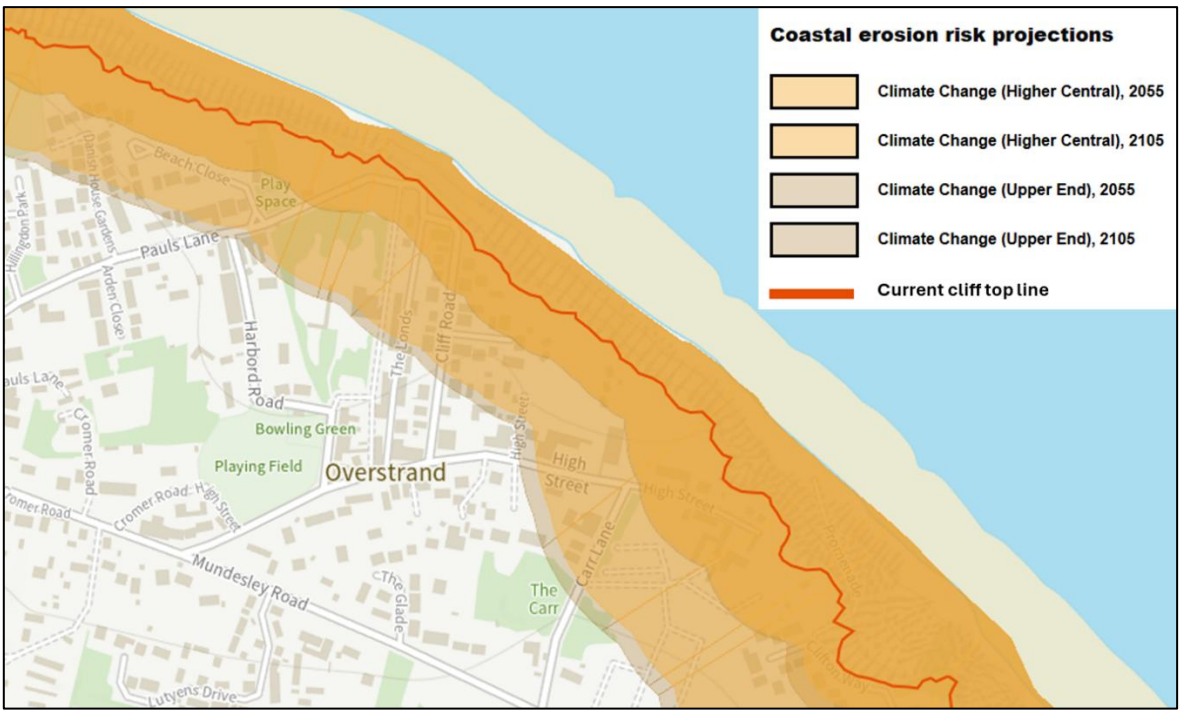


Figure 2-34: National Coastal Erosion Risk Map for Overstrand (DEFRA, 2026)

2.15 Episodic (wave dominated) versus progressive (soil strength dominated) cliff retreat

At Overstrand, while palisade and seawall toe defences currently remain present and effective, episodic toe erosion (i.e caused by wave action) is limited.

Cliff failures tends to be more progressive rather than episodic cliff due to the gradual development of movement and a reduction in strength from peak to softened to residual (see Section 2.17). However, the eventual mass movement events can still be large, sudden and dramatic (as per the Clifton Way failure in 1994) because of the way strength reduction in tills accelerates as movement accelerates (see Figure 2-37).

Example(s) of cliff retreat case studies from published sources:
Rossius et al (2025) presented a study of the effect of the exceptionally severe storm Babet in October 2023 on glacial till cliffs on the German Baltic Sea coast. These cliffs are geologically like those in North Norfolk, and at Sidestrand, where no cliff toe protection exists and direct wave attack occurs regularly.

This study identified that Babet caused around seven "normal" years of cliff retreat within a single event (Figure 2-35). This is because toe erosion (undercutting) becomes very rapid once a certain threshold combination of (tidally controlled) water level and (wind controlled) wave height are exceeded. Such single events were found to dominate "average" cliff recession rates.

Hobbs (2007) observed similar cliff recession behaviour at Sidestrand in 2005-2006 (see Figure 2-36).

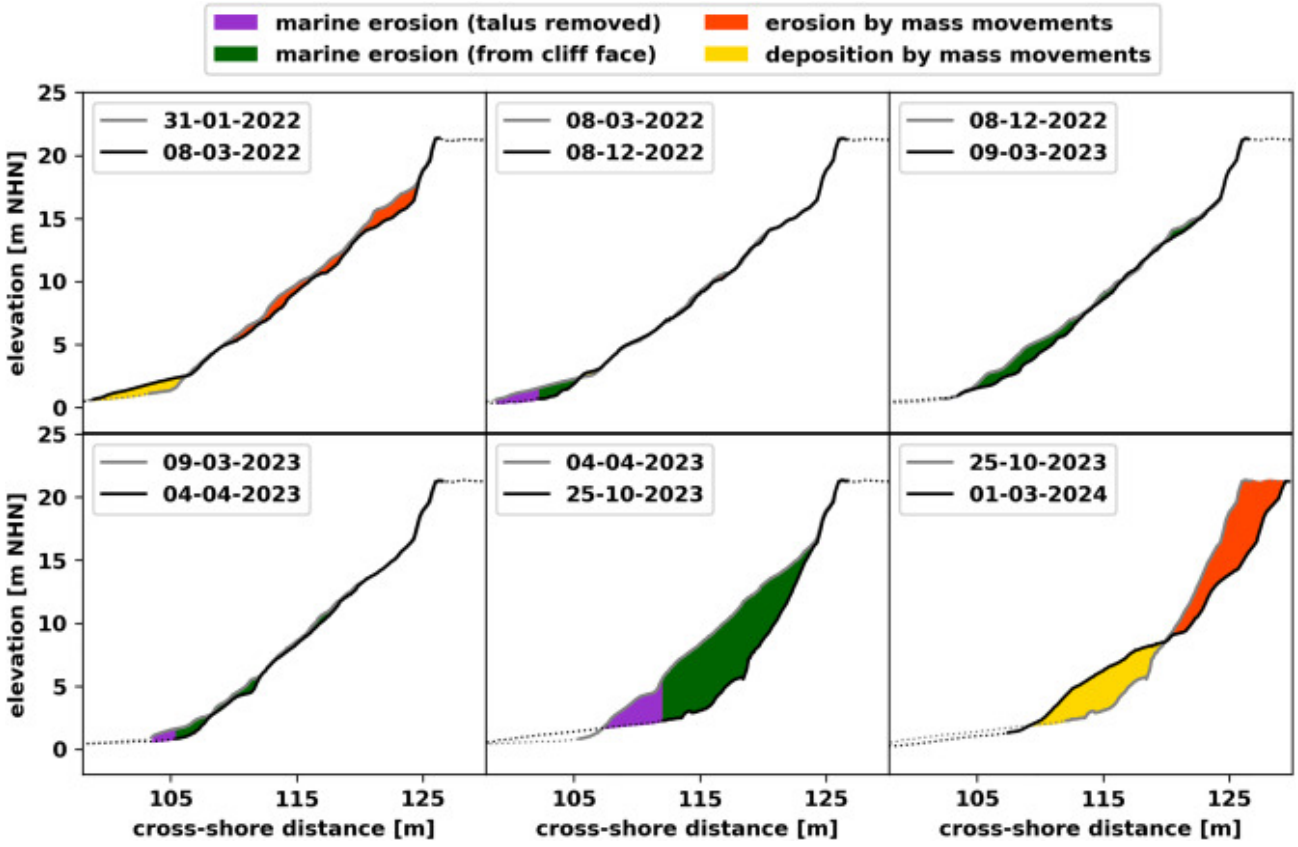


Figure 2-35: Example of an extreme storm-induced retreat event in a till cliff (Rossius et al, 2025)

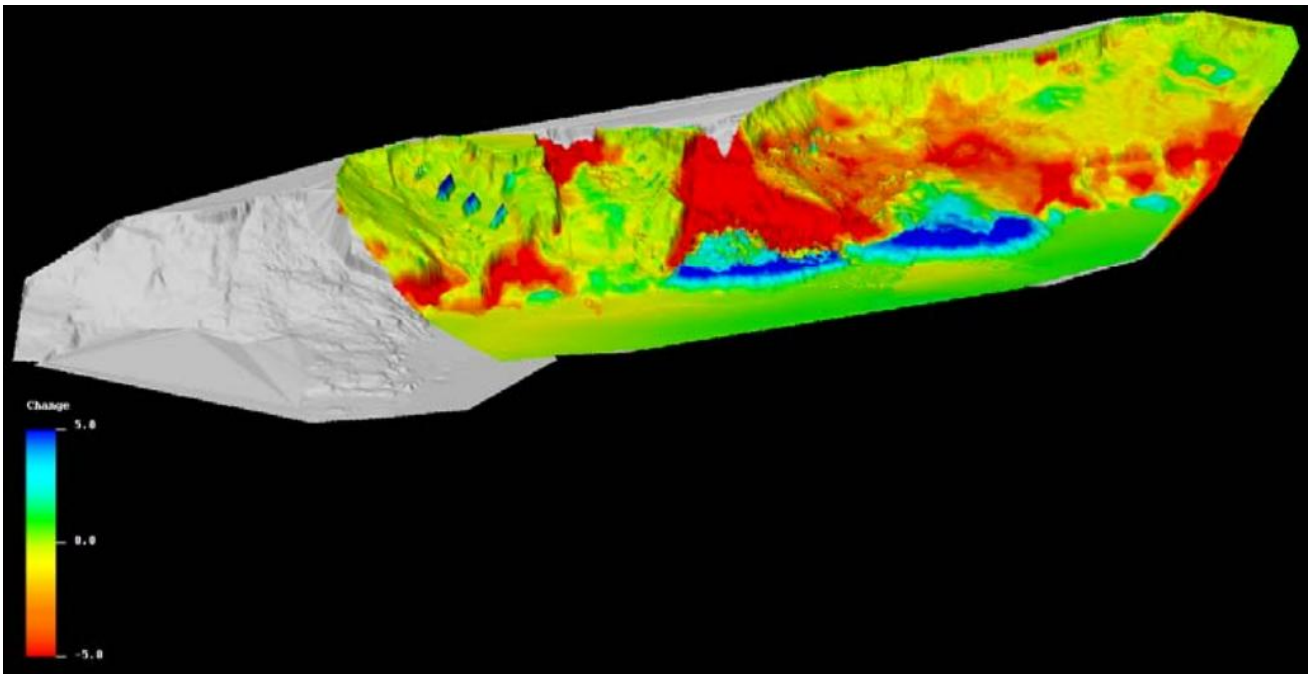


Figure 2-36: Example of episodic cliff recession from laser scans of cliffs at Sidestrand (2005 to 2006) [red=material slippage; blue=material accumulation] (Hobbs, 2007).

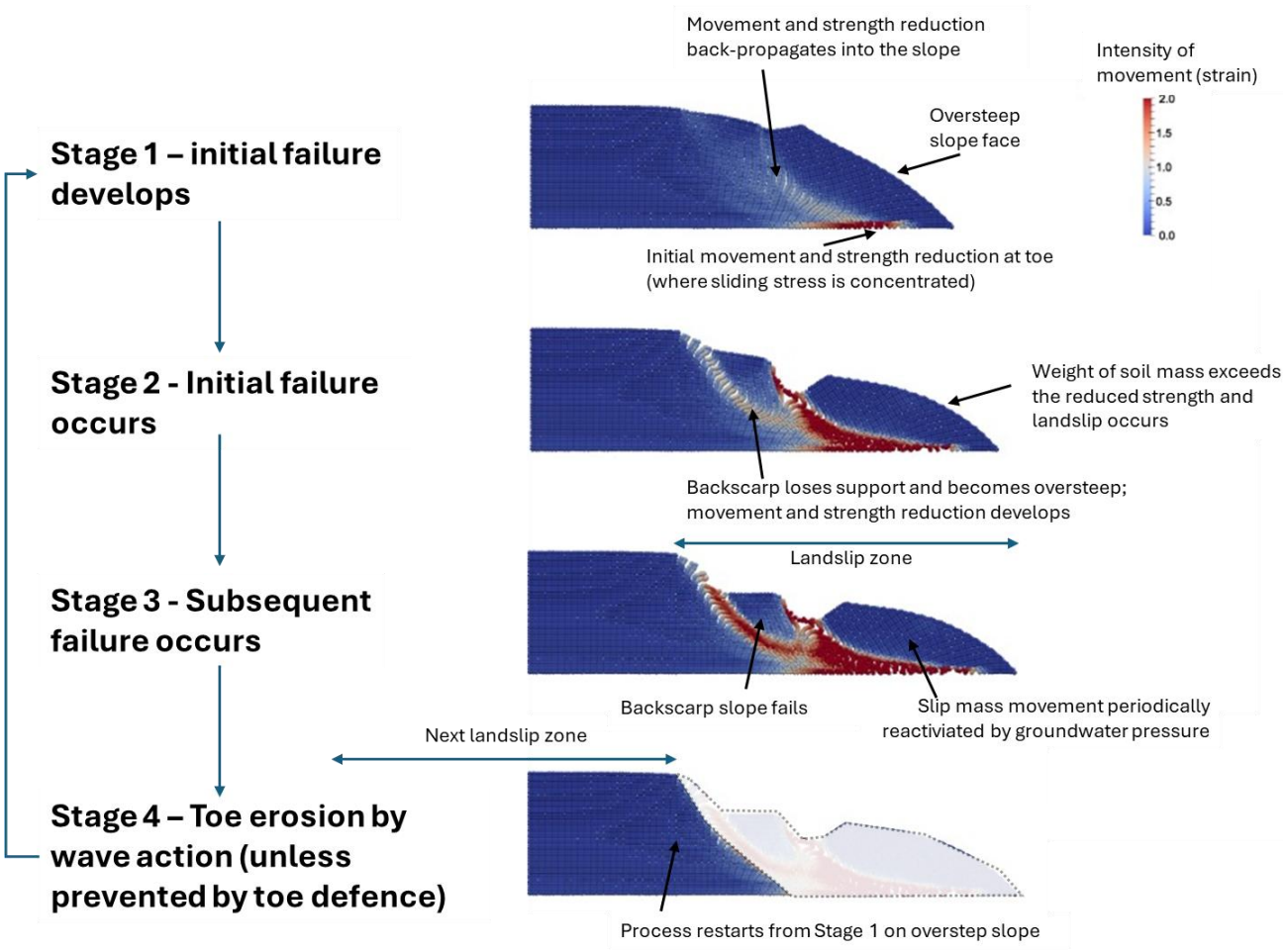


Figure 2-37: Model of progressive-retrogressive failure in a clay till cliff (adapted from Wang et al, 2016)

2.16 Beach wedge area and coastal "catch up" effects on cliff recession rates

Recent research has shown that cliff retreat rate in North Norfolk can be related to “Beach Wedge Area”, which is a simple relationship between beach width and cliff toe elevation relative to high tide level. Once beaches become narrow and lowered, cliff retreat rate tends to increase dramatically.

Example(s) of phenomenon from published research:

Lee (2008) and Lopez et al (2020) examined the relationship between cliff recession rates and simple geometrical measures of high water level, cliff toe level and beach width (in combination dubbed the beach wedge area; see Figure 2-38).

A logarithmic relationship was found, such that when the beach wedge area reduces beyond a certain point, cliff recession rate increases dramatically (see Figure 2-39).

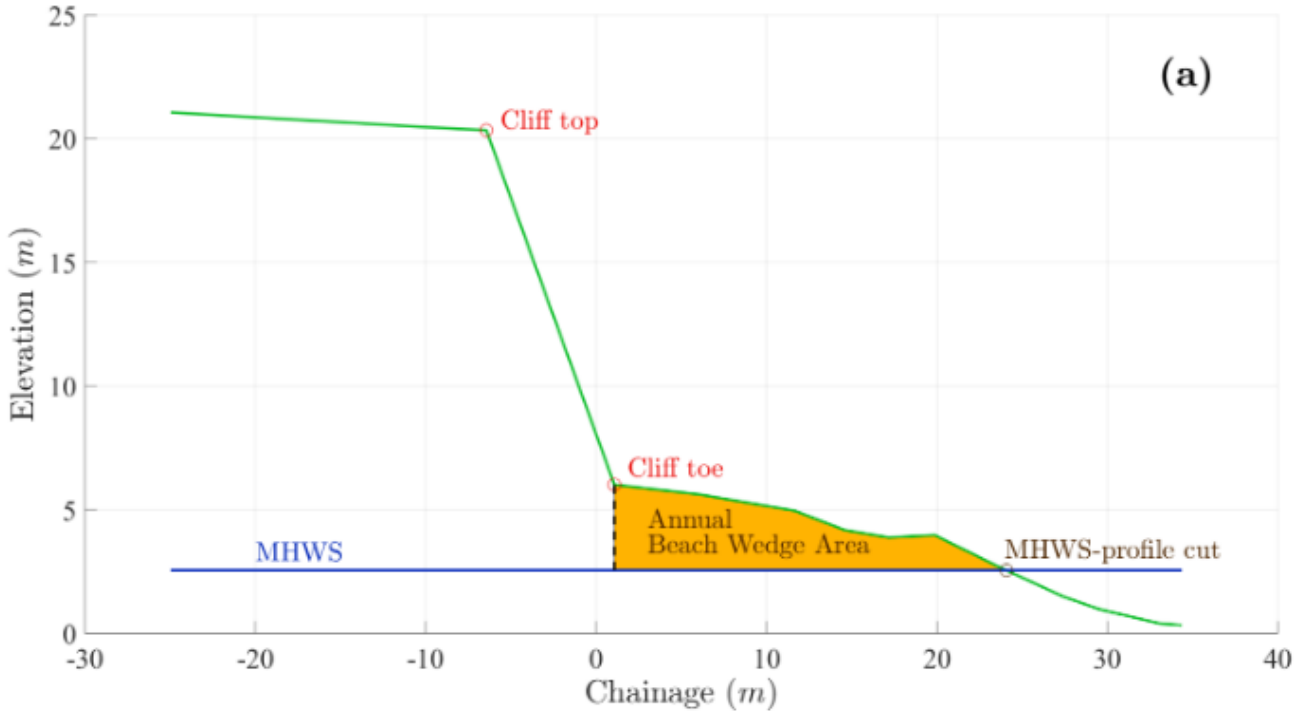


Figure 2-38: Definition of beach wedge area (Lopez et al, 2020) [MHWS=Mean High Water Springs, a level which characterises the long-term average of high tide level]

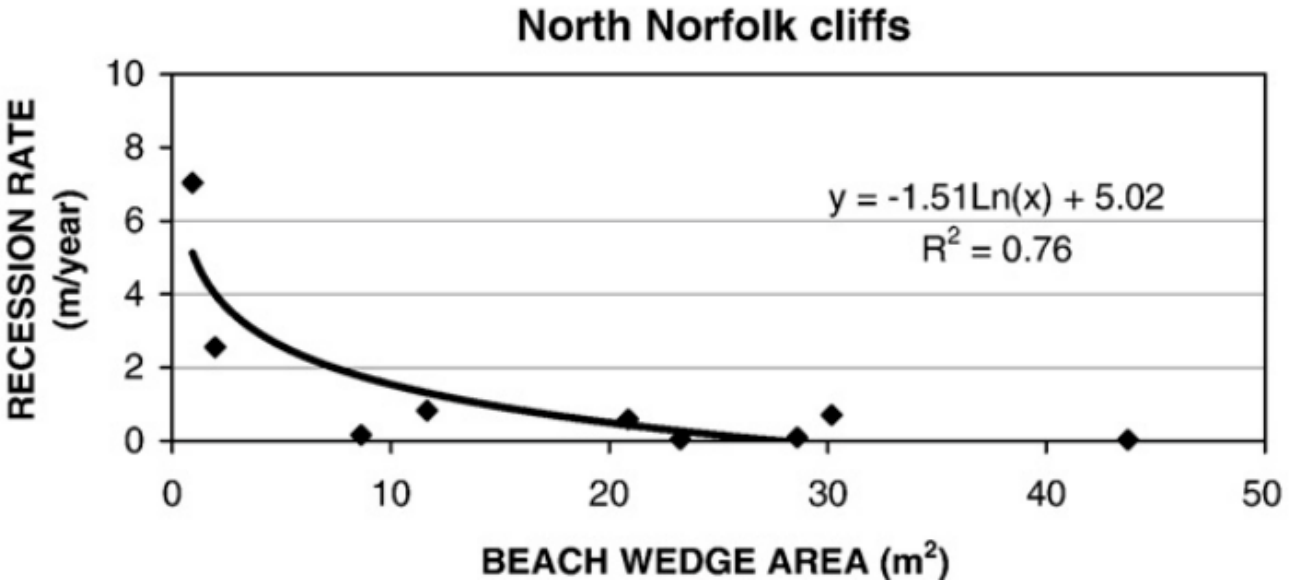


Figure 2-39: Relationship between beach wedge area and cliff recession rate for North Norfolk cliffs (Lee, 2008)

Payo and Walkden (2018) studied rates of costal retreat at Happisburgh following the 1991 abandonment of palisades and groynes (installed 1958) over a 900m section of frontage. As shown in Figure 2-40, in the period 1992-2004, the cliff crest retreated 105m (averaging 8.75m per year), a dramatic increase in the 1966-1985 average of about 0.25m/year (Frew, 2009, NNDC) which was artificially reduced by the defences. The retreat rate later reduced,

though not to pre-defence abandonment levels. The authors reasoned that extreme initial rate was the local coastal system "catching up" after a period of artificial sediment starvation (due to the defences) causing offshore seabed erosion.

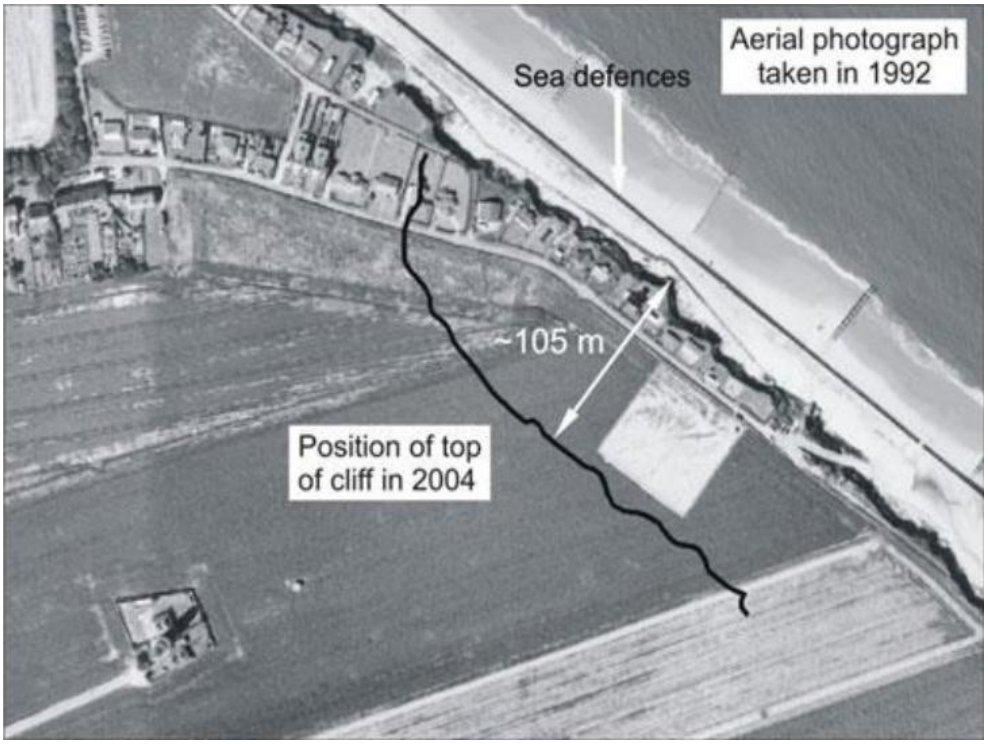


Figure 2-40: Rapid cliff retreat due to coastal "catch up" at Happisburgh 1992-2004 (Payo & Walkden, 2018)

For Overstrand, these studies have important implications for likely erosion rates once existing defences become fully ineffective (likely 10-20 years for the groynes and palisades, and 20-40 years for the seawall). These defences have also artificially increased the "beach wedge area", reduced the cliff height, and allowed Overstrand to form a promontory beyond adjacent undefended sections of coast, meaning erosion will be concentrated there once the defences are lost. This is likely to be influenced further with climate change effects and the ongoing post-glacial isostatic rebound (i.e. land subsidence).

Thus, once toe defences are lost (in accordance with the current Shoreline Management Plan), marine erosion (as compared to groundwater seepage and subaerial processes) will tend to dominate cliff recession rates in future, like the current situation at Happisburgh and Sidestrand. Any proposals related to set-back stabilisation measures (such as surface or groundwater drainage) behind the cliff line must take this into account.

2.17 Effect of till properties and groundwater on strength and stability of cliffs

In understanding cliff stability and its relationship to water at Overstrand, it is important to understand how the strength of the tills which make up the cliff relates to the physical properties of the soil and to water in the ground.

2.17.1 Till properties

As explained in Section 2.5, the cliffs at Overstrand are comprised of a complex sequence of glacial tills which have a diverse range of physical properties. This diversity causes the strength of the cliff materials (and hence their stability) to vary significantly and rapidly in space (from location to location and layer to layer) and in time (in reaction to erosional and weathering processes from waves, rainfall and groundwater seepage).

When tills are subject to sliding or shearing movement (such as that mobilised by gravity in the zone close to a cliff face) tills typically exhibit three characteristic phases of strength, reducing with development of movement (Figure 2-41) namely, peak strength, softened strength and, residual strength representing a minimum strength that develops once large movements (like landslips) have occurred.

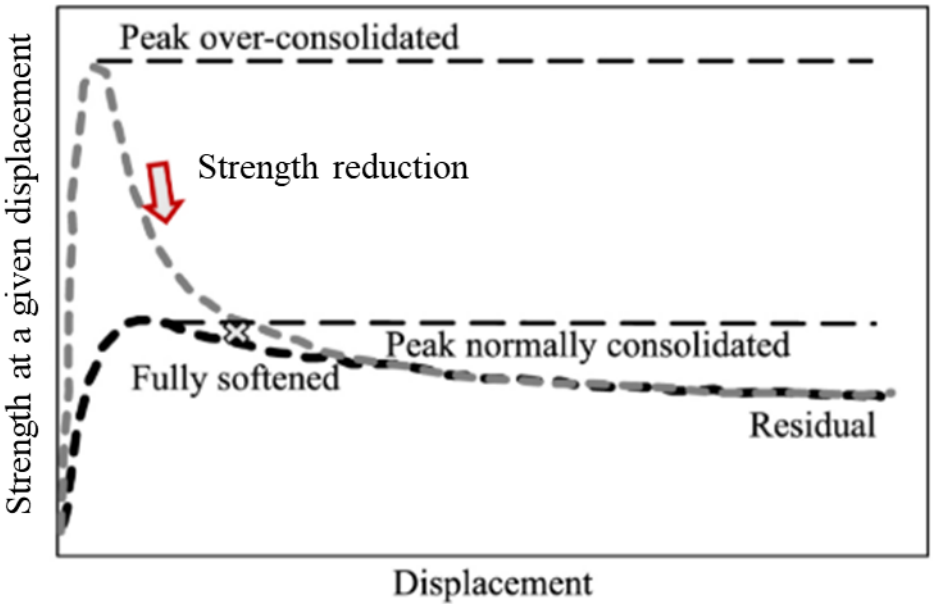


Figure 2-41: Changes in soil strength of dense (over consolidated) and loose (normally consolidated) soil with increasing displacement during sliding/shearing (Skempton, 1970)

Key factors which affect the absolute and relative magnitudes of these three characteristic strengths include (a) soil particle size and angularity (b) soil density and (c) clay proportion and mineralogy. Tills like those at Overstrand (lodgement tills) were deposited and heavily compressed under thick ice and hence are now typically found in a dense (overconsolidated or O-C) state relative to the weight of soil currently above them, particularly in clay-rich layers where water cannot quickly flow into them and reduce their density. However, some till layers, particularly shallow sandy ones permeable enough to allow rapid inflow of water during glacial thawing and unloading, may have already returned to a loose (normally consolidated, or N-C) state. The proportion and type of clay particles within a soil has a strong influence on the magnitude of residual strength relative to softened strength. Where clay is absent (e.g. in a sand or gravel) residual strength and softened strength are approximately the same.

Clays containing more plate-like particles (e.g. smectite) form smoother slip surfaces than those with more angular particles (e.g. kaolinite), further lowering residual strength (see

Figure 2-42, left).The combined effect of clay proportion and particle shape is measured by a soil property called the Plasticity Index. Higher plasticity correlates with lower residual strength. In clay-rich soils, residual strength typically varies between about a third and two-thirds of the fully softened strength (see Figure 2-42, right). A wide range of different clay minerals are recorded in North Norfolk tills (see Figure 2-43).

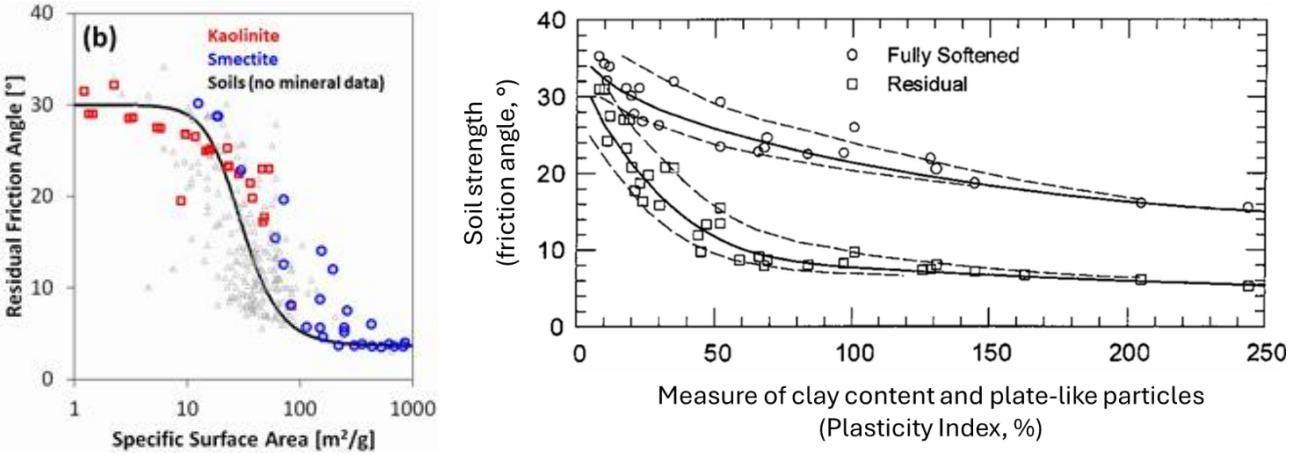


Figure 2-42: Left: Effect of clay minerology on residual strength (Lehman et al, 2021); Right: Comparison of softened and residual strength for over-consolidated clays of various plasticises (Stark & Eid, 1997)

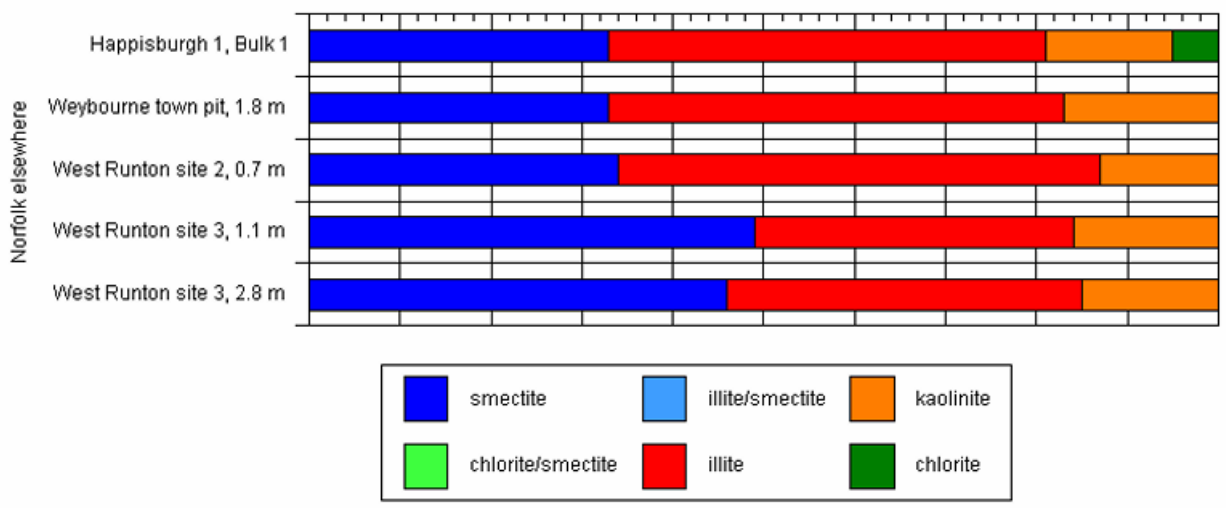


Figure 2-43: Proportions of different clay minerals recorded in North Norfolk till samples at Happisburgh, Weybourne and West Runton (Kemp et al, 2009)

2.17.2 Effect of water pressure in the ground

In addition to the physical properties of soil that affect strength, the presence of water in the ground is also fundamental to the strength of soil, due to the effective stress principle, as illustrated in Figure 2-44.

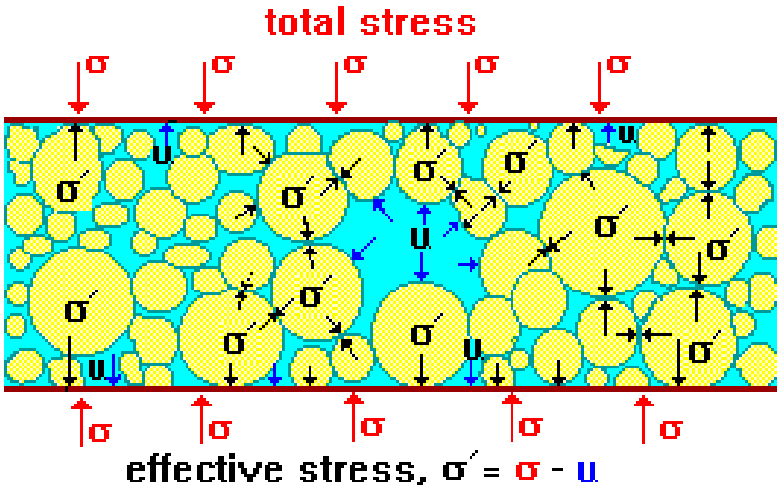


Figure 2-44: Total stress (σ), effective stress (σ') and pore water pressure (u) within a soil mass (blue=water; yellow=soil grains) (Atkinson, 2008)

Water pressures can increase due to such effects as:

- Heavy rain causing increased groundwater seepage through the cliff and out from the face or toe of the slope
- Burst or leaking water mains
- Blocked slope drainage or groundwater control wells
- Wave and tidal action

Increases water pressure are particularly important where the sliding resistance of the soil itself has already undergone reduction from peak to softened or residual strength (see Section 2.17), or where an overly steep ground profile is only just supported by peak strength. In such cases, small increases in water pressure can initialise (or reactivate) mass movements in the cliff face.

Hence controlling groundwater pressures through provision and maintenance of drainage is often used to improve the stability of slopes and cliffs, though this does rely on toe erosion, to be simultaneously absent or controlled, otherwise toe erosion will continue to case instability by undercutting (Frew, 2009, NNDC).

2.18 Shoreline Management Plan statements for Overstrand

Shoreline Management Plans (SMPs) provide a national policy framework that guides public investment in the sustainable management of coastal erosion risk. Local planning authorities use SMPs to guide where they plan and permit development.

The SMP at Overstrand (management Unit 6.06) currently includes the policies shown in Table 2-10.

Table 2-10: Summary of Shoreline Management Plan policy statements at Overstrand

Period- Policy designation: Policy name	Policy description, allowable action(s) and examples
2005 - 2025 (already passed) - HL1: Hold The Line : Maintain / replace	Retain hard defences on current alignments where already present. Refurbish or replace hard defences when necessary. e.g. 2025 Overstrand Coastal Defence Scheme
2025 – 2055: MR5: Managed Realignment (Level 5) : Repair, not replace	Limited maintenance, minor repairs and temporary works to existing hard defences for risk management only. No betterment or design life extension of existing defence, no development that will restrict natural sediment transport or continue to protect Overstrand as a promontory (see Figure 2-13). Develop a longer-term adaptive transition approach with timescale informed by strategic studies and assessments. Commence studies into options for set-back measures designed to slow, not stop, natural erosion (e.g. this report). Implement such measures where justifiable. Commence studies into social mitigation measures for managed realignment. Implement such measures where acceptable.
2055 – 2105: MR2: Managed realignment (Level 2) : Slow erosion	Maintain / replace set-back measures (designed to slow, not stop, erosion) as coastline retreats. Continue social mitigation measures.

2.19 Historical rainfall and cliff instability records

Historical daily rainfall weather station data is available from the neighbouring town of Cromer (data sampled from 1st January 1980 to 31st December 2024) and North Walsham which is located 7 miles southeast of Overstrand (data sampled from 31st December 2024 to 14th January 2026). This information has been plotted against the number of recorded failures to create Figure 2-45.

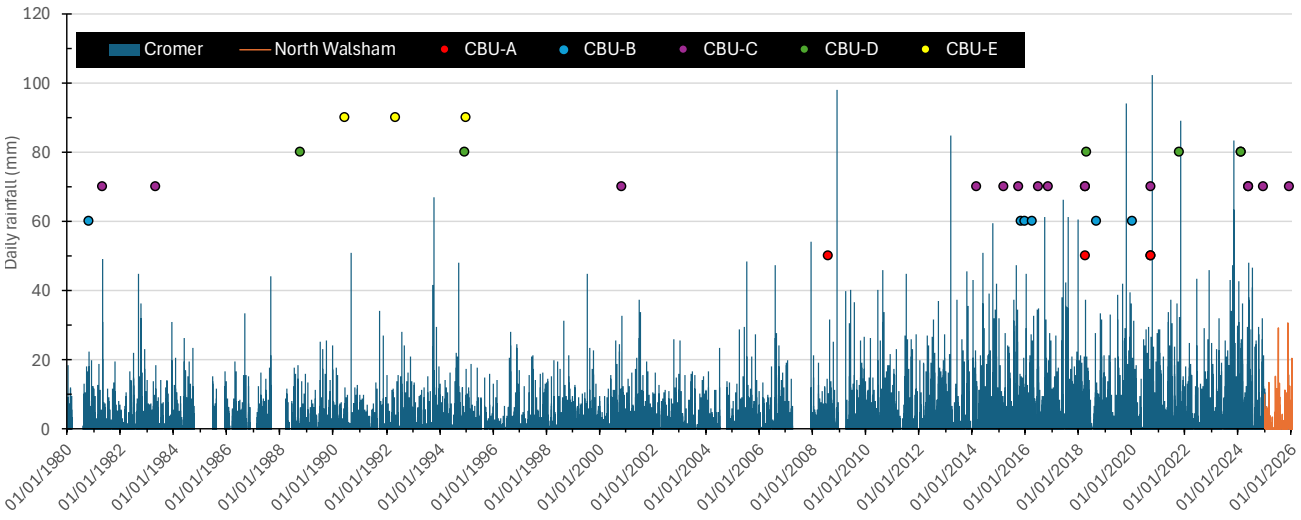


Figure 2-45: Cromer and North Walsham daily rainfall data versus observed failures. Source: Rainfall data licenced by NNDC from Met Office and EA hydrology data portal (2026).

Note the failure data is grouped into zones called Cliff Behavioural Units (CBUs) that are discussed in Section 4. For reference, the general vicinities of each CBU are: A-Pauls Lane Car Park, B-Cliff Road Ramps, C-Central Promenade, D-Ivy Farm, E-Clifton Way.

The trends with the plot can be summarised as follows:

- Average rainfall levels at Cromer between 1980 and 2007 are relatively consistent at approximately 10mm with only sporadic days of peak rainfall ranging between 50-65mm/day.
- Post 2008 average daily rainfall totals have increased to approximately 15mm with 2023-2025 presenting a notable increase to 20mm. Peak rainfall events exceeding 60mm/day have also increased to No.7 compared to just the single event pre-2008.
- Post-2014 the frequency of failure is significantly higher than that pre 2014 and correlate directly with the increases in rainfall experienced.
- CBU-A failures are not exclusive to high periods of rainfall due coastal processes also being a major contributing factor.
- CBU-B does show sensitivity to increased rainfall but most of the failures in this unit are relate to creep movements and minor mudslides.
- CBU-C is the most sensitive unit and extensive, all catalogued failures relate to reactivations of the large colluvium fans through creep or mudslides.
- CBU-D reactivation of the Old Overstrand failure is responsible for much of the instability in this unit, resulting in creep, mudslides and further regression of the backscarp. Failures have also occurred lower down the access road from the same mechanism.
- CBU-E is Clifton Way and is now remediated.

2.20 Potable, surface and foul water drainage systems

A concerted effort has been made to obtain information concerning piped water supply, storm and foul water drainage for this report. Bespoke highways drainage or soakaway information was unavailable. A recent utility search (dated 11/09/2025) was acquired by JBA for use within an affiliated project within Overstrand and surrounding areas with Anglian Water as the sole supplier of potable water and treatment of wastewater.

2.20.1 Potable and foul water systems

The foul sewer network is prevalent across the majority of Overstrand and pumps wastewater to Cromer for treatment from the pumping station at PLCP toilet block. It is unknown whether the foul sewer network continues into private estates and associated connections or septic tanks are installed.

- There is only a single, small, combined sewer connection into the foul sewer at Danish House Gardens housing estate into the foul sewer at Pauls Lane (Figure 2-46).
- Within this housing estate, there is a network of surface water sewers that can be split into independent northern and southern systems. The northern system, which links 12

houses discharge into the 150mm VC sewer to the NE of the estate which is feed back towards Pauls Lane.

- The southern system, which links into 9 houses, does discharge into the foul water sewer via the combined sewer. This housing estate is the only documented instance of a surface water sewer within Overstrand.
- The old discharge pipe to the sea outfall at Pauls Lane and Cliff Road has been decommissioned and the pipework rerouted towards the pumping station.

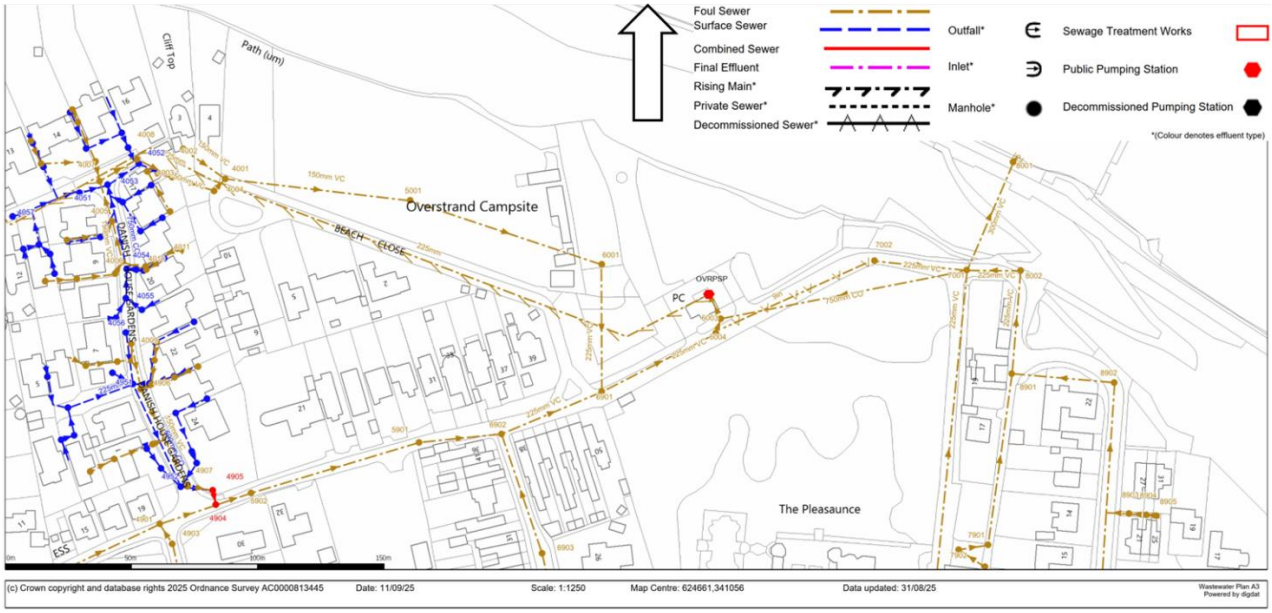


Figure 2-46: Example of foul and combined surface water sewerage within Overstrand. Adapted from Anglian Water service plan received by JBA on 11/09/2025.

The potable water plan of Overstrand from Anglian Water (Figure 2-47) shows a sample of the main water distribution for part of the village. As can be seen, the main 4” cast iron (CI) and 90mm Polyethylene (PE) water pipes run underneath the main roads and housing estates but do not show individual connections to the houses.

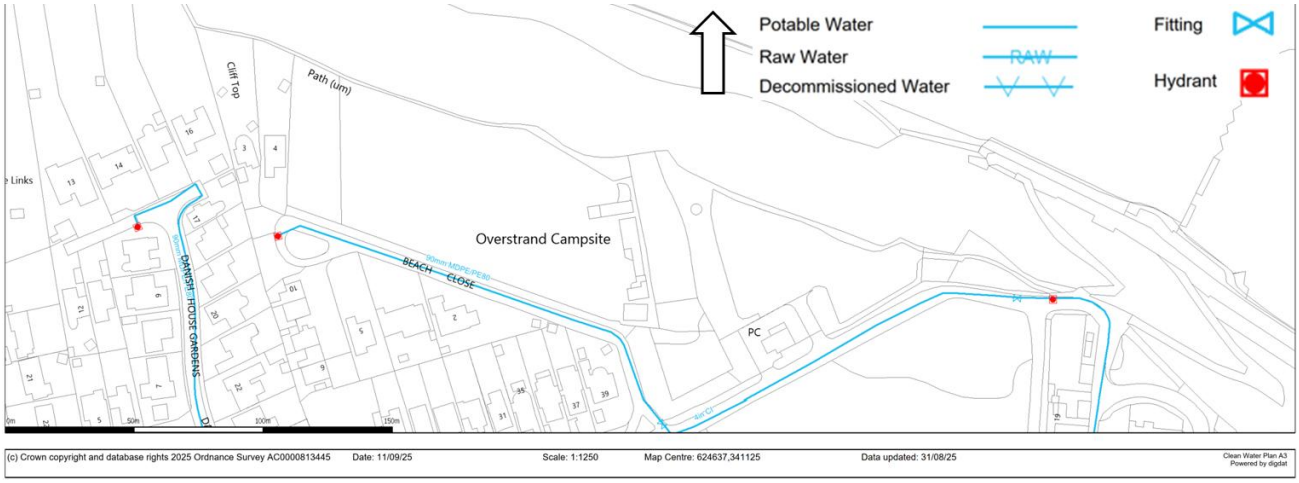


Figure 2-47: Example of potable water supply within Overstrand. Adapted from Anglian Water

service plan received by JBA on 11/09/2025.

2.20.2 Highway drainage

- Highway Authority plans showing the drainage type and alignments of local highway stormwater drainage in Overstrand were requested via a Request for Information to NNDC for use in this report, but these records were not available .
- Information on highways drainage has therefore been inferred from onsite surface observations of highway drainage on paved roads within the village and LiDAR-based analysis of road gradients.
- These assessments suggest that highways stormwater is concentrated towards Pauls Lane and Cliff Road Junction and discharged to the sea via gullies that run along the existing footpaths (Figure 2-48 and Figure 2-49).
- Analysis of the other roads suggest that these do not concentrate water towards the cliffs, rather towards the Pauls Land and Cliff Road Junction.
- Therefore, the continued good operation of the drainage at Pauls Lane/Cliff Road Junction down towards the promenade is considered important for cliff stability.
- The remaining residential roads are deemed private and from observations of the road surface (gravel), stormwater likely infiltrates rather than runs off.



Figure 2-48: Surface water drainage at the crest of the east footpath at Cliff Road leading to the promenade. Source: NNDC



Figure 2-49: Drainage gully for western footpath down from the Cliff Road as it discharges through the promenade to the sea. Source: JBA, 2026.

2.20.3 Residential properties

- Information relating to residential property soakaways was requested via NNDC for use in this report but was not available.
- Based on limited in-situ, land use map and street view imagery observations of residential properties and development density (except for Danish House Gardens Estate for which information is available; see above), it is expected that most storm drainage/guttering discharge to soakaways or infiltrates into gardens.

2.21 Surface water flooding

The surface water flood map (DEFRA, 2026) (Figure 2-50) shows that two flow paths and areas of accumulation are predicted within Overstrand during current climate models. The first flow path is to the west of the study area whilst the second flows centrally and discharges via storm drainage at the Cliff Road beach access paths. Note that this modelling is based mainly on topography and surface cover and does not explicitly account for where deeply infiltrating water would be expected to discharge or over what period (e.g. the. water shown impounded with the old railway cutting to the south of Overstrand).

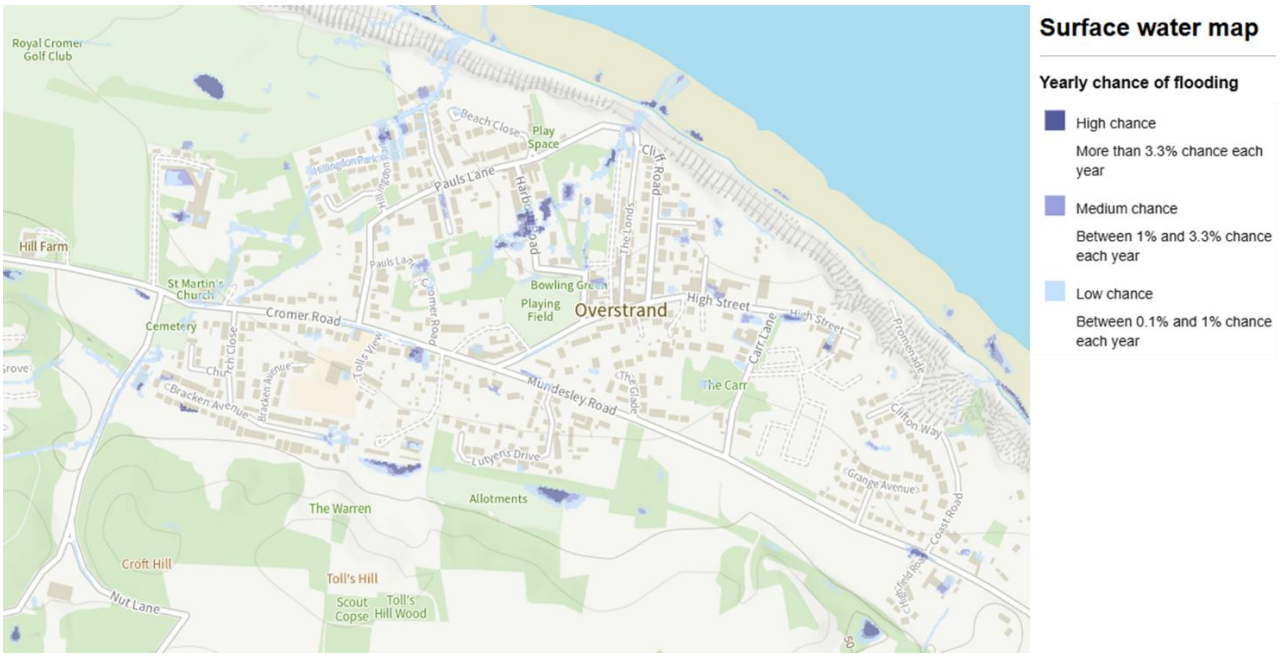


Figure 2-50: Overstrand surface water flooding map. Accessed 12/02/2026. Source: https://check-long-term-flood-risk.service.gov.uk/map

2.22 Community engagement

A map recording local community comments concerning coastal erosion, and the locations in Overstrand they referred to, were recorded at a stakeholder engagement event in 2024 (Figure 2-51). These have been reviewed for relevance to the present study report.



Figure 2-51: Community engagement event from 2024. Source 2024

The following were noted:

- The comments made by community mainly focused on the eastern part of the frontage section, expressing concerns about accessible and safe access to the promenade via the Clifton Way access road.
- A small number of comments were raised about the surface water flooding down Carr Lane and draining into local properties soakaways enroute to the cliff face.
- A further comment was made on the condition of the interceptor boreholes and the lack of maintenance, however, Harbord Lane (Well. No. 4) was stated to be working well.

Overall, the results did show that there is local interest and awareness of the historic and current use of groundwater management employed with the intention to stabilise the Overstrand cliffs.

2.23 Ground motion from satellite InSAR monitoring

The European Ground Motion Service (EGMS, 2026) provides satellite elevation monitoring of the Earth's surface within geographical Europe via a technique called InSAR (Interferometric Synthetic Aperture Radar). This provides time-histories of elevation at selected sample points. The points available within the Overstrand study area at shown in Figure 2-52. These have been divided between points on the promenade (red dots) and on the cliff top (orange dots).

The available spatial and time resolution is sufficient to compare trends between these two sets of points between January 2019 and January 2023 as shown in Figure 2-53 and Figure 2-54. These show that promenade points moved down on average at 1.56mm/year for a total of about 8mm over the period, while the clifftop points moved down on average at 1.12mm/year, for a total of about 6mm over the period.

The slight difference in results may be related to expected gradual deterioration of the promenade/seawall structure. Otherwise, the magnitudes and trends of both sets compare well to calculated rates of isostatic rebound occurring presently from the previous ice age (Shennan et al., 2000), which are applicable over Southern England as a whole.

Publicly available InSAR data therefore do not reveal any previously unknown trends, but this technique remains potentially useful for future management, particularly if used with higher-resolution, location-specific data and analysis.



Figure 2-52:Settlement monitoring sample points within Overstrand.
Source: https://egms.land.copernicus.eu/

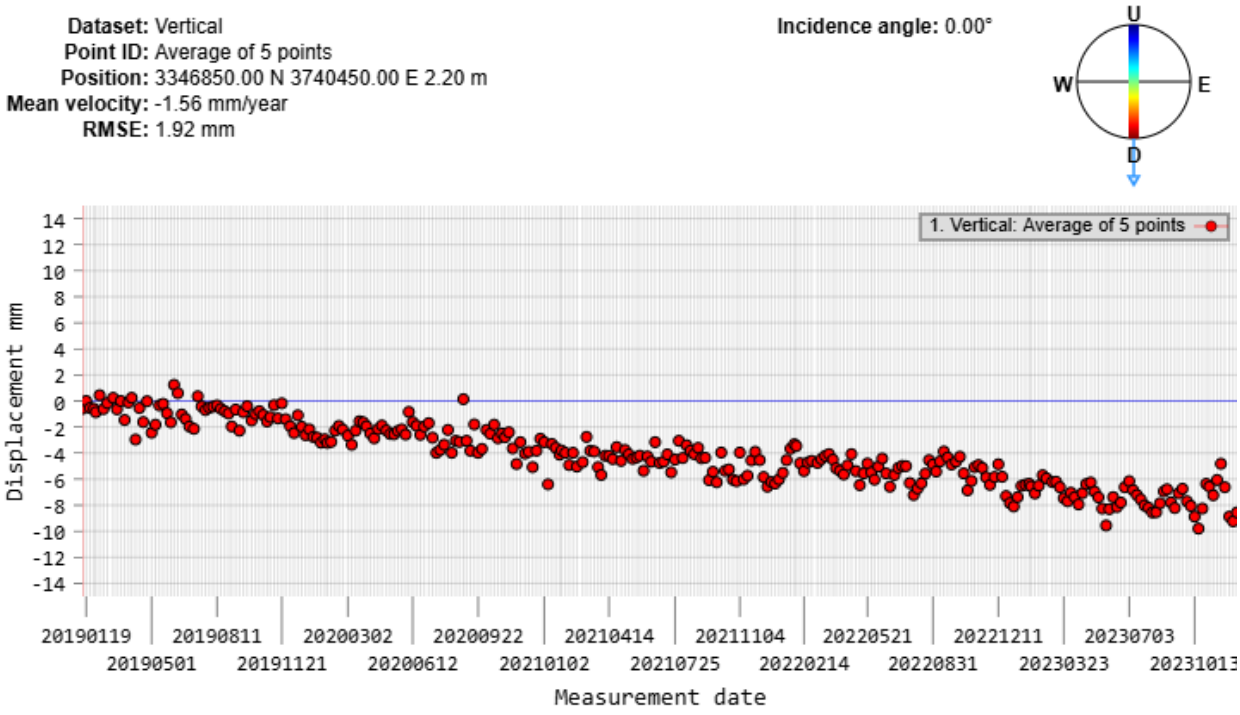


Figure 2-53: Average vertical displacement of points along the promenade (red dots in Figure 2-52)

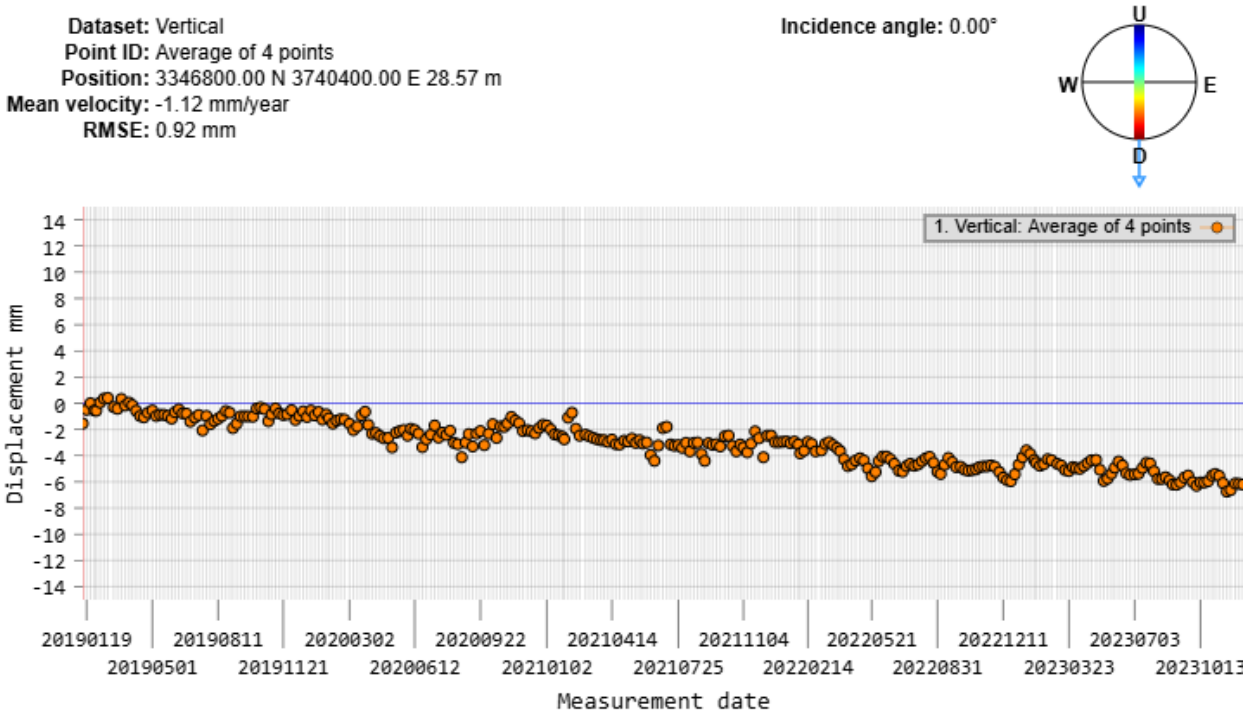


Figure 2-54: Average vertical displacement of points behind the cliffs (orange dots in Figure 2-52).Source: https://egms.land.copernicus.eu/

2.24 Unexploded Ordnance

Unexploded Ordnance (UXO) risk that may prove to be a constraint to any future options or proposals for coastal erosion management at Overstrand have been reviewed. The Zetica preliminary UXO risk assessment map (dated 10/02/2026) states that Overstrand is at a low risk of encountering UXO. The risk map also shows that within Overstrand, possibly at the former railway station, a military target has been assigned. Cromer, 2mi to the west of the site, has been designated at medium risk with a UXO find on the southern outskirts and a military target to the NW.

The Zetica Pre Desk Study Assessment (PSDA) dated 09/03/2026, states that there was military activity around Overstrand. This occurs in the form of coastal defences consisting of Light Anti-Aircraft (LAA) batteries, Anti-Tank (AT) obstructions, pillar boxes. Furthermore, Cromer golf course to the west of the site was commandeered for live fire training. After the war, all the installations were removed.

2.25 Ecological conditions and sensitive land designations

Ecological and sensitive land designations that may prove to be constraints in any future options or proposals for coastal erosion management at Overstrand have been reviewed.

Figure 2-55 shows the study area includes Site of Special Scientific Interest (SSSI) designations at the eastern and western ends, and a Marine Special Protection Area (SPA) immediately seaward of Overstrand's central promenade. Observations during the site visit (Section 3) noted that the Invasive Non-Native Species (INNS) are present on the cliff faces. Giant Hogweed is commonly present but diffuse, while Japanese knotweed grows densely on the cliff faces within a zone currently about 90m wide above the central section of the promenade.

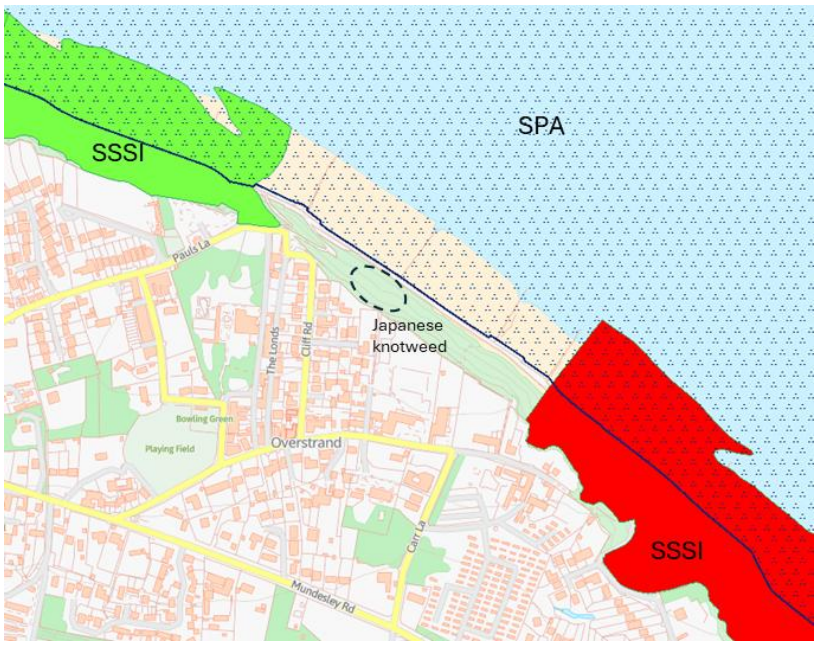


Figure 2-55: Marine Special Protection Area (blue hashed area), SSSI sites (bright green and red areas) and zone o Japanese knotweed infestation at Overstrand

2.26 Rates of cliff retreat

The rates of cliff retreat at Overstrand have been assessed historically in two separate studies involving the North Norfolk Coast by Cambers (1976) and by Clayton and Coventry (1986). The method used in these studies analysed historical OS maps and drew an average rate of cliff regression in the intervening years before surveys.

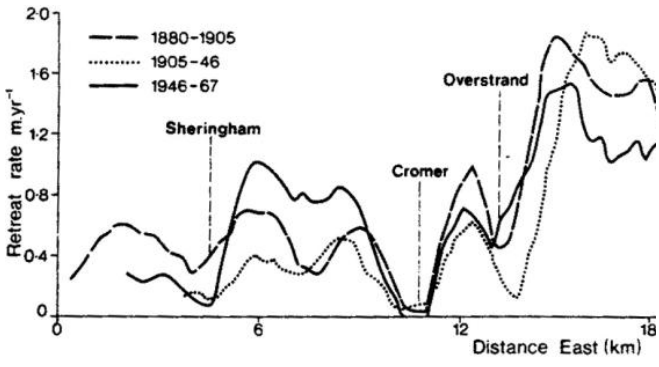


Figure 2-56: Cliff retreat rates 1880 – 1967 (Cambers 1976).

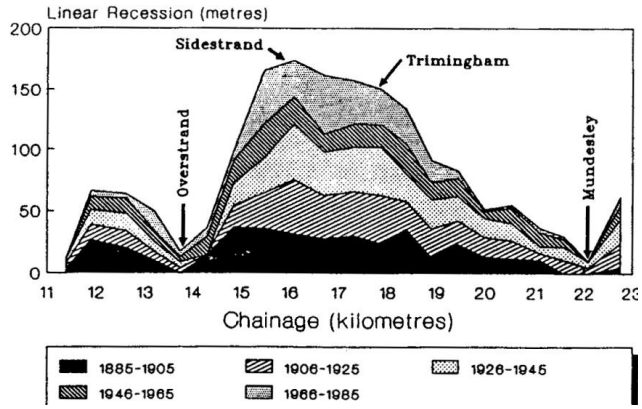


Figure 2-57: Cumulative cliff retreat 1880-1966 (Clayton and Coventry 1986).

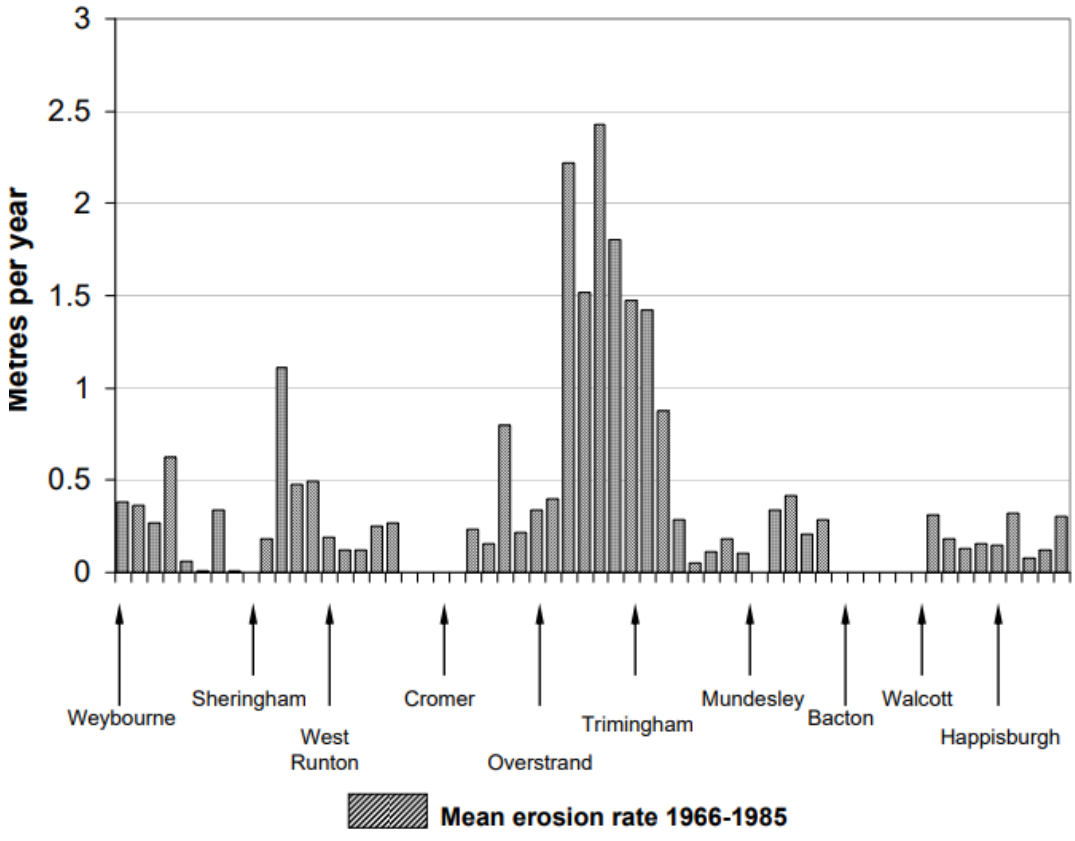


Figure 4. Coastal Erosion rates in North Norfolk.
Based on data from: Clayton, K.M. and Coventry, F. (1986). The conservation effectiveness of the modified coast protection work at West Runton SSSI. Nature Conservancy Council.

Figure 2-58: Cliff recession rate 1966-1985 (Data from Clayton and Coventry 1986 presented in Frew, 2009, NNDC).

Error! Reference source not found. and Figure 2-58 show that Overstrand has had significantly lower rates of cliff retreat than nearby Sidestrand and Trimingham due to the presence of hard defences. Precise locations of the named locations were not recorded, so the plotted data includes spatial as well as time averaging. A summary of the average rates for Overstrand is given in Table 2-11.

Table 2-11: Summary table of rates of Overstrand cliff retreat rates based on Cambers (1976) and by Clayton and Coventry (1986)*

Years	Average cliff retreat rate (m/yr)
1880 - 1905	~0.45
1906 - 1945	~0.2
1946 - 1966	~0.6
1967-1985*	~0.3 (west) to ~0.4 (east)

Table 2-11 shows apparent variation in cliff retreat rates over time, though caution is required before attaching too much significance to this due to:

- The limited resolution and accuracy of the historical mapping available
- Uncertainty over the age of survey data versus map publication date for historic maps
- Different systems of spatial and time averaging applied by Clayton (1976) and Clayton and Coventry (1986)
- Unequal periods of observation between mapping surveys versus the episodic nature of large mass movement events (with shorter intervals more likely to capture an unrepresentative number of events or magnitude of retreat)

To investigate the possible influence of these effects, a re-analysis of historically mapped cliff top lines and recent LiDAR-derived ground surface elevations have been undertaken as shown in Figure 2-59. This involved re-projecting the most detailed available historical mapping layers and LiDAR data in a Geographic Information System (GIS) and locally realigning them to minimise relative positional error. A set of representative cross sections were then defined across the Overstrand frontage to consider smaller-scale spatial variations than in the analyses of Clayton (1976) and Clayton and Coventry (1986).

Table 2-12 shows the derived retreat rates at each cross section. Overall, the re-analysed rates are comparable with those in Table 2-11, though the greater spatial resolution used highlights that:

- Construction of hard defences starting around 1890 seemingly slowed erosion from 1907 onwards.
- Sections at the eastern end of Overstrand (Ivy Farm, Old Overstrand' Hotel and Clifton Way Access) appear to be retreating more slowly recently (2015-2024) than 1888-1970. This may be due to large failures having already occurred at these sections, combined with hard toe defences, allowing the cliff to reach a more stable / lower potential state (however, this would not be expected to continue once the current toe defences become ineffective).

- Sections in the central part of the frontage appear to be in a “quasi-steady state” of retreat, with similar rates in 1907-1970 and 2015-2024.
- Recent (2015-2024) retreat rate at Paul’s Lane Car Park appears higher than previously.

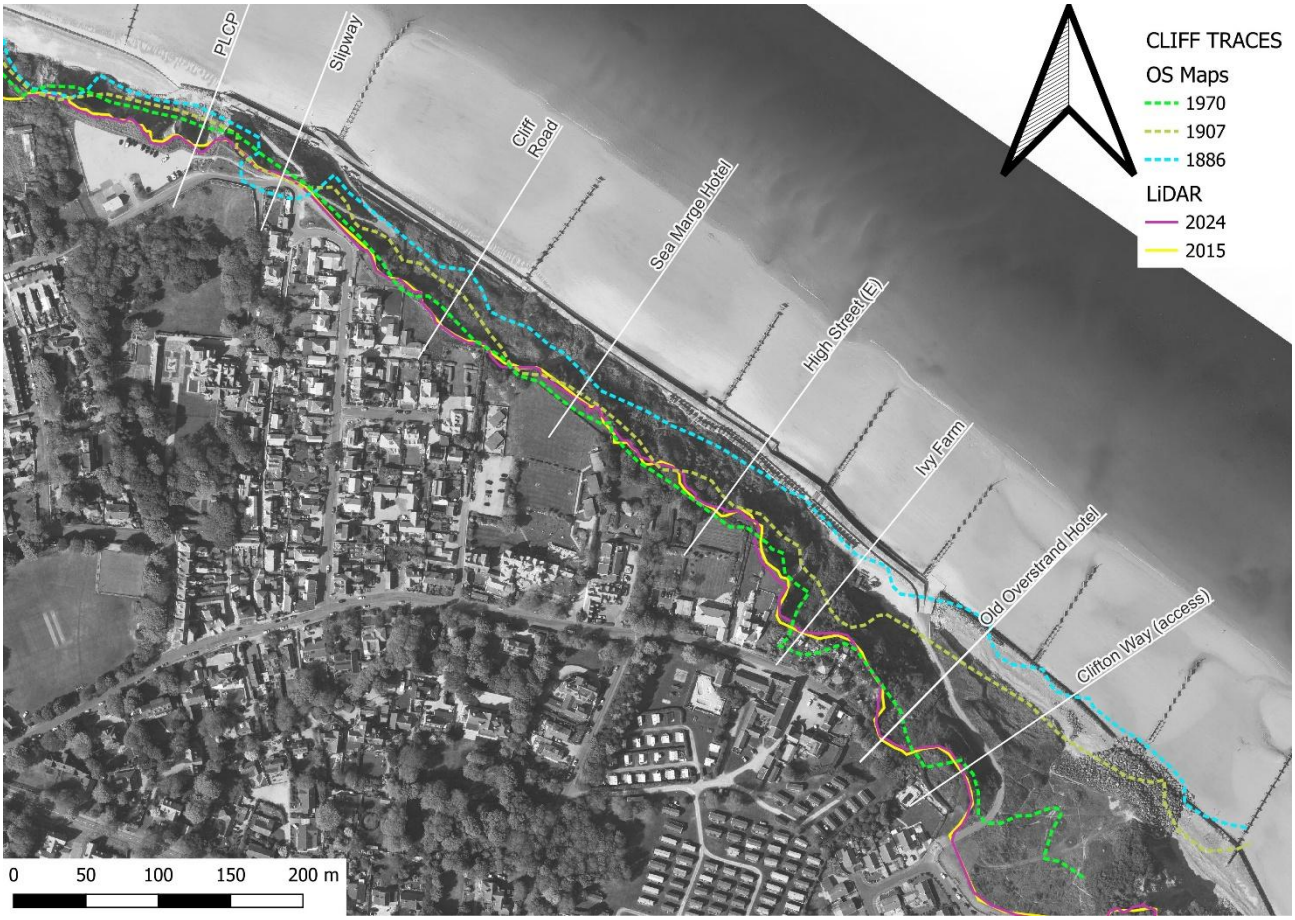


Figure 2-59: Cliff top lines derived from historical mapping and recent LiDAR-derived ground surface elevation data at Overstrand study area. Base map and LiDAR data: NNRCMP, 2026.

Table 2-12: Cliff regression rates at specific locations at Overstrand.

		Cliff retreat rate (m/yr)							
		PLCP	Slipway*	Cliff Road	Sea Marge Hotel	High Street (E)	Ivy Farm	Old O’Strand’ Hotel	Clifton Way (Access)
OS Maps	1886 – 1907	0.29	N/A	0.81	0.56	1.36	1.90	1.41	1.23
	1907 - 1970	0.09	N/A	0.25	0.18	0.23	0.67	0.9	0.99
LiDAR	2015 - 2024	0.46	0	0.22	0.2#	0.37	0.17	0.37	0.9

Notes: *Slipway/access ramps construction in this location included infilling/engineered ground causing an apparent seaward movement of the cliff line between 1886-1970, hence omitted.

#LiDAR returns at the Sea Marge Hotel crest line are strongly affected by vegetation growth, and this value is estimated

2.27 Ground elevation changes 2015-2024

A further means off assessing cliff loss is by computing the difference in ground elevations in the available 2015 and 2024 LiDAR datasets (which record elevation on a 1m grid across the entire site).

Figure 2-60 shows this comparison, with areas in blue showing a loss of elevation and red, accumulation. This shows that where directly defended, the cliff toe underwent limited change, while the crest line slowly retreated of the order of 1-2m within existing zones of overstep crest slope (i.e. embayments and backscarps), at Pauls Lane Car Park, Sea Marge Hotel, Ivy Farm and High Street (east).

This result demonstrates the role of the toe defences in preventing toe undercutting, which would otherwise dominate the overall rate of cliff retreat. Having toe defences means that the slower, secondary processes acting close to the crest (mainly surface run-off and groundwater seepage) get sufficient time to cause measurable crest loss.

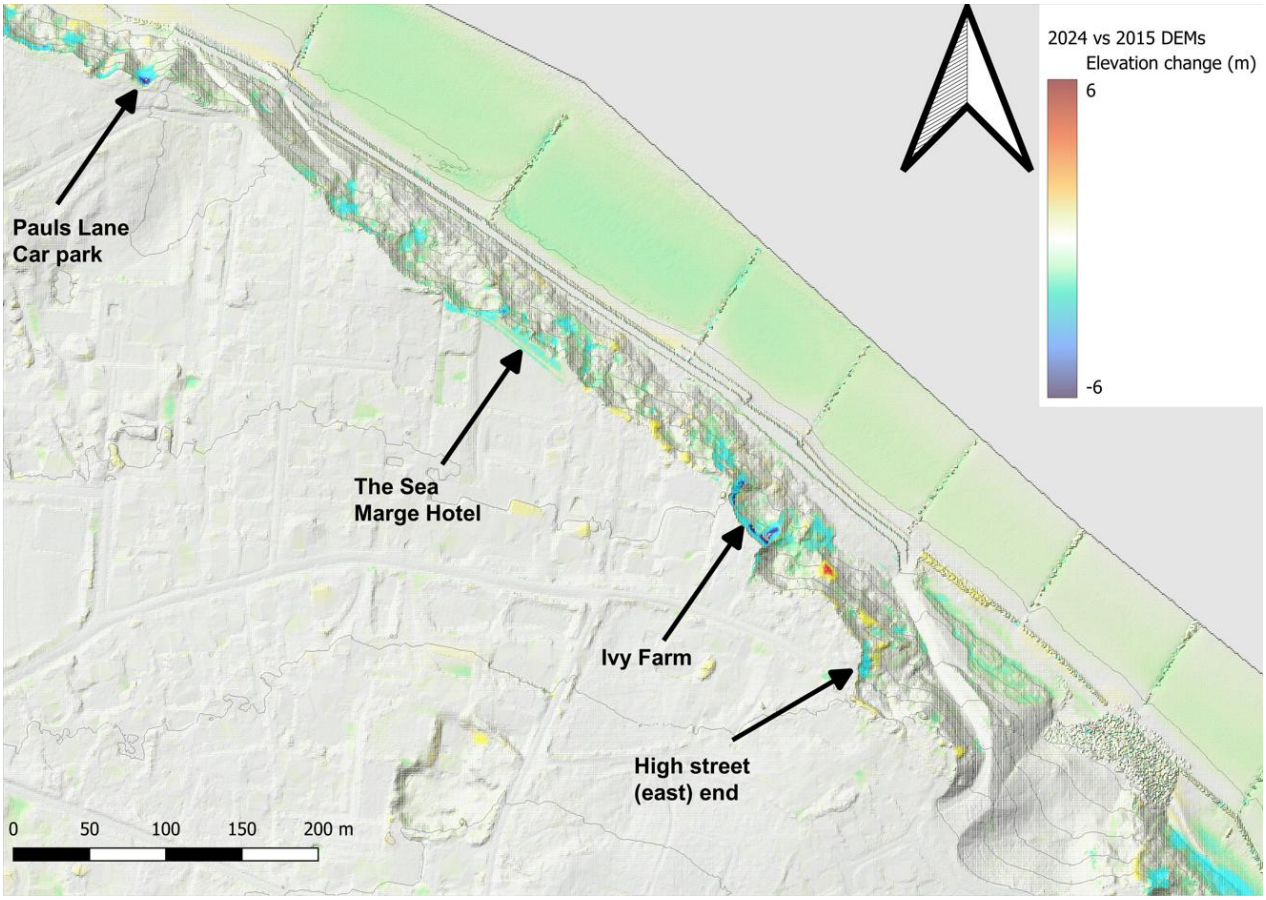


Figure 2-60: Comparison of 2024 and 2015 DEM models.
Positive (red) = Accumulation of material, Negative (Blue) = Loss.

2.28 Cliff slope angles

Site-wide slope angles derived from LiDAR data are shown in Figure 2-29 and developed as cross sections on the lines shown in Figure 2-62. The local slope angles have been colour-shaded to indicate the differences in steepness in different regions of the slopes.

In the cross sections, points locally above 20º are highlighted as likely to exceed the residual friction angle of any clay-rich till layers in the Sheringham Cliffs Formation (SMCL), providing a useful indicator of potential areas of instability over a widely variable set of geologies across the site.

An exception is at Clifton Way Access, where the slope was deliberately engineered by cutting through chalk exposures in the 1980s, hence these cut slope faces are expected to be relatively stable despite exceeding 40°.

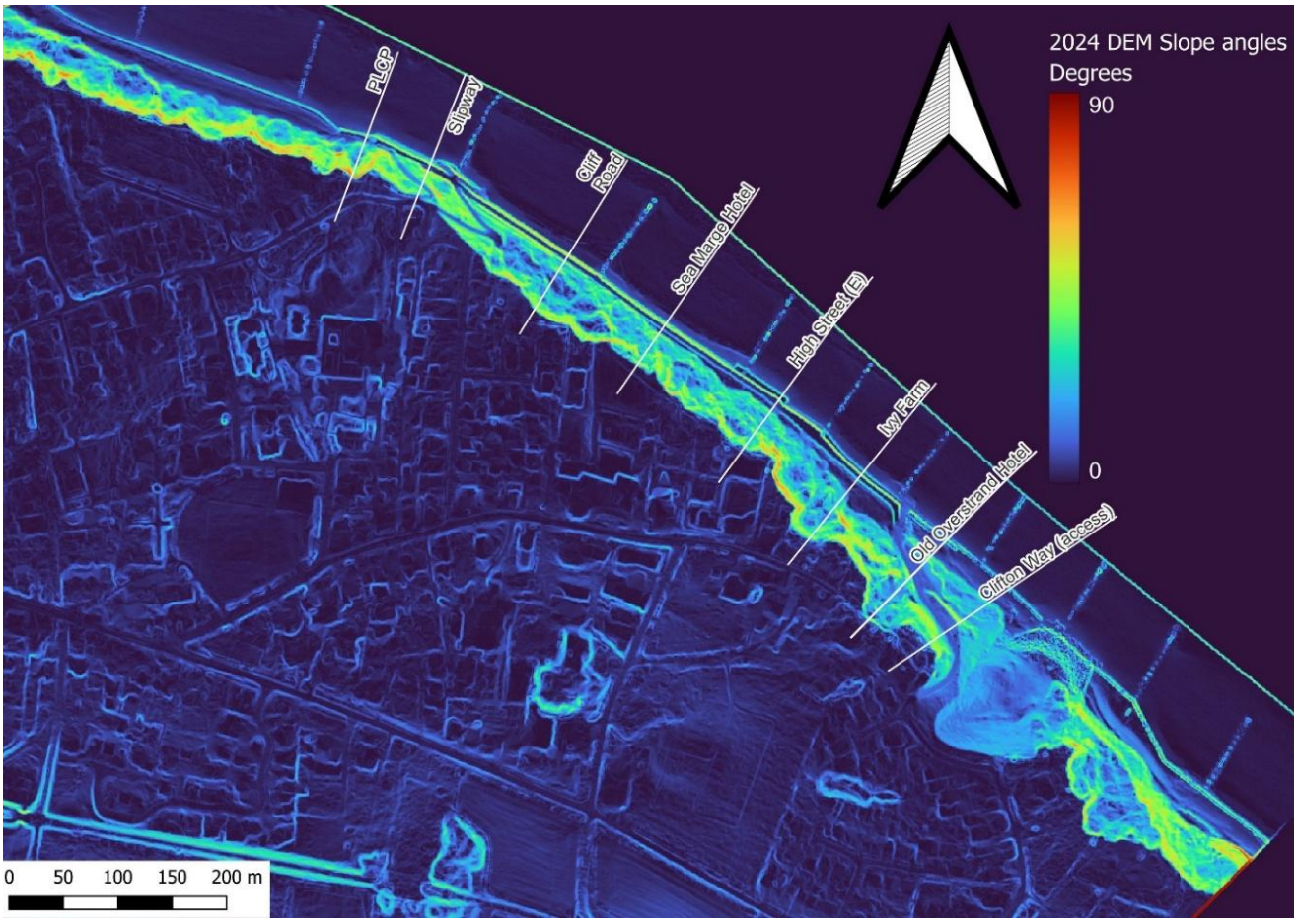


Figure 2-61: Topographic slope angles (degrees) within Overstrand based on 2024 LiDAR.

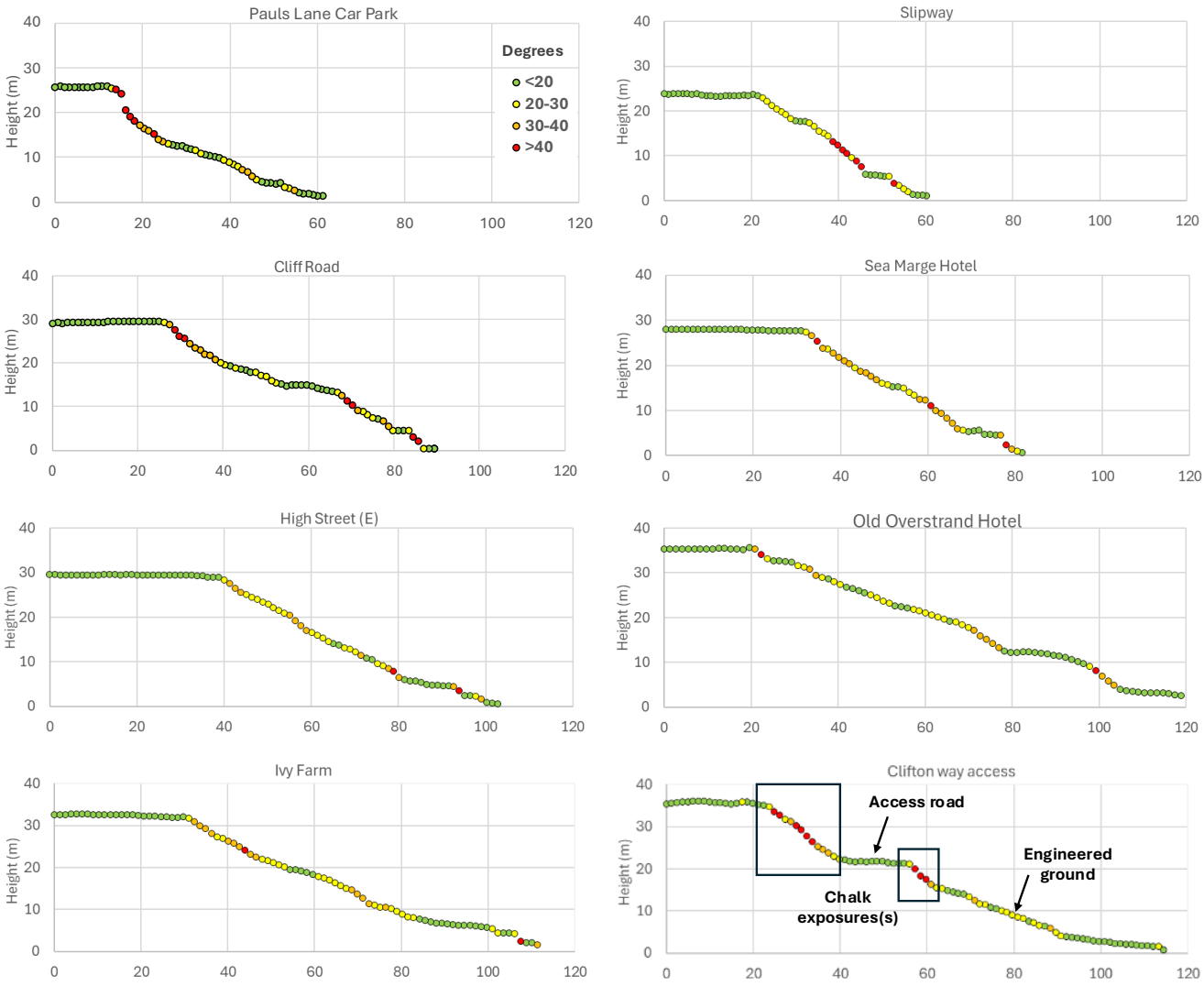


Figure 2-62 Cross sections of cliff face locations showing local slope angles

3 Site Visit

A site visit was undertaken by Richard Rees and Yasmin Hassall of JBA Consulting on Thursday 29th and Friday 30th of January 2026 to familiarise the report authors with the site and to make observations relevance to site. Brain Farrow of NNDC accompanied on the Friday visit acting as an experienced local guide. Key site visit photographic observation locations are shown in Figure 3-1.

3.1 29 January 2026

The Thursday visit commenced at approximately 14:30 in overcast but dry weather with a walkover commencing from Paul's Lane car park, from which the edge of the latest cliff failure could be observed (Figure 3-2). Observations were made of the site leading down the access ramp to the promenade. The remainder of the site walkover for this day focussed within Overstrand Village, its surface drainage and notable locations including the easternmost failure.

3.1.1 Public coastal footpath

At the time of the visit sections of the coast path, which runs parallel to the cliff edge, were closed due to material loss at the cliff face. Access was still permitted from the high street access between the properties 18 Cliff cottage, and 12 East Dene. The path also remained open between High Street and Clifton Way. From the coastal path, heavy vegetation impeded view of the cliff faces however, faces that were exposed and visible did not have any observable water features and appeared dry.

3.1.2 The Overstrand Hotel

The public footpath between High Street and Clifton way crosses the location of the remains of the Overstrand Hotel, which built down in 1948 (Figure 3-7). Brick and concrete foundations are still visible and debris from this property lies on the slope beneath. A set of displaced timber steps are also present but closed "for repair".

3.1.3 Highway drainage

Observations within the village demonstrated that predominately, most roads do have surface water drains connected to them to prevent surface flooding.

Drainage is present at the foot of Carr Lane or servicing the adjacent homes but was obscured by parked vehicles at the time of the visit, and only limited drainage is visible to Mundesley Road.

This area would be suspectable to overland flow entering their perspective ground, if the existing drains were overwhelmed and has been reported by residents as such. This has led to water accumulating out the front of the Sea Marge Hotel and infiltrating into the ground soakaways, potentially aiding in flooding of the hotel's rear garden.

Residential properties within the study zone typically have soakaway drives in the form of gravel and vegetated gardens, with very few being tarmac or paved. Furthermore, terraced houses, which encapsulate the bulk of the older houses in the village, only have on street parking. This indicates that the areas within Overstrand is readily permeable, but it is not known whether houses directly discharge gutter water into soakaways for the surface drainage system.

3.1.4 Eastern failures and geology

Valuable information was attained by inspecting the un-vegetated cliff faces beyond the study site extent towards Sidestrand. Large chalk exposures are spaced at regular intervals at the base of the gradually wave eroding cliffs. These support the laminated clay/sand beds of the Sheringham Cliff Formation above with some visible outcrops of the Briton's Lane Sand and Gravel Member (BRLSG) above characterised by gravel/cobble sized material embedded towards the cliff top. The BRLSG was not identified at Overstrand where there are back-scarp exposures of recent cliff failures.

3.1.5 Non-native invasive species

Two vegetative non-native invasive species are present and are observable within the site study area.

Japanese Knotweed is present densely in a large area of the cliff-face and is presently cordoned off to prevent it spreading by reaching the sea and spreading along the coast. This plant is known for having dense, wide and deep root systems and several information boards are a warning to the public to prevent its spread, stating a treatment plan is ongoing (Figure 3-5).

Giant hogweed was observed consistently across much of the cliff face, however its existence appeared less dense than the Japanese Knotweed.

3.1.6 Historic railway cutting

A disused railway cutting (approximately 150m long and 3m at its deepest) is to the southeast of Overstrand leading off the junction between Carr Lane and Mundesley Road, towards a now infilled railway bridge. Visual observations confirmed that no groundwater egress was emanating south of the site nor was there any evidence of pooling water or hydrophilic vegetation at the bottom of the track bed. This suggests the cutting is well drained and any groundwater is beneath its base level.

3.2 30 January 2026

The Friday visit commenced at approximately 09:00 in intermittent rain conditions where Brian Farrow of NNDC was accompanying for the site visit, and available to provide additional information and context for the area.

3.2.1 Existing defences and planned works

All defences as mentioned in section 2.1 are confirmed present although several are seen to be at limited performance capabilities.

The sheet-piled platform, structurally supporting the sea wall and promenade adjacent to the beach huts, has reached the end of its design life. Previous contractor engagement by NNDC, with design work won by JBA, of the proposed future extension of the apron via new sheet piles and supporting mass concrete behind, at two separate locations. The first being western promenade by 55m and the second, the eastern promenade by 140m with the purpose of extending the serviceable design life of the existing structure by 20 years.

A series of gabion baskets being used as retaining are present below one of the footpath ramps, near the Paul's Lane Carpark. Material is creeping over the top of the uppermost set of baskets however, the lower sets of baskets are heavily corroded and losing material. The base of the gabions did now show water accumulation nor fines contamination; this was due to weep holes being built into the seawall itself (observed within the catchpits) and the gravel base behind which the gabions sit on (historical site photos).

Timber-framed sections of rock and waste concrete blocks are present to the furthest extent of both ends of the site area. These do not provide toe support but reduce wave impact to the cliff bases and loss of beach sediment.

3.2.2 Cliffs below Pauls Lane Car Park

Below the car park failure site, two chalk exposures are embedded into the cliff base with the washout failure flowing between them. The same features also appear to be present in the failure immediately to the northwest of this.

It is noted that the failure body (clay/silt) is a highly saturated with rills formation from identified groundwater seepage flow exiting the cliff face approximately 4m down from the top. It is possible that this egress is sourced from the permeable sand horizon underneath the clay/silt layer. It is not confirmed whether this is the cause of the slope failure or if other sources of water exist i.e. perched water table(s). This is the only location where the exact source of groundwater could be visually identified during the site visit, with implications discussed further in section 2.11.

Further instability was also evident where cliffs boarding the car park above leading to the western end of the study area (Figure 3-10) whereby additional mudflow and toe erosion has been noted. Note, the figure is based off drone footage of the cliffs from You Tube due to site photos being obscured by the rain.

3.2.3 Overstrand Car Park to Sea Marge Hotel

At the pedestrian access ramps to the northwest, shallow translational failures are in progress on the upper 300mm of the surface (Figure 3-3). The gradient of the slope in this section is steep (at least 40º) for its material type, with the exposed surface appearing "wet" and material slipping over debris boards, indicating slope creep.

At the location of the Japanese Knotweed contaminated material, as stated above in section 3.1.5, concrete legato blocks have been installed as additional toe support for the wooden debris barriers holding material up-slope. Both within and immediately beyond the Legato barriers, slope creep has resulted in further, highly saturated material being actively deposited onto the promenade (Figure 3-6). Within the main body of retained material, previous attempt at slope drainage (perforated pipes) have been ripped up and no water is discharging at the weep holes at the base of the seawall. The latter would imply these are blocked with low permeability material i.e. clay.

These slips resulted in an estimated 4-5m high back scarp of exposed material at the cliff edge of the Sea Marge Hotel (Figure 3-7). From visual identification this appeared to expose the sand and laminated silts/clays consistent with the description of the Sheringham Cliff Formation. No safe access to the slipped material was possible but importantly, no groundwater egress from the slope could be identified from an observable stratum within the backscarps or main body of the failures, only towards or at their toe.

During the visit it was reported that a “pond” and “gulley” was previously present beneath the Sea Marge Hotel’s land, on the cliff slope and this was believed to have prevented instability of the cliff above the hotel’s grounds. The presence of the gulley has been confirmed via historical site photos with a further gully adjacent the gabion baskets which showed distinct orange staining from possible low-grade iron or sand. The now absence of these features is believed to contribute to the failures at the cliff face within his property. This water is now suspected to be a significant contributor to the saturation of the failure body of material, instead of directly flowing out to sea.

3.2.4 Beach Huts to Clifton Way

To the rear of the beach huts, a mass failure is in progress with the toe of the failure creeping into rear of these buildings, with no retaining structures in place at this locality. Water accumulation is occurring behind the rear of the huts via seepage egressing from the toe body. It was not known whether the primary source of the water was groundwater based or only the draining of the saturated material due to recent rainfall at the site.

Large chalk rafts are present within the cliffs above the gravel vehicle/plant parking area as well as beyond the large Clifton Way failure (beyond the study site extent). Multiple chalk exposures are observable end of the promenade, but none are visually determined in the central section. Due to the regularity of these features observed, it is speculated that these have likely been obscured by the debris slides and/or vegetation present. There is no evidence to suggest these would not be present within the till, in-situ. There are on-going failures at the previous Overstrand Hotel location with foundation material continuing to be deposited onto the access road.

From all the failures noted along the cliff study area, previously failed material is often very saturated enabling it to become more readily mobile and reactivate mudslide or creep action towards the sea. The in-situ slope material, where the estimated 4-6m high back scarps are exposed show no evidence of seepage flow (except for Paul’s Lane car park failure). This

would strongly suggest that directly along the seawall, seepage egress is occurring at a depth deeper than that of the cliff exposures and aid in the saturation of the failed material. Like the beach carpark failures, it is not known whether multiple points of water egress are occurring at different depths from resulting perched water tables or if there is a specific stratum primarily instigating slope failure

3.2.5 Site visit photos and supplementary drone footage

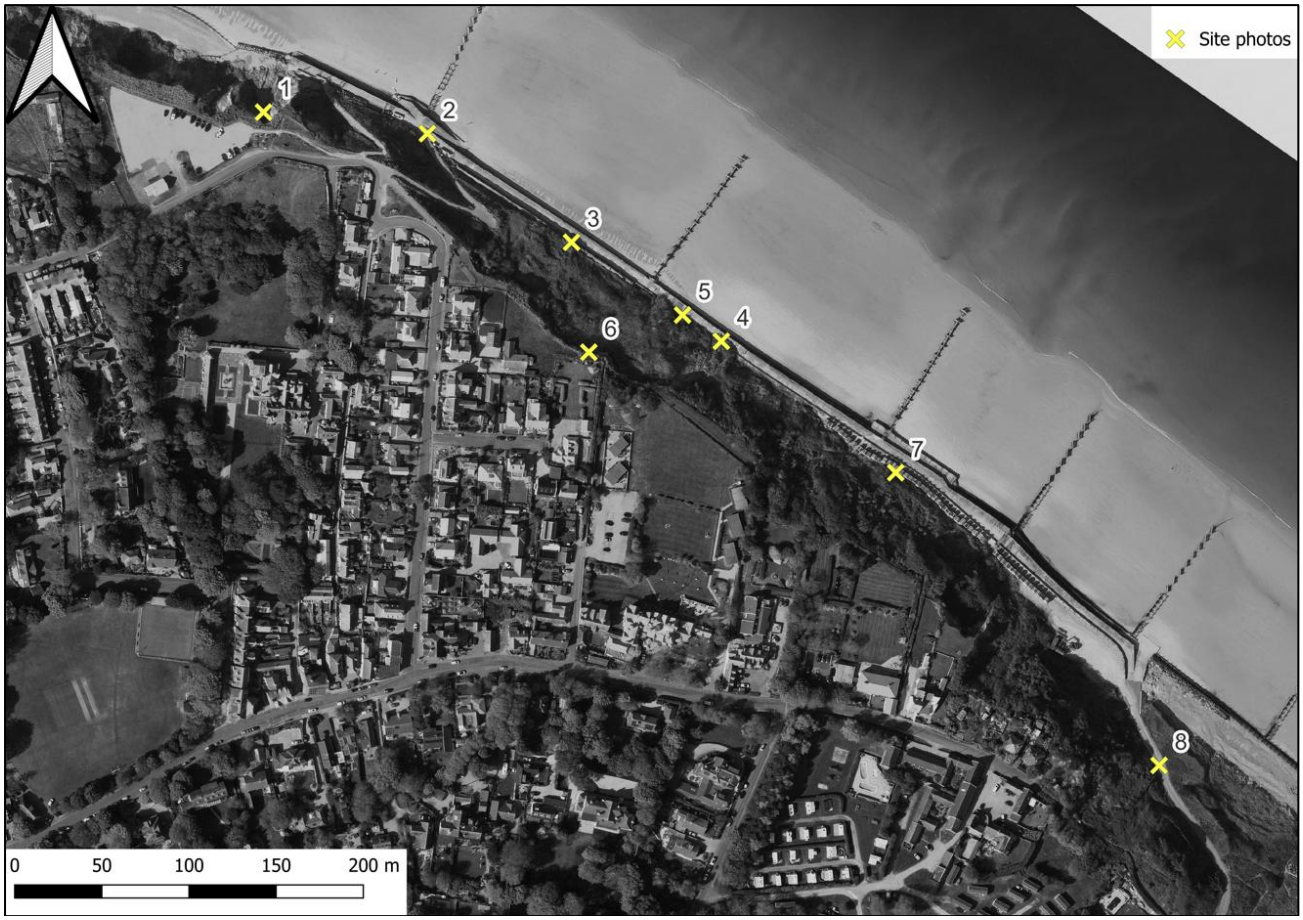


Figure 3-1: Locations of referenced JBA site visit photos. Base map from NNRCMP Aerial Imagery (2025).



Figure 3-2: PLCP failure (photo 1)



Figure 3-3: Shallow translation slides off promenade slipway being retained by boards (photo 2)



Figure 3-4: Gabion baskets retaining failure above. Creep is still occurring and overwriting the upper gabions in places, the condition of the steelwork on the lower gabions is poor (photo 3).



Figure 3-5: Legato blocks supporting debris boards behind containing Giant Hogweed infested earth. Note seepage from multiple faces, water is also accumulating behind the seawall. (Photo 4)



Figure 3-6: Previous failure creeping over promenade wall. Note the level of saturation within the material and giant hogweed in the background. (Photo 5)



Figure 3-7: The Sea Marge Hotel cliff failure exposed back scarp. Approximate height 4m with no ground water noted. (Photo 6)



Figure 3-8: Water accumulation and seepage egress from creeping failure behind the beach huts at the central promenade (Photo 7).



Figure 3-9: Clifton Way promenade access road. Notable amount of seepage from the previous failure. (Photo 8).



Figure 3-10: Supplementary drone footage of the Pauls Lane car park vicinity on January 18th 2025. Source: YouTube video "Overstrand Cliff Slip" by The Content Creator Shaun Button.

4 Assessment of Cliff Behaviour Units (CBUs) including relationship to water

The assessment in this section is based on the information presented in Sections 2 and 3 and the general approaches of the Soft Cliffs Report by DEFRA (2002), developing the previous assessment work by HR Wallingford (2003).

As defined by DEFRA (2002), Cliff Behaviour Units (CBUs) attempt to characterise sections of coastal frontage in terms of their geomorphology, geological and hydrogeological observations and likely behaviour in response to coastal erosion processes.

Using this methodology, 5 distinct units have been characterised as shown in Table 4-1 and located in Figure 4-1 (which summarises historical seepage and failure locations).

Table 4-1 compares the 5 CBUs identified in this study to the previous assessment results by HR Wallingford (2003), which identified only 4 units (see Section 2.6).

The comparison indicates good agreement between the two assessments for CBUs A, B C and E, but additional information available to this study has enabled identification of an additional unit (CBU D) with combination features.

Table 4-1: Summary table of CBUs location

Cliff Behavioural Unit (CBU) in this study	General location	CBU Type based on DEFRA, 2002 (for illustrations see TABLE)	Recession model assessed by HR Wallingford (2003)	Recession Model reference by HR Wallingford (2003)
A	**Paul's Lane Car Park**	Mudslide	High-angled debris slides and lobate mudslides within narrow gullies	Type A
B	**Slip/walkways**	Engineered slope (Mudslide-Rotational transition zone)	High-angled debris slides and lobate mudslides within narrow gullies	Type A
C	**Main Promenade**	Rotational landslide	Rotational or multiple rotational landslides	Type B
D	**Ivy Farm**	Composite rotational slide over rock (chalk)	(not identified)	(not identified)
E	**Clifton Way**	Deep-seated landslide with failure at more than one level	Major elongate mudslides and multiple rotational failures	Type C

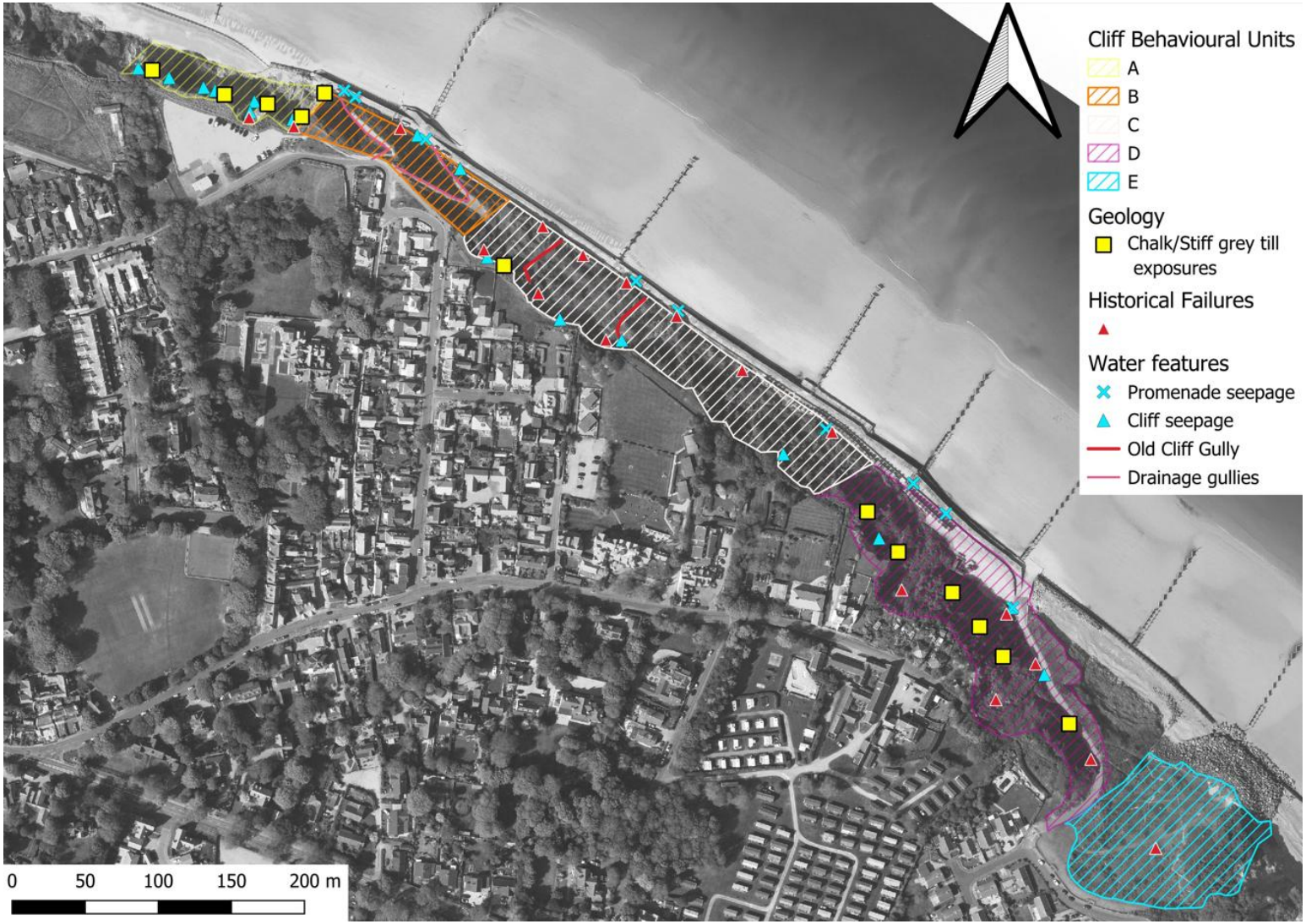
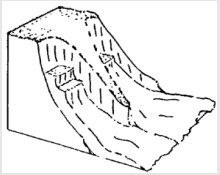
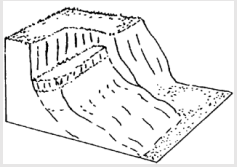
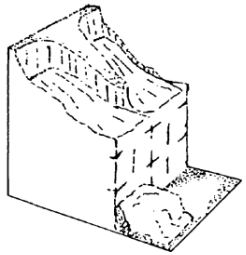
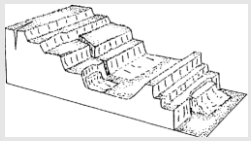


Figure 4-1: Summary of CBUs, identified cliff failures/toe slips, chalk exposures and cliff/promenade seepage locations at Overstrand between 1946 and 2026.

Table 4-2: Cliff Behaviour Unit characteristics and significance of water on cliff stability

CBU	Location	Characteristic CBU type cliff form (DEFRA, 2002)	Geology (based on limited exposures)	Human activity	Vegetation	Coastal Defences	Slope support measures	Significance of marine water	Significance of groundwater	Significance of surface water
A	**Paul's Lane Car Park**	 Narrow embayments with accumulating mudslide colluvium between headlands of chalk or stiff till	Variable depth of orangey, seemingly sandy till over a thin dark band with seepage springs, over white chalk erratics or light grey stiff till.	Disused groundwater interception boreholes close to crest line. Car park may cause small additional loading but mainly in good weather only.	Zones of thick vegetation on flatter parts of colluvium fans	Horizontal palisades (assumed supported on sheet piled foundations). Beach groynes. Ad hoc rock armour and sheet piling at interface with CBU-B. All have <20 years remaining useful life.	None.	Direct wave undercutting to toe during storms when palisades overwhelmed. Dominant influence on cliff stability Influence will become even more dominant once palisades reach end of life.	Groundwater seepage in upper cliff slope reduces stability of material above. However, this material then falls to beach level which boosts wave attack protection to cliff toe.	Records indicate surface water may be being concentrated into groundwater by erroneous drainage connections to nearby disused interceptor boreholes
B	**Slipway & walkways**	Engineered slope at transition zone between CBU-A (mudslide) and CBU-C (rotational)	Upper slope obscured, lower slope massive stiff grey till with "pockets" of some other less stable geology at promenade level.	Localised infilling/reprofiling within upper slope c.1906 Slope faces substantially reprofiled to current angles c.1946-1953 Stormwater drainage gullies discharging water from roads sloping towards Cliff Road/Pauls Lane junction.	Grass & small shrubs	Seawall and promenade, refurbished in 2026 with new sheet piles adding minimum 20 years design life. Beach groynes likely <20 years remaining life.	King post timber post wall, ad hoc rock fill and gabion baskets (located in "toes pockets" of seemingly less stable geology)	Promenade currently protects against wave undercutting but can be overtopped during extreme storms. Influence on cliff stability currently less than groundwater seepage, but will become dominant once promenade / seawall reaches end of life.	Seepage observed in the "pockets" of less stable material at toe, suggesting locally increased permeability, Support measures in place appear to allow free drainage of seepage water.	Historic photos of surface washout due to highway run-off from Paul's Lane / Cliff Road junction. Currently appears managed by existing surface cover and drainage, but may be undersized for climate change rainfall projections.
C	**Main Promenade**	 Deep rotational failures forming wide embayments (50-60m across) prevalent.	Single chalk exposure identified in upper slope adjacent to CBU-B. Backscarps (6-10m high) formed in stiff, light-coloured, seemingly cohesive till. Observed seepages at base of backscarps and at promenade level.	Two historical drainage gully draining pond forming at top of colluvium fan at the rear of the Sea Marge Hotel. Likely draining groundwater egress accumulating in ponds	Well established vegetation, small trees/heavy brush common, some large trees at crest. Localised Japanese Knotweed infestation at Sea Marge Hotel. Giant hogweed also common. Vegetation overall likely beneficial for stability via root reinforcement and evapotranspiration of groundwater	Seawall and promenade	Gabion baskets King post timber wall debris boards. Reinforced with Legato blocks Slope toe drainage including catch pits and weep holes though promenade.	Promenade currently protects against wave undercutting but can be overtopped during extreme storms. Sections with additional support measures are most vulnerable to this. Influence on cliff stability currently less than ground and surface water, but will become dominant once promenade / seawall reaches end of life.	Current dominant influence on stability of midslope / toe and reactivation of slips. Groundwater seepage observations seemingly coincide with backscarp / embayment locations and zones of periodic movement reactivation. Slope toe drainage internal condition and effectiveness unknown. Multiple external pit covers are damaged, allowing overtopping marine water to ingress as groundwater.	Current dominant influence on localised crestline weathering, but effect magnitude is small. Surface water ponding in midslope at depressions or benches. Drainage ditches used historically to manage ponding now destroyed by slope creep movements.

CBU	Location	Characteristic CBU type cliff form (DEFRA, 2002)	Geology (based on limited exposures)	Human activity	Vegetation	Coastal Defences	Slope support measures	Significance of marine water	Significance of groundwater	Significance of surface water
D	**Ivy Farm**	 Composite rotational slides over rock (chalk)	Variable sand to clay tills over large chalk rafts. Rafts founded on earlier till layers (composition uncertain). Chalk raft top levels and positions relative to the cliff line vary, resulting in a wide range of embayment widths and depths.	Numerous buildings situated and now demolished/destroyed from failures. Construction of promenade access road forming cuttings though chalk rafts Formation of hardstanding area (1980) via extension of promenade. Foreshore fill slope at western end constructed 1995 during Clifton Way radiation from recompacted landslide material.	Well established trees/bushes above chalk rafts where composite slide embayments have reached metastable equilibrium.	Wide promenade / hardstanding (western side) Palisades and short sections rock armour supported on sheet piled foundations (eastern side) Beach groynes	Buried sheet piled retaining wall at interface between rear of western foreshore fill slope and front of Cliton Way access road.	Limited effect on cliff toe due to wide promenade and set back cliff line prevents wave undercutting on the western side. Dominant effect on foreshore fill slope at western end (constructed 1995 during Clifton Way radiation from recompacted landslide material) which is subject to wave attack in extreme storms when palisades / rock armour are overtopped.	Groundwater seepage is the dominant influence on stability of till slopes above chalk. Increased groundwater pressure observed to periodically reactivate existing composite rotational failures e.g. Old Overstrand Hotel site.	Current dominant influence on localised crestline weathering, but effect magnitude is small.
E	**Clifton Way**	 Large landslide complex with lower multiple rotational slip and upper wide translational slip	Head deposits over laminated clay over sand band over stiff clay till over dense sand and gravel over chalk.	Comprehensive remediation scheme completed in 1995 (see Section 2.7).	Grass	Large rock armour revetment (toe of former landslide) Palisades and rock armour (fill slope adjacent to CBU-D)	Reprofiled slope, structural fill, rock revetment, surface and subsurface drainage, drainage groundwater interceptor boreholes	Rock armour protects remediated slope toe. Engineered slope eroding. Surface and subsurface interceptor drainage prevents strength reduction of clay tills that remain present post-failure. Side slopes adjacent to rock armour remain vulnerable to wave attack. Significance will increase once CBU-D & E palisades reach end of life.	Dominant influence on stability within midslope of remediated failure. Drainage systems including interceptor boreholes reportedly working, but inspection or maintenance routine uncertain. Ongoing stability requires drainage continued functioning.	Limited significance due to formal drainage system, including graded, grassed slopes, permeable surface materials over subsurface drainage and beach-level outfalls. Inspection and maintenance routine unknown. Ongoing stability requires drainage continued functioning.

4.1 CBU A - Pauls Lane Car Park (Mudslide type)

CBU-A (Figure 4-2) extends the length of Pauls Lane Car Park to the chalk/stiff grey stiff exposure behind the seawall, and is characterised by:

- Coastal defences: The seawall (western ramp), the ad hoc rock armour, timber palisades and the sheet piles, all are designed to protect the cliffs from wave action.
- The sheet piles purpose is to protect the coastal infrastructure and cliff toe from indirectly by retaining beach material.
- The only unit where the cliff toe is directly subject to wave erosion due to a lack of seawall protection.
- The highest concentration of embayment formations, chalk/still grey till exposures and groundwater egress points of all the units.

Figure 4-3 shows two adjacent embayments between 2008 and 2026, with the seepage locations historically identified in 1953 (Figure 4-4). The 2026 photos (Figure 4-3 b-d) shows a 5-6m high backscarp exposing head (gravel) deposits and orangey/buff tills, with groundwater egressing from an interfacing layer of Clay and Sand, approximately 3-4m from the top of the cliff (Figure 4-3 c&d).

The size of the embayment is directly related to the distance between the chalk/stiff grey till exposures and the ability of the defences to absorb wave energy. Wider embayments from where the space between chalk or stiff till headlands is larger.

An additional instability mechanism is groundwater seepage, as it weakens the upper slope material, leading to smaller scale shallow translational failures above. Importantly, any cliff material that falls to beach level as colluvium offers beach nourishment and hence some additional cliff toe protection.

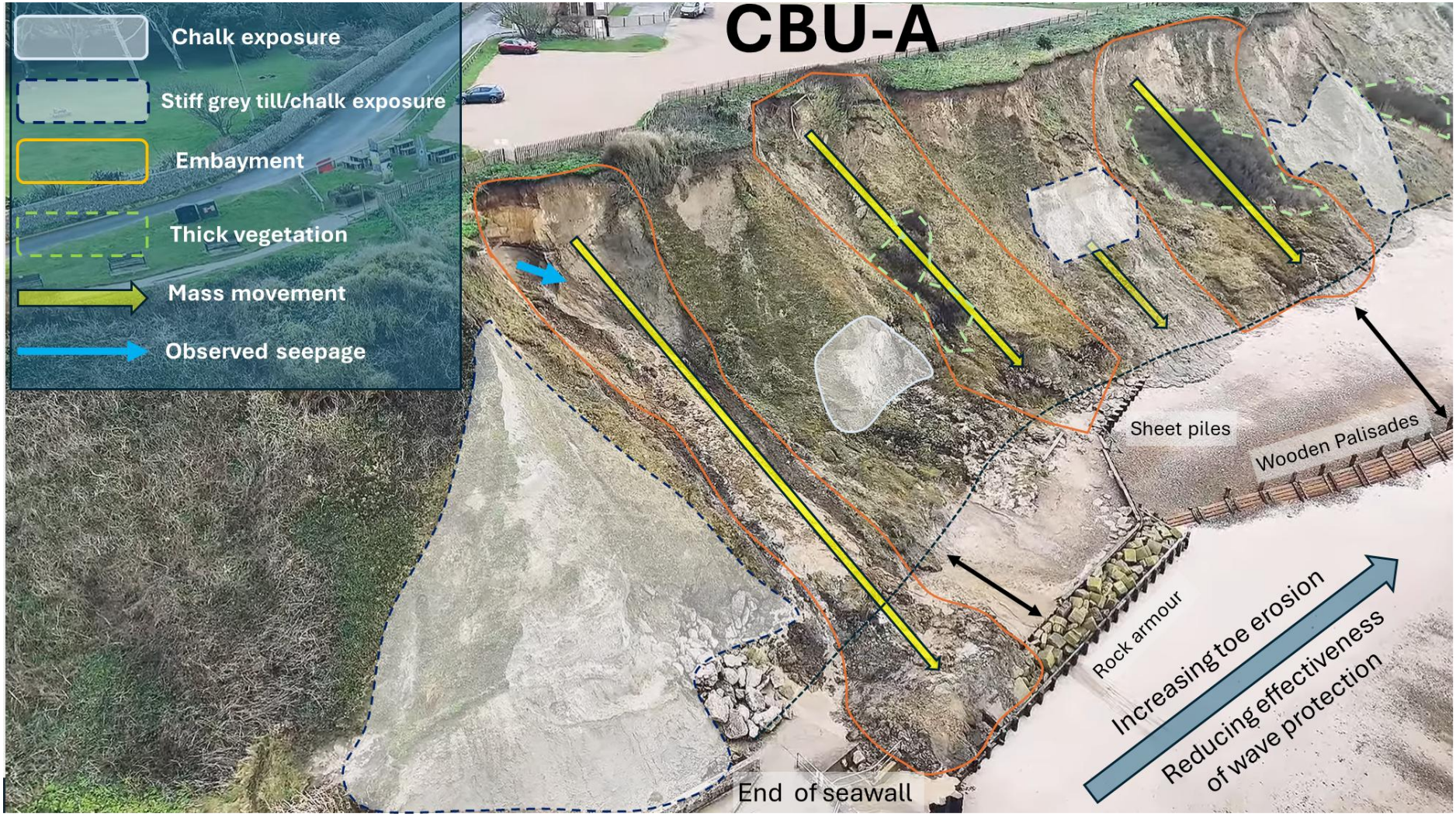


Figure 4-2: CBU-A: Chalk and stiff till headlands and embayments with mudslide-type failures at Pauls Lane Car Park. Background image: YouTube video “Overstrand Cliff Slip” dated 18 Jan 2025 by The Content Creator Shaun Button.

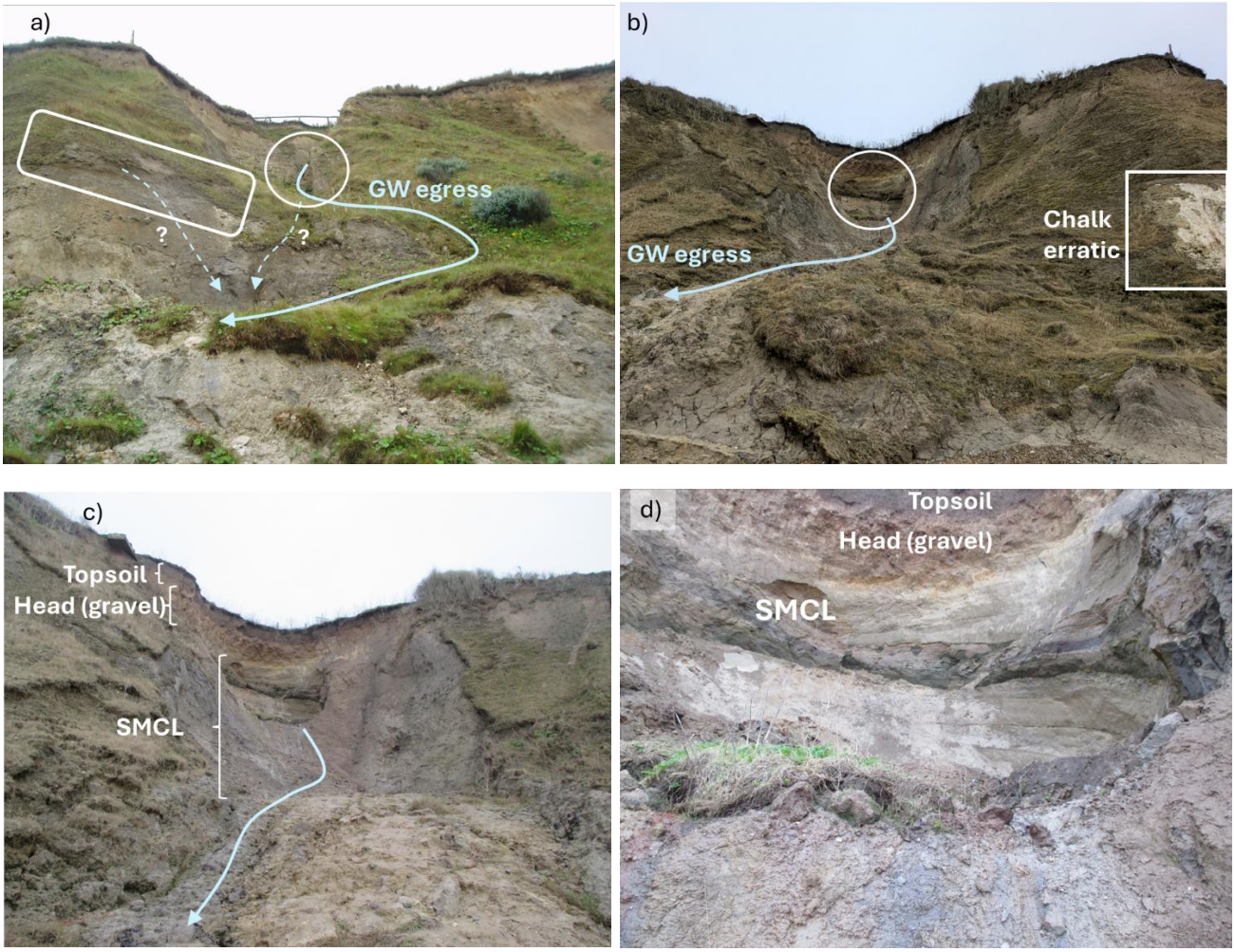


Figure 4-3: CBA-A: Seepage egress within an embayment in a) 2008 (Source: Brian Farrow NNDC), and b to d) January 2026 JBA site visit.

4.2 CBU B - Slipway/walkways (Mudslide/Rotational transition zone)

CBU-B (Figure 4-4) extends from end of the western promenade to eastern most walkway running down to from the top of the cliffs to the promenade. Several historical modifications have occurred at this location to improve slope stability.

- In c.1906 the infilling of a previously failed section cliff above Pauls Lane approaching Cliff Road, presumed to ensure the continued use of this road.
- In 1946 a large failure within CBU-C is noted to have damaged the eastern most extent of the eastern footpath leading to the promenade.
- The largest modification occurred in 1953 in conjunction with the refurbishment of the existing seawall and subsequent slope reprofiling of the entire unit, compares against the 1906 photograph (Figure 2-12).
- Notably, the 1953 photograph shows regions at the lower part of the slope that appear to have a different geology and have all subsequently failed requiring additional slope protection measures.

Toe protection is provided by the seawall, and a functional drainage system is present to manage water in a controlled manner from the Pauls Lane/Cliff Road above the cliffs, discharging out to sea. This also includes functional weep holes within the promenade to alleviate water pressure within the retained slope material. There is evidence of Pauls Lane/Cliff Road storm drainage being overwhelmed historically, flowing over the car park and causing a washout failure in 1972 (see Volume II).

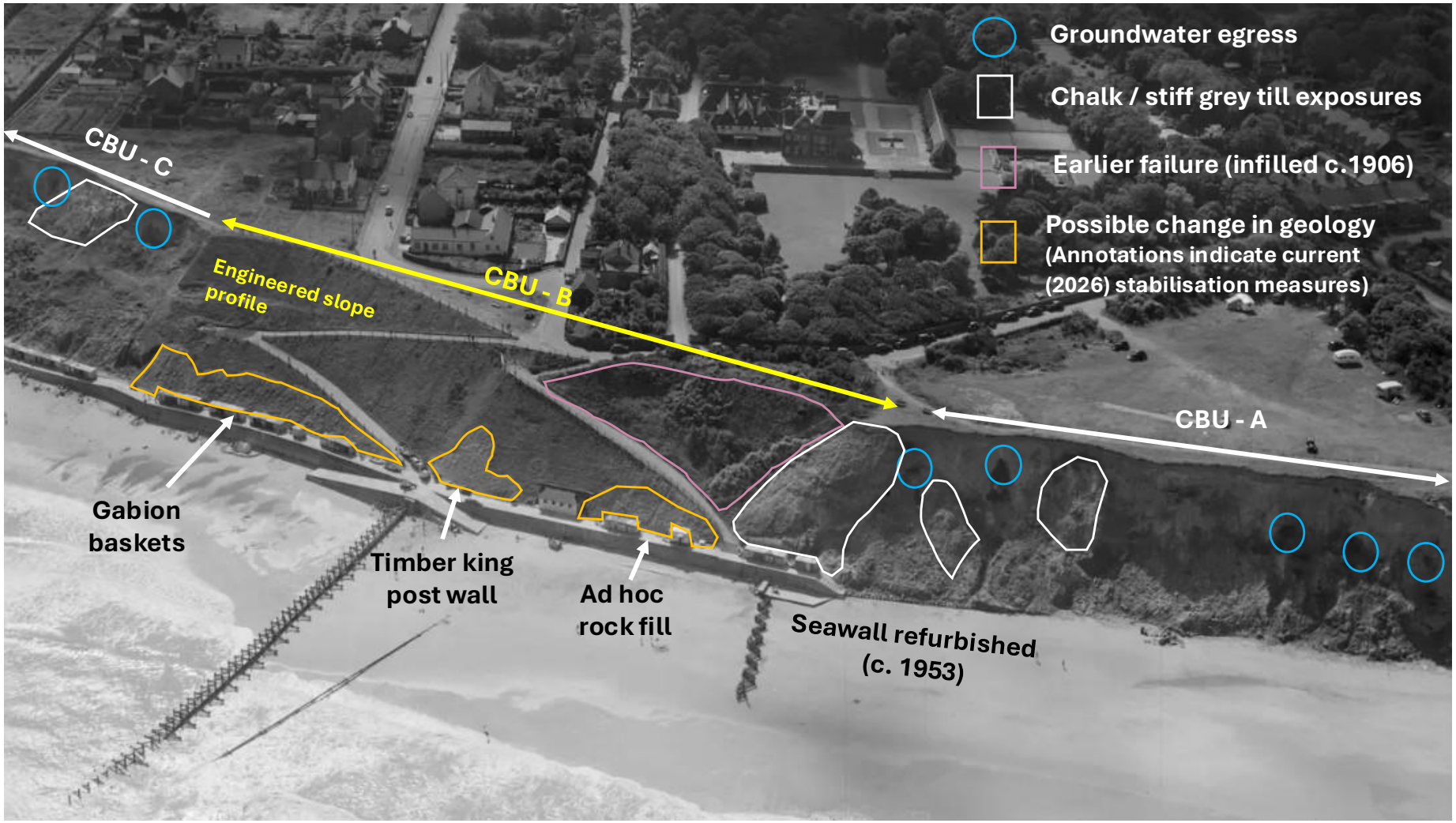


Figure 4-4: Overstrand 1953 showing CBU-B mudslide-type to rotational-type transition zone. At this time, the promenade had been recently rebuilt and slopes reprofiled . Source: Britain from Above archive (licenced) .

4.3 CBU C - Main promenade (Rotational type)

CBU-C (Figure 4-5) has the largest extent (~300m long) and is characterised by:

- Wide embayments / backscarps formed above deep rotation slips which undergo suffer periodic reactivations in response to groundwater pressure increase after heavy rain, most notably towards the lower part of the slope with seepage egressing from the toe.
- The size and shape of the failures (deep rotational slips) suggest clay tills constitute a significant proportion of the cliff material.
- A chalk or stiff light grey till exposure (possible raft) appears to be present (approximately 3-4m before the cliff top) adjacent CBU-B (Figure 4-4). This exposure appears to have seepage egress either side of it.
- Two historical cliff gully systems have been constructed (Figure 4-1) and subsequently destroyed following failures, both appeared to drain regions approximately 4-5m below the cliff top, based on historical photographs, but these are no longer present.
- Currently there is substantial vegetation growth over the slope that impeded any recent identification of these or any other areas of groundwater seepage across the unit. Japanese knotweed grows densely over a circa 90m section of slope face.

The current seawall alignment was largely established 1953-55, by building seaward of earlier 1920s seawall structures where present, and closer to the cliff toe where they were absent. Today this means that the elevation of the cliff toe relative to the top of the promenade varies along throughout the unit.

- To the west of the CBU unit, the cliff toe level is in effect above the promenade, prompting the installation of kingpost walls and legato blocks to contain the slope toe.
- These provide additional support, but also allow the slope to remain oversteep and increase vulnerability to toe undercutting in extreme storms and movement reactivation
- Slopes angles are notably steeper here, compared to those found in the central section of the promenade, as more space is available for the colluvium fan to migrate forward and approach its angle of repose (20^{o}) or until contact with the rear of the seawall made, as is the case approaching the beach huts from the west.

The failure mechanism, shown in Figure 4-6, is proposed for the current situation where the seawall and promenade remains present and functional.

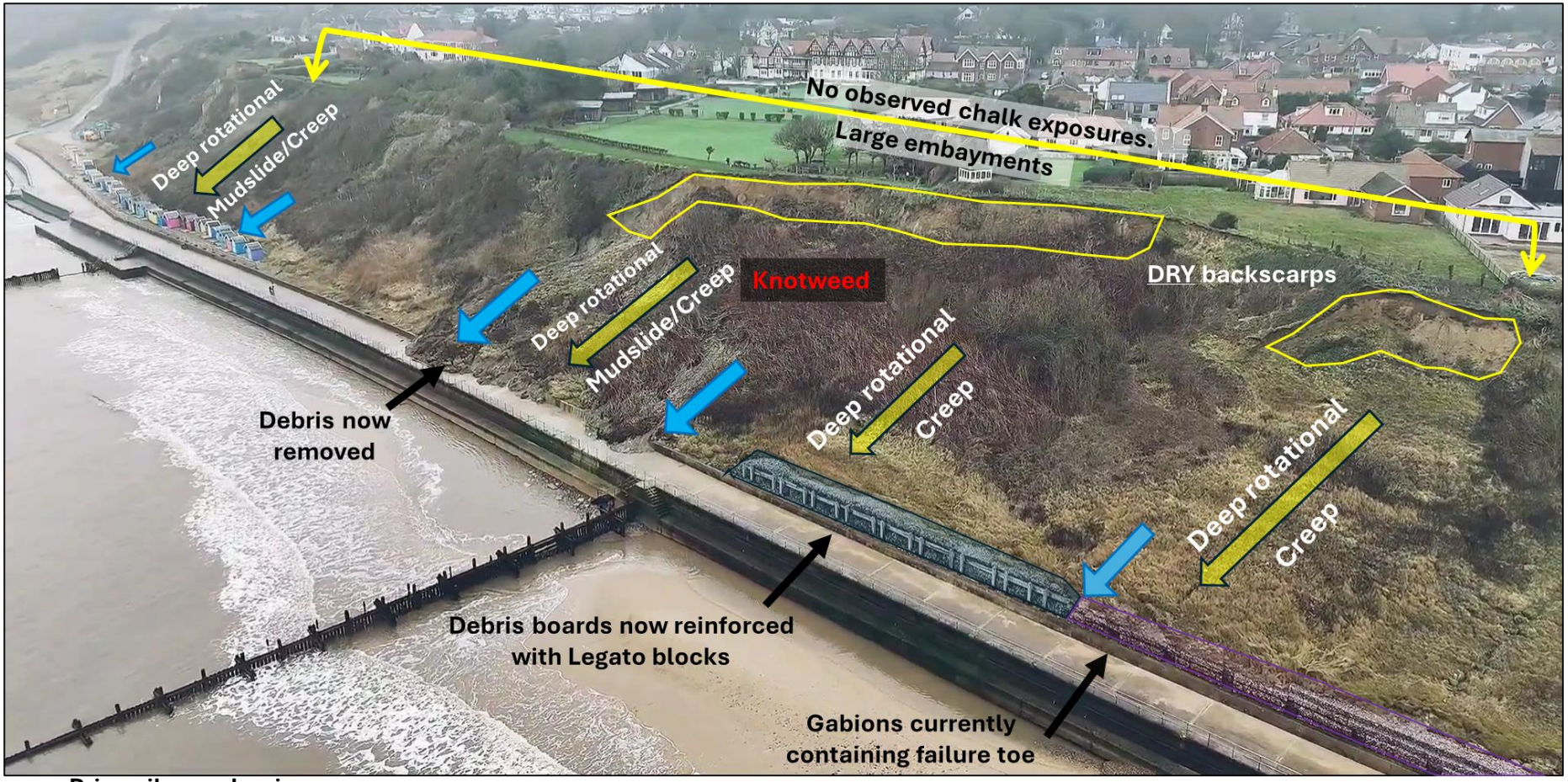


Figure 4-5: Central promenade cliff (CBU – C) observations and suspected failure mechanisms. Background image: YouTube – "Overstrand Cliff Slip" by The Content Creator Shaun Button.

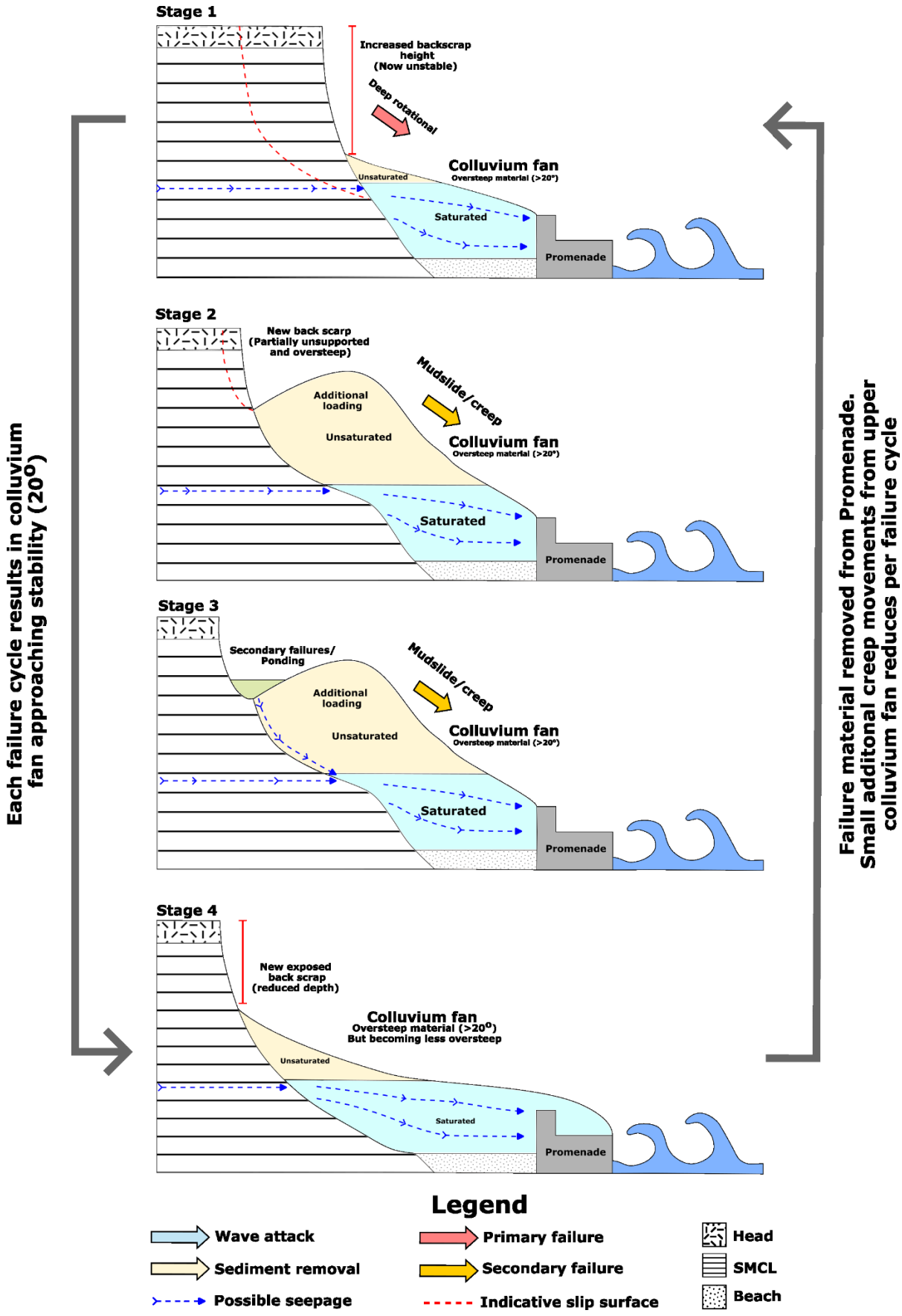


Figure 4-6: Progressive-retrogressive rotational failure mechanism for CBU-C

4.4 CBU D – Ivy Farm (composite rotational slide over rock - chalk)

Figure 4-7 shows CBU-D and E in its entirety in 1998 and Figure 4-8 provides closer view of the majority of units D & E from 2024.-

CBU – D is characterised by:

- Large, high exposures of chalk, present due to glacial uplift of massive basal chalk blocks
- Variable top level and plan position of chalk rafts relative to the overlying tills, causing a wide range of rotational slip embayment widths and depths across the CBU.
- The eastern extent of the CBU-D unit, a set of chalk rafts account for approximately 50% of the cliff height with superficial deposits over the top.
- Back scarps indicating rotational failures in the mixed tills above the chalk caused by strength reduction and groundwater seepage.
- Periodic movement reactivations on the existing composite failures, e.g. Old Overstrand Hotel

4.5 CBU E – Clifton Way (Deep-seated landslide with failure at more than one level)

CBU-E is a remediated unit, but its failure mechanism and method of remediation remain important:

- Increased porewater pressures within a susceptible and hydraulically conductive layer of sand destabilised the overlying clay material causing strength reduction to residual strength.
- Benching of the clay, substantial dewatering infrastructure has been installed to reduce groundwater levels and surface water drains.
- Rock armour has been installed along the toe of the remediated failure.

The interface between CBU-D and E, a transitional zone of the material response for this failure exists with only the chalk rafts interrupting this sequence. Therefore, it is possible this may in the future may suffer from instability, particularly with ongoing erosion of the engineered slope.

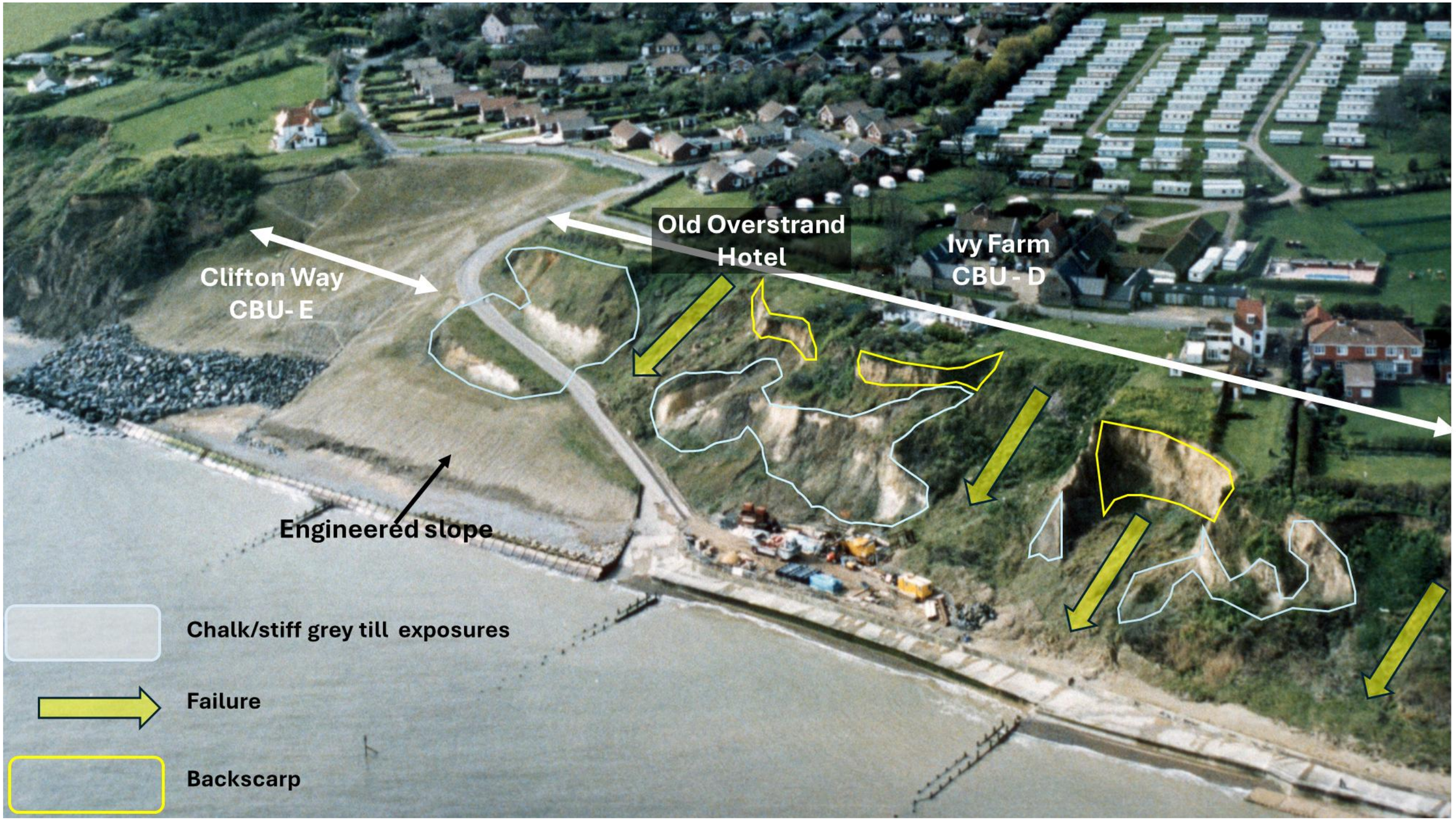


Figure 4-7: Composite rotational slides over chalk at Ivy Farm (CBU-D) and the remediated multi-level landslip complex at Clifton Way (CBU-E) shown in 1998 aerial photograph (NNDC, 1998)



Figure 4-8 East promenade standing area (CBU - D) and Clifton Way remediated failure (CBU – E) observations and proposed failure mechanisms. Background image NNDC.

5 Summary (Sections 2 to 4)

This section summarises key findings from Sections 2, 3 and 4, relating each back to its significance to the relationship between water and cliff stability at Overstrand.

- 2.1 Site location and description
    - The cliffs at Overstrand are around 30m high
    - Coastal erosion of the North Norfolk coast is a natural process has been occurring since the end of the last glaciation (c.10-20,000 years ago).
    - Human adaptation to coastal erosion in North Norfolk is also not new; records indicate many villages overtaken by erosion in the past, for example Shipley, which was about 150m north of Cromer Pier and was lost around 1400.
- 2.2 Site history
    - Overstrand was a fishing hamlet until as late as 1906 when the railway opened.
    - Rapid tourism-led development drove clifftop hotel construction and demand for beach access, and in turn, coastal defences to protect them.
- 2.3 Coastal defences
    - Coastal defences have been continuously present at Overstrand for around 140 years (since circa 1886).
    - Suppression of natural erosion over this period means the cliff top at Overstrand is now around 350m seaward of equivalent undefended cliff top lines towards Cromer and Sidestrand.
    - Had natural erosion been allowed at Overstrand, it is likely that much of Overstrand north of Cromer Road/Mundsley Road would have eroded by now.
- 2.4 Recent coastal defence works
    - 260m of Overstrand's existing promenade / seawall was refurbished via sheet piing and concrete infilling in 2025-2026 at a cost of £1.28M.
    - This work bridged the transition from "Hold The Line" based management to "Managed Realignment" based management.
    - Further hard defence works of this type and scale are unlikely to be repeated.
- 2.5 Geology and geological setting
    - The geological setting at Overstrand is highly complex, due to the North Norfolk Coast being in a geographical zone that has been subject to multiple glaciations between c.400,000 and c.20,000 years ago.
    - These glaciations deposited, re-deposited and re-worked the "till" materials that make up Overstrand's cliffs that vary rapidly in composition and physical characteristics.
    - This highly variable geology makes the precise response of the cliffs to water-driven actions like waves, groundwater seepage and rainfall difficult to predict

in the absence of detailed information. For example, a thin sand layer in a clay till can affect its response to groundwater seepage.
    - However, a likely range of behaviour can be identified; these have been used to inform the significance of marine water, groundwater and surface water for various cliff sections in Section 4 of this report.
- 2.6 Previous geotechnical investigations
    - Boreholes and other intrusive investigations have been undertaken at various times in Overstrand since the 1960s; unfortunately, much of this information has seemingly been lost.
    - The information that is available (concentrated at the site of a major landslide that occurred at Clifton Way in 1994) generally confirms findings from the general geological literature that the strata are highly variable and have a wide range of strengths and responses to water and sliding actions.
- 2.7 Previous cliff stability studies
    - DEFRA (2002) and HR Wallingford (2003) produced comprehensive research reports of direct relevance to the cliffs at Overstrand and are considered essential information sources.
    - The general methods in these reports for characterising and assessing cliff forms and factors affecting stability have been adapted for use in Section 4 of this report.
- 2.8 Hydrogeological designations
    - The basal sand, gravel and chalk strata around 30-40m depth below Overstrand form a Principal aquifer but not a designated Source Protection Zone (SPZ).
    - Despite absence of an SPZ, onerous regulatory processes would likely still apply to demonstrate any proposed new groundwater interception boreholes would not create new contamination pathways.
- 2.9 Water abstraction licences
    - No groundwater abstraction licences are currently active close to Overstrand
    - In principle, abstraction for other purposes (e.g. notional cliff stability enhancement) would hence not affect any existing licences.
- 2.10 Near-surface soil permeability
    - Mapping for topsoil and superficial deposits indicate a generally permeable near-surface zone, and that sand and gravel hills to the south of Overstrand are also likely to be highly permeable.
    - Below this, boreholes and geological literature indicates clay and clayey till layers are present in many locations, but their continuity and extent may vary.
    - Therefore, highly localised sensitivity of groundwater flows, pressures and development of perched water tables is expected

- 2.11 Groundwater interception boreholes
    - Boreholes intended to intercept water closer to the surface and then divert it down in the basal Principal Aquifer have been attempted in Overstrand since the 1960s.
    - Available evidence is very mixed on the effectiveness of these boreholes in relation to improving cliff stability.
    - Boreholes constructed around 1995 at Clifton Way are likely to have been (and remain) effective, but this success resulted from appropriate investigations and design as part of a high-cost stabilisation scheme for landslip remediation.
- 2.12 Groundwater monitoring
    - Groundwater interceptor boreholes considered still operable between 1998-2002 were monitored.
    - Review of this information suggests that of 21 holes:
        - ~30% appeared to transfer water to the lower aquifer
        - ~30% appeared blocked (and potentially causing adverse effects)
        - ~30% may have been operating to some degree, but lacked sufficient data to prove this
        - ~10% had insufficient data for determination
- 2.13 Observable water features and cliff failure locations
    - Historical site photographs and recent observations have been used to locate apparent seepage flows, springs, drainage construction and other water-related slope features relative to observations of geology and slope form.
    - In general, there is correlation between zones of apparent seepage and the development of failure embayments or backscarps.
    - Seepage points have been observed at elevations close to crest and close to toe, highlighting the variable nature and permeability of the ground.
- 2.14 Climate change effects on cliff stability
    - Between 2.7 and 3.5°C peak warming is now considered likely by 2100.
    - This level of warming is currently predicted to cause around 30-40cm mean sea level rise and around 2 to 4 times more frequent severe storms, rainfall and cliff retreat rates, intensifying from 2055 onwards.
    - Current National Coastal Erosion Risk Maps suggest up to 60m of retreat within 2025-2055 (assuming an 8°C peak warming scenario).
    - The design life of any set-back measures designed to slow erosions must take this into account, potentially using an adaptive approach that would also allow for relocation or safe decommissioning prior to overrun.
- 2.15 Episodic (wave dominated) versus progressive (soil strength dominated) cliff retreat

- When waves can attack the cliff toe directly, retreat is generally rapid and is dominated by toe undercutting. This tends to occur episodically during severe storms.
- Where a hard toe defence is present, retreat is slowed and hence slower retreat processes driven by groundwater and surface water flows become dominant.
- With a toe defence, cliffs can also reach a quasi-stable state once enough slipped material accumulates at the toe

- 2.16 Beach wedge area and coastal "catch up" effects on cliff recession rates
  - Recent research has shown that cliff retreat rate in North Norfolk can be related to “Beach Wedge Area”, which is a simple relationship between beach width and cliff toe elevation relative to high tide level.
  - Once beaches become narrow and lowered, cliff retreat rate tends to increase dramatically.
  - In addition, studies of cliff evolution at Happisburgh following abandonment of toe defences in 1992 showed a ~35 times increase in retreat rate.
  - Researchers concluded that this was the coastal system “catching up” historic sediment starvation. These findings again highlight the need for appropriate lifecycle planning for any future intervention works.
- 2.17 Effect of till properties and groundwater on strength and stability of cliffs
  - The cliffs at Overstrand are formed in tills.
  - These materials are highly variable and hence exhibit a wide range of responses to the action of water. A common feature is a tendency of these materials to become weaker once subject to sliding movements.
  - This enables these materials to remain stable at steep angles before failing back to a lesser angle.
- 2.18 Shoreline Management Plan statements for Overstrand
  - The current SMP designation disallows measures designed to maintain Overstrand as a coastal promontory, including replacement or betterment of existing hard defences or systems that restrict natural sediment transport.
  - Limited maintenance, minor repairs and set-back measures intended to slow but not stop erosion are permissible.
  - It is likely that drainage-based measures behind the current promenade alignment would comply with these statements.
- 2.19 Historical rainfall and cliff instability records
  - Historical photos and NNDC records for 1980 to present have been used to determine locations and dates of slope instability events in the cliff faces at Overstrand and relate these to historical rainfall
  - Failure events appear to be correlated with heavy antecedent rainfall.

- There is also an apparent increase in the intensity and frequency of rainfall, and with this the frequency of slope failures/movement, from around 2008 onwards (relative to the period 1980-2007).

- 2.20 Potable, surface and foul water drainage systems
  - Available information on drainage systems within Overstrand have been reviewed. Details of highway drainage were not available but were inferred from road gradients and surface observations.
  - All combined and foul water drainage in Overstrand is pumped away for treatment at Cromer (the historic sea outfall now disused).
  - Highway stormwater drains discharge via gullies down the ramps at
- 2.21 Surface water flooding
  - The surface water flood map provides an indication of where heavy rainfall may concentrate if it runs off and does not infiltrate.
  - The map indicates surface water concentrates at the junction of Cliff Road / Pauls Lane, where it must discharge via the gullies below the beach access ramps.
  - These gullies must be appropriately sized to handle future flows which are likely to increase with climate change.
- 2.22 Community engagement
  - Output from recent community engagement with local stakeholders was reviewed for relevance to this report.
  - This highlighted that there is awareness and interest amongst Overstrand's stakeholders about historic use of groundwater interceptor boreholes.
- 2.23 Ground motion from satellite InSAR monitoring
  - Satellite InSAR-based ground motion monitoring data from the EU Ground Motion Service was reviewed.
  - Overall this did not indicate any notable trends beyond expected, site-wide post-glacial isostatic rebound.
- 2.24 Unexploded Ordnance
  - A UXO Pre-Desk Study Assessment returned low risk for the general vicinity of Overstrand, in principle not requiring further assessment.
- 2.25 Ecological conditions and sensitive land designations
  - Overstrand's cliffs and beach are subject to zones of SSI and Marine SPA protections.
  - Invasive non-native species including hogweed and knotweed are also present on the cliff slopes.
  - Proposals for notional intrusive investigations or control measures would require appropriate management of these environmental constraints.
- 2.26 Rates of cliff retreat

- Historic (1886-1970) and recent (2015-2024) rates of cliff top retreat at Overstrand were shown (based on historical maps and LiDAR elevation data) to vary between about 0.2-0.3m/yr in most areas following construction of hard defences, compared with 1.2-1.9m/yr prior to construction.
- Caution is advised on interpretation of historical retreat rates given evidence dramatic rate increases following defence abandonment at Happisburgh in 1992

- 2.27 Ground elevation changes 2015-2024
  - The difference between site-wide LiDAR elevations 2015-2024 indicate general stability of the cliff toes (where defended) and slight clifftop retreat, mainly at backscarps of existing failure zones.
- 2.28 Cliff slope angles
  - Local cliff slope angles were plotted for a set of representative cliff cross sections.
  - These show how slope angles can be used as a useful measure of local slope stability and to highlight areas most likely to be affected by heavy rainfall, groundwater pressure increases or toe undercutting.
- 3 Site Visit
  - Observations from the site visit have been used throughout to assist with the interpretation of site conditions and interpretations of Cliff Behavioural Units.
- 4 Assessment of Cliff Behaviour Units (CBUs) including relationship to water
  - The approach of DEFRA (2002) has been used to characterise the cliffs at Overstrand into Cliff Behaviour Units (CBUs) based on their slope form, failure mechanisms, geology and likely future behaviour in response to foreseeable changes to defences and climate change.
  - A total of 5 location specific CBUs were identified (overview in Figure 4-1 and Table 4-21).
    - CBU A - Pauls Lane Car Park (Mudslide type) - Figure 4-2
    - CBU B - Slipway/walkways (Mudslide/Rotational zone) - Figure 4-3
    - CBU C - Main promenade (Rotational type) - Figure 4-4.
    - CBU D – Ivy Farm (composite rotational slide over rock - Figure 4-5
    - CBU E – Clifton Way (Deep-seated landslide with failure at more than one level) -Figure 4-6.
  - These were compared with the 4 units identified by HR Wallingford (2003), which showed generally good agreement but additional information available to this study allowed identification of the additional CBU following recognition of the important role of chalk rafts in this unit.
  - The 5 CBUs are summarised in Table 4-2 of this report, including the relationship between cliff stability and water in each unit. Specific conclusions and recommendations for each of these have been summarized in Section 6.4 of this report.

6 Conclusions on relationship between water and cliff failure at Overstrand

Overstrand is a geologically complex site, and this has a direct influence on how groundwater moves through the cliffs, as well as how stable and vulnerable they are to erosion. Climate change is expected to have a significant impact on future cliff behaviour. At Overstrand, projections indicate a 2–4-fold increase in extreme rainfall events, with rainfall intensity increasing by around 5–10%. These trends are already visible in data from the Cromer weather station and are expected to continue.

Sea levels are also projected to rise by approximately 0.3–0.4 m between 2055 and 2100, alongside increases in storm intensity. In addition, parts of the existing seawall are now over 130 years old, meaning that many sections are beyond their original design life.

These factors are important when considering both the impact of groundwater on cliff stability and the ability of the current coastal defences to continue protecting the base of the cliffs from erosion.

To support this assessment, we have followed DEFRA (2002) guidance to divide the site into Cliff Behaviour Units (CBUs). These units group together areas of cliff with similar characteristics, including their shape, geology, instability mechanisms, and likely future behaviour. Five CBUs have been identified across the site (Figure 6-1). These are summarised in Table 4-2, along with key information such as their location, observed instability issues, current level of protection, and associated risks.

This section sets out our conclusions on groundwater and cliff stability, linked to each of the identified CBUs. We have also provided concise summaries for each unit, which will form the basis for assessing potential management options for different parts of the site.

The options appraisal, including recommended mitigation measures, will be presented in Part 2 of this report.

6.1 Role of groundwater

Sources of groundwater: Based on site observations and the limited historic ground investigation data reviewed as part of the desk study, the following key points can be inferred:

- The principal source of groundwater at Overstrand is likely to be the Briton's Lane Sand and Gravel Member (BRLSG). This unit forms the higher ground surrounding the village and allows water to infiltrate down into the underlying Sheringham Cliffs Formation (SMCL) (see Figure 2-20).
- The superficial head deposits present across much of Overstrand are generally expected to be relatively impermeable.
- A significant proportion of residential properties dispose of rainfall via soakaways and garden drainage. However, the interaction between these soakaways and the

head deposits is not fully understood, particularly whether material has been locally removed to install them, which could influence drainage behaviour.

- Although detailed highway drainage plans were not available for review, there is sufficient evidence to suggest that the highway drainage system makes only a limited contribution to groundwater within the town or at the cliff face.
- Historical evidence from 1972 indicates that surface water runoff along Pauls Lane may have flowed over the cliff at CBU-A/B, contributing to a localised washout failure of the upper clay layers.
- Correspondence with North Norfolk District Council (NNDC) confirms that, at CBU-B, the drainage system directs most of the surface water in a controlled manner via a gully system to the cliff toe, behind the seawall, and ultimately to the sea.

Groundwater and Seepage: With respect to groundwater seepage and discharge at the cliff face, only CBU-A and CBU-C have locations that can be clearly identified, based on both historical records and current observations.

- Groundwater is not evenly distributed along the cliffs and instead emerges at specific, concentrated locations. Seepage at these locations typically occurs at discrete “focal” points within the upper exposed sections of the Sheringham Cliffs Formation (SMCL). These areas show a strong correlation with the presence of chalk and stiff grey till layers. These relatively impermeable units act as barriers to flow, causing groundwater to be redirected around them, which in turn leads to localised increases in flow and pore water pressure. These areas are therefore more susceptible to instability.
- Seepage is focused where less permeable layers (such as chalk and stiff clay/till) redirect groundwater flow, leading to localised increases in pressure and a higher risk of erosion or slope failure.
- In other areas of the site, the exact locations of groundwater discharge are uncertain. This introduces an element of risk, as instability could develop in less predictable locations. Indicative areas have been inferred from features such as backscarp exposures, zones of saturation within colluvial fans, and, in the case of Clifton Way, limited historic ground investigation data. However, precise discharge points cannot be confirmed.
- Groundwater levels vary significantly across the site, from beach level to near the top of the cliffs, which influences how and where instability may occur. Levels are variable across the site, ranging from approximately beach level at the CBU-D/E interface to near the upper sections of the cliffs at CBU-A.

Groundwater impact on Cliff Stability:

- Groundwater is a primary factor influencing instability across all CBUs. This is largely due to the characteristics of the Sheringham Cliffs Formation (SMCL),

which is prone to developing high porewater pressures and allows drainage into colluvial deposits formed by previous failures.

- At Clifton Way, this effect has already been observed. Elevated pore water pressures built up within slightly more permeable sandy clay layers in the upper slope, contributing to a series of slope failures.
- In CBU-A, groundwater is seen to emerge at boundaries between less permeable clay layers and more permeable sandy clay/silt materials. This can lead to the gradual removal of finer particles, reducing the strength of the material and triggering localised instability.
- A similar mechanism is likely to have contributed to failures at the base of CBU-B, where sandier materials are more vulnerable to erosion and loss of support. However, in these locations, the influence of wave action cannot be ruled out as a contributing factor in initiating failure.
- Note: It cannot be ruled out in these locations that the failure was initiated from wave spray impacting the promenade and eroding these exposed areas, triggering the collapse of material above.

Groundwater impact at Promenade and Cliff Toe–

- Groundwater seepage emerging at the cliff face is the primary driver of instability behind the promenade. This process weakens the clay layers within the Sheringham Cliffs Formation (SMCL), increasing the likelihood of failure.
- The colluvium fan (accumulated debris at the base of the cliff), where contained between the cliff and the promenade retaining wall, plays an important stabilising role by supporting the material above. Retaining this material in place is therefore beneficial for maintaining cliff stability.
- However, when the colluvium fan becomes saturated, it becomes significantly more prone to movement, including creep and localised mudslides. These movements can occasionally extend onto the promenade.
- Loss or displacement of this supporting material reduces stability at the back of the cliff (backscarp), which can lead to further failures and additional loading onto the colluvium fan below.
- This risk is greater in areas where there is sufficient space for the colluvium fan to spread naturally (typically at slopes of 20–25°), such as behind the beach huts and near the former Overstrand Hotel (close to Ivy Farm).

6.2 Role of groundwater interception scheme

- The original concept of intercepting groundwater to reduce destabilising seepage at the cliff face remains sound and appropriate for the site.

- At the time the scheme was developed, the ability to accurately identify groundwater pathways beneath Overstrand was limited by the available investigation techniques.
- Modern geophysical methods now provide a more reliable and non-intrusive way to understand ground conditions and identify groundwater levels and flow paths. This presents an opportunity to improve targeting and effectiveness of any future measures.
- Historical borehole monitoring data (1998–2002) indicates that some boreholes were effective in draining groundwater into the underlying chalk aquifer. Variations in recorded water levels suggest that certain boreholes were more hydraulically active and therefore more effective than others.
- Records from North Norfolk District Council (NNDC) indicate that, during the operational period of the interception system (1966–2014), the frequency of recorded cliff failures was notably lower than in the period after 2014, when maintenance ceased.
- It should also be noted that, since 2014, rainfall totals and intensities recorded at Cromer weather station have increased, which is likely to have further contributed to the observed increase in instability.

6.3 Sea cliff toe protection and its impact on stability

Natural cliff toe protection:

Some areas of the cliffs benefit from natural protection, where chalk or stiff grey till exposures occur (e.g., CBU-A and CBU-D prior to the promenade extension). These exposures:

- Are more resistant to erosion than the surrounding Sheringham Cliffs Formation (SMCL) material.
- Provide additional toe weight, supporting the cliff material above.
- The spacing of these exposures directly influences erosion rates—the closer they are together, the more effective they are at reducing wave impact and limiting cliff retreat. As the distance between chalk exposures increase, so does the rate of erosion and cliff regression.

Examples across the site:

- In CBU-A, narrow embayments have formed because chalk/stiff grey till exposures are frequent, offering strong natural protection.
- In CBU-C, these exposures are less frequent, so erosion and cliff regression are more pronounced. CBU-B has engineered slope post historic failures, still subject to creep.
- In CBU-D, chalk/stiff grey till exposures play a critical stabilising role, supporting the superficial deposits above.
- CBU-E lacks natural chalk “rafts,” resulting in minimal toe protection and a history of significant failures that have been remediated.

Man-made defences:

Engineered structures are the most important factor in reducing cliff regression and maintaining long-term stability:

- The promenade provides the highest level of protection, preventing toe erosion and loss of supporting colluvium.
- Rock armour and palisades also reduce wave energy and erosion, though to a lesser extent.
- Rising sea levels will reduce the effectiveness of all defences, allowing more wave energy to reach the cliffs.
- This will be compounded over time as maintenance ceases and existing structures deteriorate, with palisade-protected areas likely to be the first affected.

6.4 Specific conclusions on Cliff Behavioural Units (CBUs) extents on Figure 4-1

6.4.1 CBU A - Pauls Lane Car Park (Mudslide type) -Figure 4-2

- Groundwater is actively emerging from the cliff face between embayment formations, approximately 3–4 m below the crest.
- Well No. 3 indicates a possible perched water table at 18.9–23.8 mAOD, roughly corresponding to levels in the cliff, though this is based on a single borehole 175 m away.
- Existing ad-hoc rock armour and palisades play a key role in reducing erosion and should be maintained as long as cost-effective.
- Primary failure mechanisms here are toe erosion and weakening of the SMCL from porewater pressure spikes, leading to shallow translational or mudslide-type failures.
- Climate change, sea level rise, and general land subsidence are likely to reduce the effectiveness of existing structures over time, increasing cliff regression rates.

6.4.2 CBU B - Slipway/walkways (Mudslide/Rotational transition zone)) - Figure 4-3

- No groundwater has been identified in this historically reworked unit.
- Geological changes at the base correspond to three slope stability interventions since 1953.
- Post-1982 failures have been dominated by creep, with historical mudslide and rotational movements.
- The seawall provides reliable toe protection, with footpath drainage managing surface water.
- Planned additional toe protection in 2026 will extend the seawall's serviceable life by 20 years.

- This is also the oldest area of the seawall having been refurbished and not replaced in 1953.
- If the existing timber king post wall along the promenade continues to deteriorate and fails to provide toe protection, then substantial rotational/shallow translational failures of the backfill cliff slope are likely to occur.

6.4.3 CBU C - Main promenade (Rotational type) - Figure 4-4

- Grey till exposures exist, including sites affected by a 1946 failure.
- Probable seepage was also observed in a 2025 drone survey near the Sea Marge Hotel. (NNDC25) This was approximately 6-8m downslope from the Sea Marge Hotel.
- Large embayment exist in this unit; the presence or absence of chalk rafts further east is unknown.
- Failures tend to be deep rotational, forming large colluvium fans that are contained by the seawall, which provides backscarp support.
- These areas are highly sensitive to increased saturation, leading to creep or washout failures and further backscarp loss.
- Climate change will exacerbate these effects through increased rainfall or groundwater flow through the cliff or from direct infiltration via rainfall.
- Where space allows, colluvium fans will regress and settle to ~20° slopes; where space is restricted, these will extend to the seawall. Functioning toe drainage is critical to reduce saturation and risk of rotational failure.
- Deterioration of the sheet piles at the promenade base will further increase the likelihood of failure. This area was constructed in 1955, the state of the sheet piles protecting the promenade itself were not subject to investigation in the report. Therefore, their condition is unknown.

6.4.4 CBU D – Ivy Farm (composite rotational slide over rock (chalk) - Figure 4-5

- Previously exposed to the sea until 1980, this unit was protected by palisades, limiting toe erosion.
- Chalk/stiff grey till exposures play a critical role in stabilising the unit by supporting superficial deposits.
- Groundwater seepage can trigger embayment formation where platform levels drop or regress.
- The most prolific section of CBU-D is that of the Old Overstrand Hotel failure. This section is the most active, reactivating during rainfall events and regressing landwards; climate change will likely worsen this.
- Regression in this area can destabilise adjacent sections, leading to further failures.

- Large hardstanding areas allow colluvium fans to form naturally within constraining the chalk/stiff grey till exposures.
- A sheet pile renewal is planned in 2026 to address current deterioration of the old walls constructed in the 1980s.

6.4.5 CBU E – Clifton Way (Deep-seated landslide with failure at more than one level) - Figure 4-6

- Historical series of mass failures have been remediated.
- No current concerns identified.

7 Next Steps

This report consolidates technical and local knowledge to improve understanding of how groundwater interacts with cliff stability at Overstrand.

Part 2 report will outline practical approaches to manage groundwater locally, aiming to reduce cliff failures. This will include potential engineering interventions to control, manage, or redirect groundwater flows.