Gunton and Corton Options Appraisal

Appendix B - Cliff Instability Assessment

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Coastal Partnership East

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Contents

Executive Summary

The coastal cliffs at Corton were formed by coastal erosion and have been protected by a seawall since the 1960s. Toe protection measures have been partially effective with periodic retreat of the cliff top continuing at a low rate; historical geo-spatial data show evidence of widespread and repeated cliff instability since 2003. The data reveal failures of the upper to middle part of the cliff with debris coming to rest on the lower cliff and in some cases with debris run-out over the promenade and rock armour. However, historical aerial imagery reveals that clifftop recession is a rare occurrence and of local significance.

The observations from site and historical records of cliff activity confirm that cliff activity along the defended frontage of Corton is driven by two processes:

1. Semi-natural shallow groundwater flows that are locally enhanced by runoff from hard standings and soakaway drains, which lead to failure of the upper cliff and debris apron mantling the slope and occasionally lead to retreat of the clifftop.
2. Erosion of the debris apron that mantles the cliff during periodic storms that overtop the defences. This also sometimes leads to retreat of the clifftop.

As stated above, historically these processes have resulted in limited clifftop recession, but as the debris apron becomes progressively undercut and over-steepened, cliff instability and recession will be triggered and clifftop assets will be at increasing risk of damage and loss. But these processes can be managed.

A Defra-funded Community Resilience Pathfinder project was commissioned in 2010 to investigate the reasons for ongoing cliff retreat and to recommend stabilisation options. The Pathfinder project recommended a deep drainage scheme to extend the life of cliffs. The scheme, constructed in 2011/12, comprised a series of vertical drains designed to intercept shallow groundwater and convey discharge to gravity drains at a depth of 2 to 3 m below ground. The gravity drains discharge to soakaway drains 12.5 m below ground.

Control of land drainage and early detection and repair of water leakages on the clifftop and hinterland area are important measures to prevent adverse effects on cliff stability and erosion. Management of groundwater at the clifftop can be controlled by ensuring all land drainage is connected to the mains network. Soakaways should be prohibited for assets at the clifftop and avoided at other locations. Runoff from hard standings should be managed to ensure connections with the mains drainage system and does not enter the ground or discharged over the edge of the cliff. All mains water supplies and drainage connections should be checked to ensure that there are no leaks. Particular attention should be paid to swimming pools and ornamental ponds to ensure no water leaks into the ground. This will likely be the responsibility of the cliff top property owners to address, who are also the parties most immediately affected by not doing so. Based on the findings of this report and experience elsewhere (i.e., Undercliff, Isle of Wight), guidance on the control of surface and ground water for property owners, developers and utilities could be prepared and distributed to stakeholders to ensure this aspect is understood and appropriately addressed in future.

Engineered interventions to stabilise the cliff could also be considered. These would be considerably more expensive to implement but have the advantage of stabilising and fixing the clifftop position. Options include:

1. Regrading the cliff face to a more stable angle. This would be achieved by cutting back the clifftop to a shallower slope, but that requires a swathe of clifftop area to be sacrificed which may not be feasible where private property and assets are located immediate along the clifftop.
2. Minor improvements to the Pathfinder cliff drainage scheme to resolve local groundwater problems where deep drainage is absent, or existing drains are located inland of assets of risk (such as Cliff house). This would require additional inclined gravity-fed drains to intercept groundwater and direct it to the existing deep soakaways.
3. Cliff stabilisation measures, such as soil nails and meshing, which would prevent slumping of the cliff face and failure of the debris apron. This option also encourages vegetation to establish and will form a stable green cliff.

Any engineered interventions should also be considered in conjunction with options being considered for the coastal defence works, to protect the toe of the cliff; erosion of the lower cliff face by waves will continue as long as the beach is narrow and storm waves are able to overtop the defences. Sea-level rise will mean that overtopping events will occur more frequently in the future. Construction of a new larger sea wall for example could significantly reduce wave overtopping and erosion of the lower cliff face. Conversely, if works are not being undertaken at the base of the cliffs, any interventions dealing with upper cliff instability (either in terms of additional drainage and/or cliff stabilisation) should be designed with recognition of their likely short-lived benefit. Given the increased frequency and severity of defence overtopping and erosion of the lower cliff face due to sea-level rise, upper cliff interventions on their own will have limited cliff stabilising effect in the long-term.

1. Introduction

1.1 Scope of this Assessment

On behalf of East Suffolk Council, Coastal Partnership East (CPE) are concerned that cliff activity along the defended frontage of Corton has increased in recent years, with cliff failures causing localised clifftop recession that threatens holiday park assets on the clifftop and runout of debris (sediment) onto the promenade and beach. The objective of this study is to assess the nature of recent cliff activity that threatens these assets, consider its causes and make recommendations for cliff management to limit future losses. This scope of work includes reviewing historical maps and coastal monitoring data, mapping of drainage pathways, instability features and geology from remote sensing data, site inspection of the cliffs at Corton and adjacent sections, and validation of records and observations including definition of cliff behaviour units, mechanisms and causes of cliff failure, and review of options for cliff instability management.

Following a review of remote sensing data collected as part of the regional coastal monitoring programme, a site visit was undertaken by Prof. Roger Moore and Dr Paul Fish on Wednesday 7 July 2021 accompanied by CPE. The assessment has been supported by information and knowledge shared by CPE during and after a workshop held on 5th July 2021 to establish the coastal defence and event history of the site. Details of the geology, geomorphology and drainage were added to a GIS database.

1.2 Site Description

The Corton coastline is characterised by soft sediment cliffs that have been subject to rapid cliff recession, when undefended, since the 19th Century (Blake 1884; Grove, 1953). The Corton site forms a transition zone between relict cliffs fronted by a broad accumulation of beach sediment at Lowestoft Ness and Gunton Warren to the south, and the eroding open coast cliffs towards Hopton-on-Sea in the north.

This frontage has a long history of coastal defences at the base of the cliffs. Records indicate that defences were originally built in the late 19th century and have been replaced, upgraded and extended since. The present defences comprise steel sheet piles and a concrete walkway at the base of the cliff, backed by a sloping concrete slab revetment on the lower cliff face, constructed in the 1960's. The sheet piles are fronted by the later addition of large rock armour at its toe, placed in 2003/4. Where sections of the sloping concrete revetment have been displaced, this been replaced with further large rock to provided protection to the lower cliff face. Following earlier failure of the seawall north of Bakers Score, the 2003/4 works included a larger rock armour revetment that extends northwards of the remaining concrete and sheet piling, providing further protection to the cliffs up to the point where an old and derelict timber revetment extends along the beach towards Hopton. This timber structure is in a derelict condition and now no longer maintained.

The defended sections of coastline typically form lower-angle degraded cliffs that are mantled with a debris apron. The debris apron is periodically remobilised by sustained wet weather, seepage erosion and excess groundwater when shallow slumps occur. The debris apron is also remobilised by periodic storms that overtop the defences and erode the base of the cliff. These processes occasionally lead to clifftop recession and consequently holiday park caravans and chalets have gradually encroached very close to the clifftop. Freely degrading sections of coast have a high rate of cliff recession, with cliff failures occurring in response to toe erosion and collapses related to wet weather.

The cliffs along this section of the Suffolk coast are formed of soft sediments, deposited in geologically-recent times. The geology records the advance and retreat of two different ice sheets during the Anglian cold stage, around 450 ka ago and the section fronting Corton Woods and the Azure Seas holiday park is notified as a Site of Special Scientific Interest (SSSI) by Natural England. Most of the coastline is fronted by a modest sand and gravel beach, but the beach fronting the defended section at Corton has been narrow or absent for much of the past three decades.

1.3 Information Sources

The main sources of technical information supporting the Corton Cliffs site inspection and review are listed in Table 1-1.

Table 1-1. Information Sources (references cited in the report)

Date/Source/Reference	Description
Blake (1884) Sections of the Suffolk Cliffs at Kessingland, Pakefield and Corton. Geol. Surv. of England & Wales, Horizontal Section no. 128	Long section and description of the sediments exposed in the Corton cliffs before construction of the cliff protection measures.
Blake (1890) The Geology of the country around Yarmouth and Lowestoft. Mem. Geol. Surv. England & Wales	Description of the sediments exposed in the Corton cliffs and comment on high erosion rates in the late 19^{th} Century.
Grove (1953) The Sea flood on the coasts of Norfolk and Suffolk, Geography. 38, 164-170	Description of the impact of the 1953 surge event on the undefended cliffs at Corton.
Banham (1971) Pleistocene beds at Corton, Suffolk. Geological Magazine. 108, 281-285	Long section and description of the sediments exposed in the Corton cliffs soon after construction of the cliff protection measures.
Halcrow Group Ltd (2001) Futurecoast Cliffs Database v5.	Projections of future cliff erosion and cliff failure mechanisms with and without coastal defences.
Lee (2001) Genesis and palaeogeographical significance of the Corton Diamicton (basal member of the North Sea Drift Formation), East Anglia, UK. Proceedings of the Geologist's Association. 112, 29-43	Interpretation of the depositional history of the glacial sediments.
EA National Coastal Team (2010) Assessment of Coastal Erosion and Landsliding for the Funding of Coastal Risk Management Projects. Guidance Notes. Report by Halcrow Group Ltd.	This document provides guidance on the assessment of coastal erosion and landsliding for the funding of coastal risk management projects under the Coast Protection Act 1949.
Moore R & Davis G (2015) Cliff instability and erosion management in England and Wales. Journal of Coastal Conservation. DOI 10.1007/s11852-014-0359-3	Review of coastal management practices and impacts of coast protection measures on cliff geomorphology.
Jacobs for East Suffolk Council (2021)	Review and analysis of coastal monitoring records.

2. Site Conditions

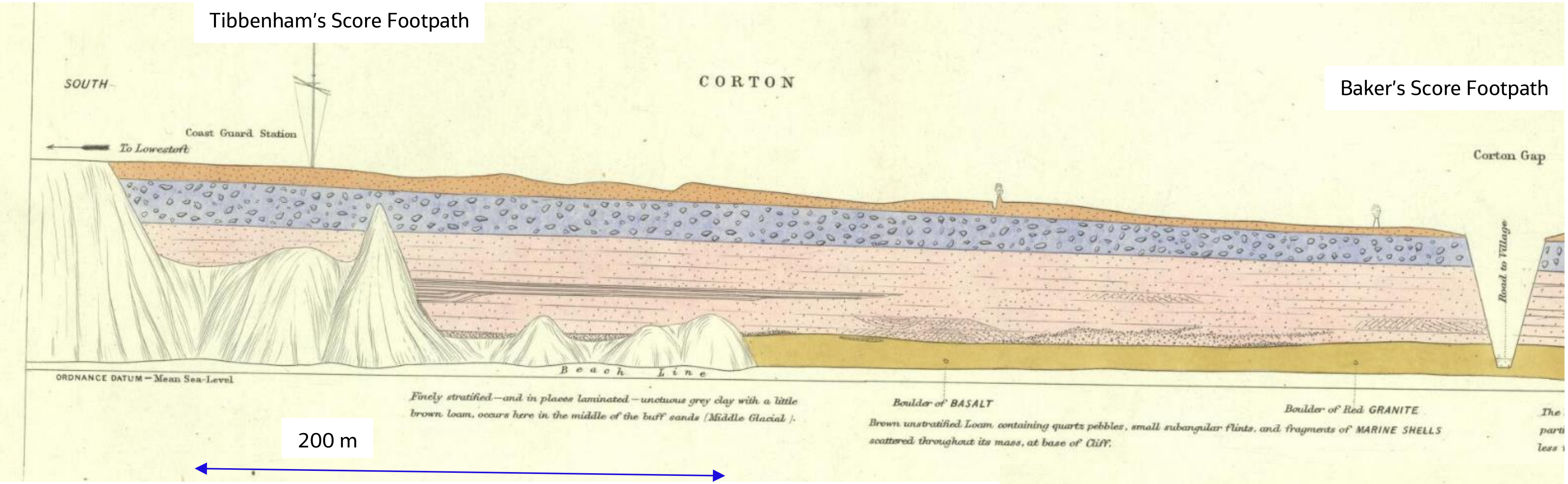
2.1 Geology

The geology of the site comprises a sequence of generally weak, unlithified sediments deposited in the Middle and Early Pleistocene between around 1 million and 0.5 million years ago. The sediments are summarised in Table 2-1. A 19th Century sketch of the cliffs (Blake, 1884) is provided in Figure 2-1, and a more recent sketch of the cliffs (Banham, 1971) is shown in Figure 2-2. Both show essentially the same stratigraphy. Images of the sediments exposed are provided in Figure 2-3. The cliffs were first described by the British Geological Survey in the late 19th century (Blake, 1890), when rapid cliff recession was reported for the coastline, which was freely eroding at the time.

Table 2-1. Summary stratigraphy of the Corton frontage.

Unit	Max. thickness	Sediments	Description
Plateau Gravels (Lowestoft Formation)	4 m	Sand and gravel, and silty sand	Middle Pleistocene Glacial outwash. Highly permeable. Generally obscured by slumping of the cliff.
Pleasure Gardens Till (Lowestoft Formation)	3 m	Diamicton[1], similar to Lowestoft Till	Middle Pleistocene flow till derived from ice sheet that deposited the Lowestoft Till. Low permeability. Generally obscured by slumping of the cliff.
Oulton Beds (Lowestoft Formation)	4 m	Laminated clay overlain by sand	Middle Pleistocene glaciolacustrine deposit originating from ice sheet that deposited the Lowestoft Till. Low permeability. Generally obscured by slumping of the cliff
Lowestoft Formation	7 m	Stiff diamicton comprising clasts of chalk and flint in a matrix of Jurassic clay	Middle Pleistocene subglacial traction till. Low permeability. Sometimes exposed in slump scars on the upper cliff face.
Corton Sands (Happisburgh Glacigenic Formation)	7 m	Fine to medium grained chalky sands with bedding deposited by flow from the north-west	Middle Pleistocene Glacial outwash from a 'Scandinavian' ice sheet. Unit forms the bulk of the cliff along the Corton frontage.
Cromer Till (Happisburgh Glacigenic Formation)	3 m	Stiff silty sand diamicton, sometimes band gravel. Well jointed with iron staining and cemented layers	Middle Pleistocene subglacial grounding-line fan with reworked 'rafts' of till. Undulating surface that occasionally rises above the level of the cliff protection measures.
Cromer Forest-bed Formation	1 m	Freshwater and marine sediments comprising peats, clays and sand and gravel.	Early-Middle Pleistocene temperate and cold-climate sediments. Obscured by cliff protection measures.

[1] A diamicton is a descriptive term for an unsorted sediment that comprises a range of particle sizes, from clay to gravel. No depositional process is implied. Examples of diamictons include subglacial tills and debris flow deposits.



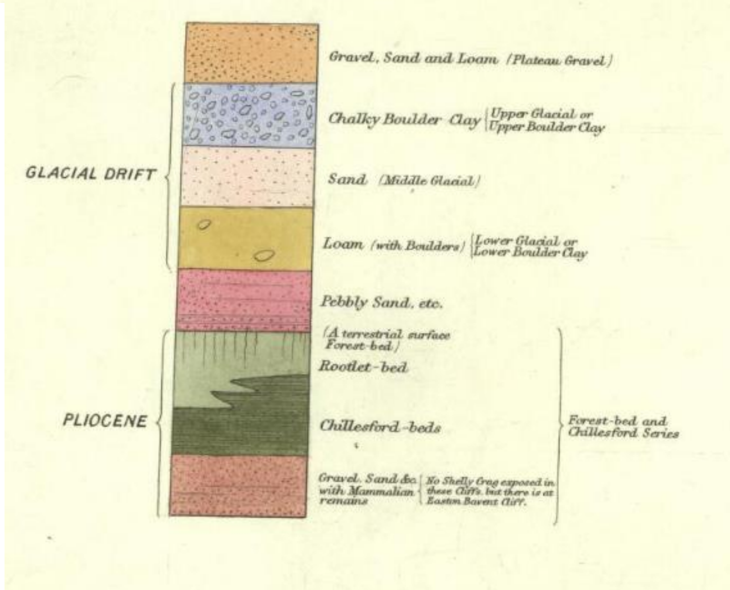


Figure 2-1. 1884 section of the Corton frontage prior to construction of the original late 19th century defences (modified after Blake 1884)

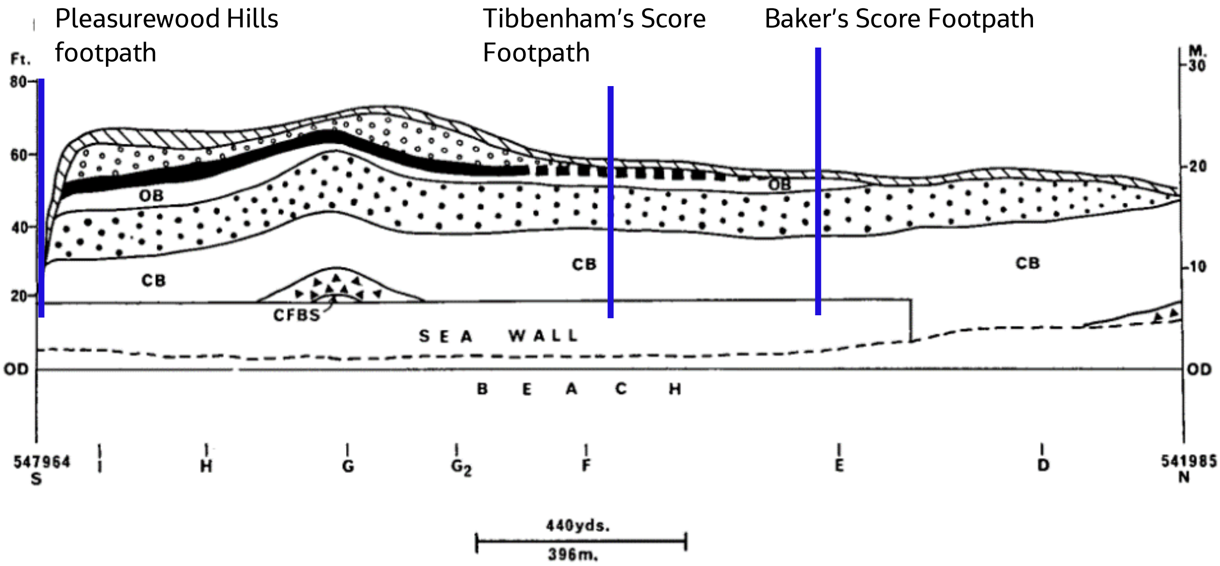


Figure 1. Horizontal section of the cliffs to the south of Corton, Suffolk. Explanation of symbols: CFBS—Cromer Forest Bed Series; black triangles—Cromer Till/Norwich Brickearth; CB—Corton Sands (Beds); black dots—Lowestoft Till; OB—Oulton Beds; black—Pleasure Gardens Till; open circles—Plateau Gravels; oblique lines—soil and blown sand; F.P.—footpath; D-1—sites of measured vertical sections.

Figure 2-2. Schematic section of the Corton frontage after improvement of defences in the late 1960s/early 1970s (modified after Banham, 1971)

The basal unit, which is now obscured by the toe defences, comprises a series of Early to Middle Pleistocene freshwater and marine sediments, known as the Cromer Forest-bed Formation. This regionally extensive unit is seen in the base of cliffs in Norfolk and north Suffolk and is associated with palaeolithic archaeology at Happisburgh and elephant remains at West Runton.

The Cromer Forest-bed is overlain by the Cromer Till, which is a stiff and over-consolidated brown sandy diamicton (i.e., an unsorted sediment comprising a wide range of grain sizes) that contains gravel erratics of Scandinavian origin and marine shells (Figure 2-3A). It is well jointed, with joints often marked by iron-staining, sometimes banded, and sometimes with beds of gravel at its upper contact with the Corton Sand (Figure 2-3B and D). The Cromer Till was deposited by a Scandinavian ice sheet that advanced into the region from a north-easterly direction. A regional study by Lee (2001) shows that most outcrops of this deposit are subglacial tills, but that the sediments exposed at Corton were deposited at a debris fan by a floating ice sheet. As this ice sheet retreated the pro-glacial lake grew in size and was progressively infilled with outwash sediments, represented on site by the Corton Sands. This unit comprises a thick sequence of fine to medium-grained well-bedded sands that sometimes contain silty/clay-rich beds (Figure 2-3C).

The Corton Sands are overlain by the Lowestoft Till, which is a stiff and over-consolidated dark grey clayey diamicton that contains abundant chalk and flint gravel, as well as quartz and quartzite from the English Midlands and granite from northern Britain. The Lowestoft Till is very widespread across eastern England and was deposited by an ice sheet originating in northern Britain, that flowed south across eastern England and the North Sea basin, reaching a line between north London and Bristol. It is overlain by the Oulton Beds, Pleasure Gardens Till and Plateau Gravels that represent localised sediments associated with the retreat and melting of the British ice sheet.

The hydrogeological properties of these units vary; the over-consolidated tills form 'aquitards' that confine groundwater flows, and the Cromer Forest-bed, Corton Sands and Plateau Gravels form 'aquifers' that allow free flow of water.

	
A. Cromer Till. Stiff brown sandy diamicton with occasional gravel deposited beneath a floating ice sheet. Note iron stained bedding and joints.	B. Interbedded gravel and diamicton sometimes seen at upper part of the Cromer Till. Deposited as a debris flow from a floating ice sheet.
	
C. Corton Sand with darker silty/clay layer in middle of photo.	D. Banded diamicton and sand and gravel. Cromer Till.

Figure 2-3. Glacial sediments exposed along the Corton frontage.

2.2 Cliff-face and Hinterland Geomorphology

The site and hinterland geomorphology has been mapped in ArcGIS using Environment Agency 2 m resolution composite LiDAR data and aerial imagery, flown since 2011 to monitor coastal processes. The LiDAR elevation model was processed to generate hillshade and slope angle layers. The data were used to record hinterland drainage pathways and topography, clifftop in recent imagery and details of cliff instability features.

Mapping shows the hinterland behind the cliff edge is a very gently undulating plateau incised by a series of subtle valleys that are aligned in east-west (Figure 2-5). Drainage off the plateau is mainly directed towards the west (i.e. inland), with streams flowing west into the River Waveney, which then enters the sea at Lowestoft. The only location where valleys drain directly towards the coast is at Baker's Score, where surface water is transmitted to the shoreline by a pipe. Anglian Water also have an outfall pipe at this location.

Observations made by the BGS in the late 19th century, prior to construction of defences, indicate the coastline was characterised by rapid rates of erosion (Blake, 1884). A concrete seawall/promenade was first constructed along the frontage between Tibbenham's Score and Cliff House in the late 19th Century. Defences were progressively extended since the 1960s, with periodic repairs and upgrades. Coastal monitoring data collected since the late 20th century indicates a step-change in the beach occurred in 1999 when severe lowering occurred, leading to undermining of the sea wall and exposure of piles. Rock armour was then placed to protect the toe of the defences.

The effects of the 1953 storm surge on the cliffs were noted by Grove (1953). At this time the defences did not extend along the whole frontage of the Corton:

"The position of the top of sandy cliffs at Corton remained unchanged as a result of the storm, but the base of the cliffs was cut away and in subsequent weeks numerous slumps occurred. These slumps are at intervals of about 30 ft., arcuate in plan, and separated by buttresses giving the cliff a scallop"

These observations suggest that prior to construction of coastal defences the cliffs were freely degrading, with periods of low activity where a debris apron accumulated on the cliff, and periods of greater activity where the debris apron was subsequently removed by wave action, the base of the cliff was cut, and cliff failures resulted in retreat of the clifftop. Once coastal protection measures were installed, toe erosion ceased but the upper cliff face has continued to degrade. The impact of toe protection is shown conceptually in Figure 2-4. In an undefended cliff the toe (T1) and clifftop (H1) retreat at the same rate, and the cliff angle remains constant over time. Debris from cliff erosion may periodically accumulate at the cliff toe, but over time it is reworked into the coastal system. Once toe protection measures are in place, the cliff toe (T2) is fixed but the clifftop (H2) degrades and retreats through weathering and mass wasting processes forming a debris apron above the toe protection measures. The cliff angle is reduced over time until a stable slope angle is achieved. Note that the actual form of the actively eroding and freely-degrading cliff will be affected by the properties of the constituent strata.

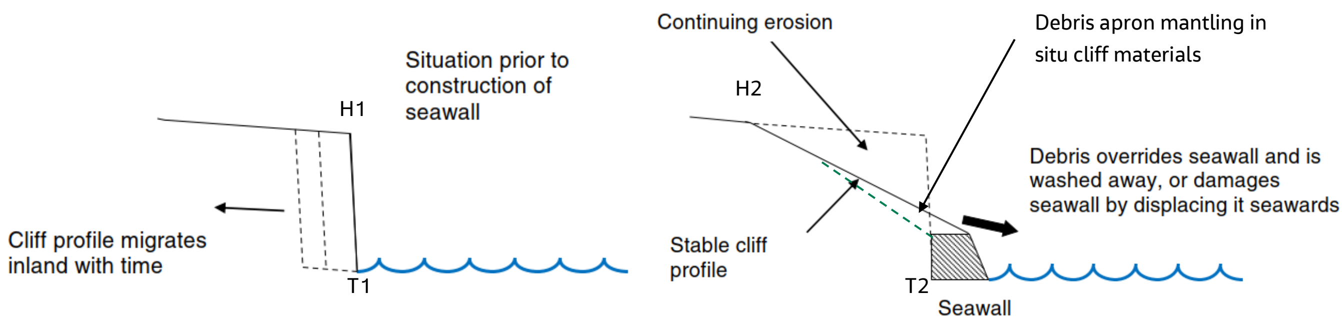


Figure 2-4 . Impact of toe protection measures on cliff behaviour (after Moore and Davis, 2015).

2.3 Records of Historical Cliff Instability

The Corton coastline benefits from an extensive programme of monitoring, which includes beach and bathymetric surveys, aerial photography and LiDAR. These data have been analysed in a GIS database to record the pattern and nature of recent coastal change. Site observations have also been recorded in the GIS.

The aerial photography data have been used to assess cliff recession by mapping the position of the clifftop in different epochs of imagery and measuring change. Recent clifftop recession rates have been determined using aerial imagery from 2011 and 2019. At the relatively freely-degrading section between Corton and Hopton, 10 to 20 m of cliff retreat has occurred along the whole frontage, with an average retreat rate between 1.25 to 2.5 m/yr. Along the defended section at Corton, only very localised clifftop recession can be detected, where 0.5 to 3 m of retreat has occurred along short, 5 to 10 m long, sections of cliff (Figure 2-5). This implies an average clifftop recession rate of less than 0.4 m/yr. These average rates of clifftop retreat are in line with measurements of change in the cliff toe and position of mean sea level made from biannual shore profile surveys collected since 1999. They are also corroborated by judgement-based estimates of cliff erosion in the Futurecoast cliffs database (Halcrow, 2001).

LiDAR surveys have been undertaken along the coast, annually between 2015 and 2019, and less frequently between 2015 and 1999. Difference models can be created by subtracting one elevation model from another to show areas of positive and negative change, which indicate accretion and erosion respectively. LiDAR data collected prior to 2015 have a resolution of 2 m and an accuracy of ±0.25 m, which means difference models only record very significant change over large areas. In contrast, more recent data has a resolution of 1 m and an accuracy of ±0.15 m, meaning subtle change over smaller areas can be detected. Difference models covering the periods 2003 to 2015, and 2015 to 2019 have been used to record the location and magnitude of recent cliff instability. The locations of recent cliff instability are plotted on Figure 2-5.

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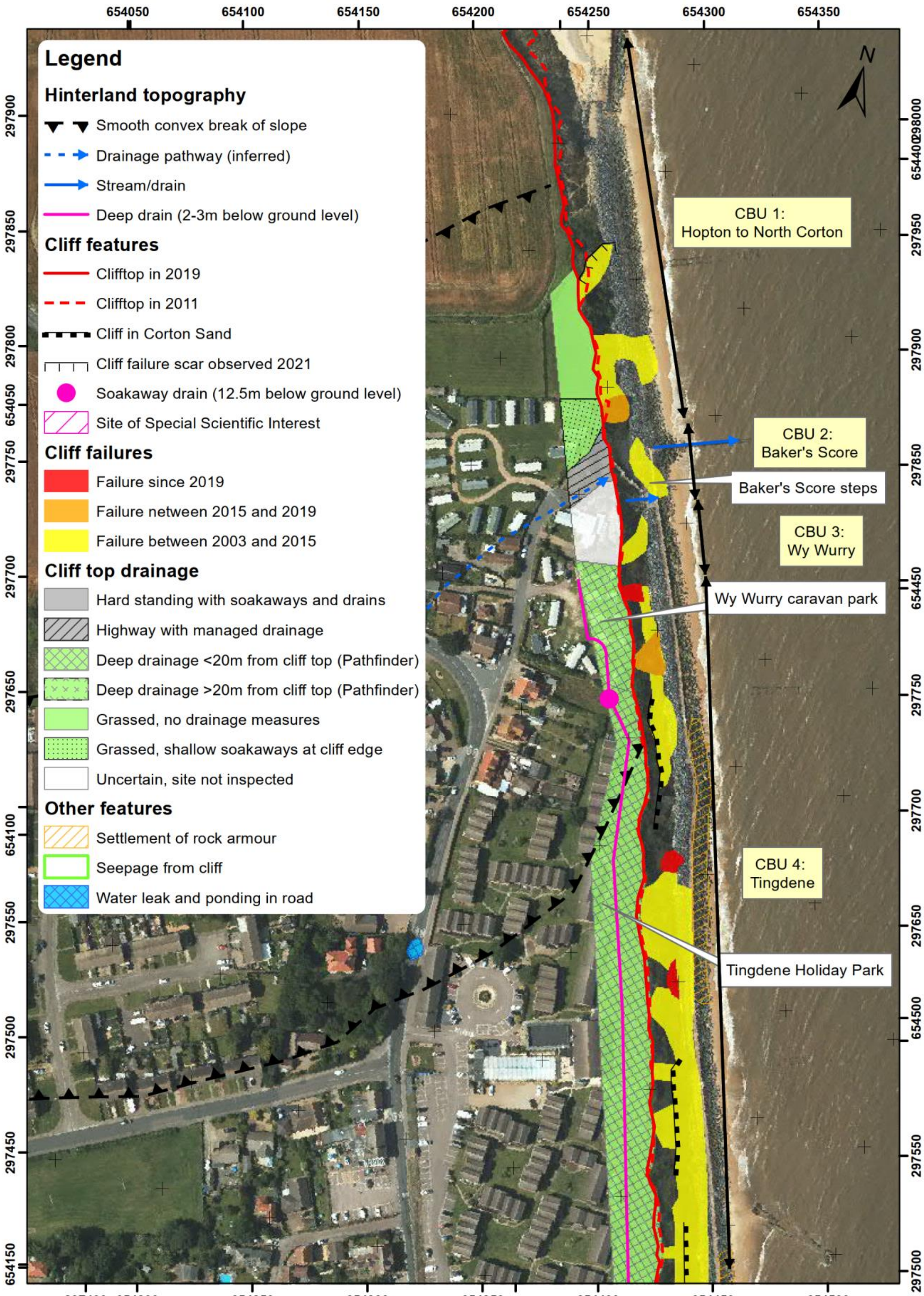

Figure 2-5a. Geomorphology, cliff activity and drainage, Baker's Score to Tingdene Holiday Park. Note: section is divided into Cliff Behaviour Units (CBU)

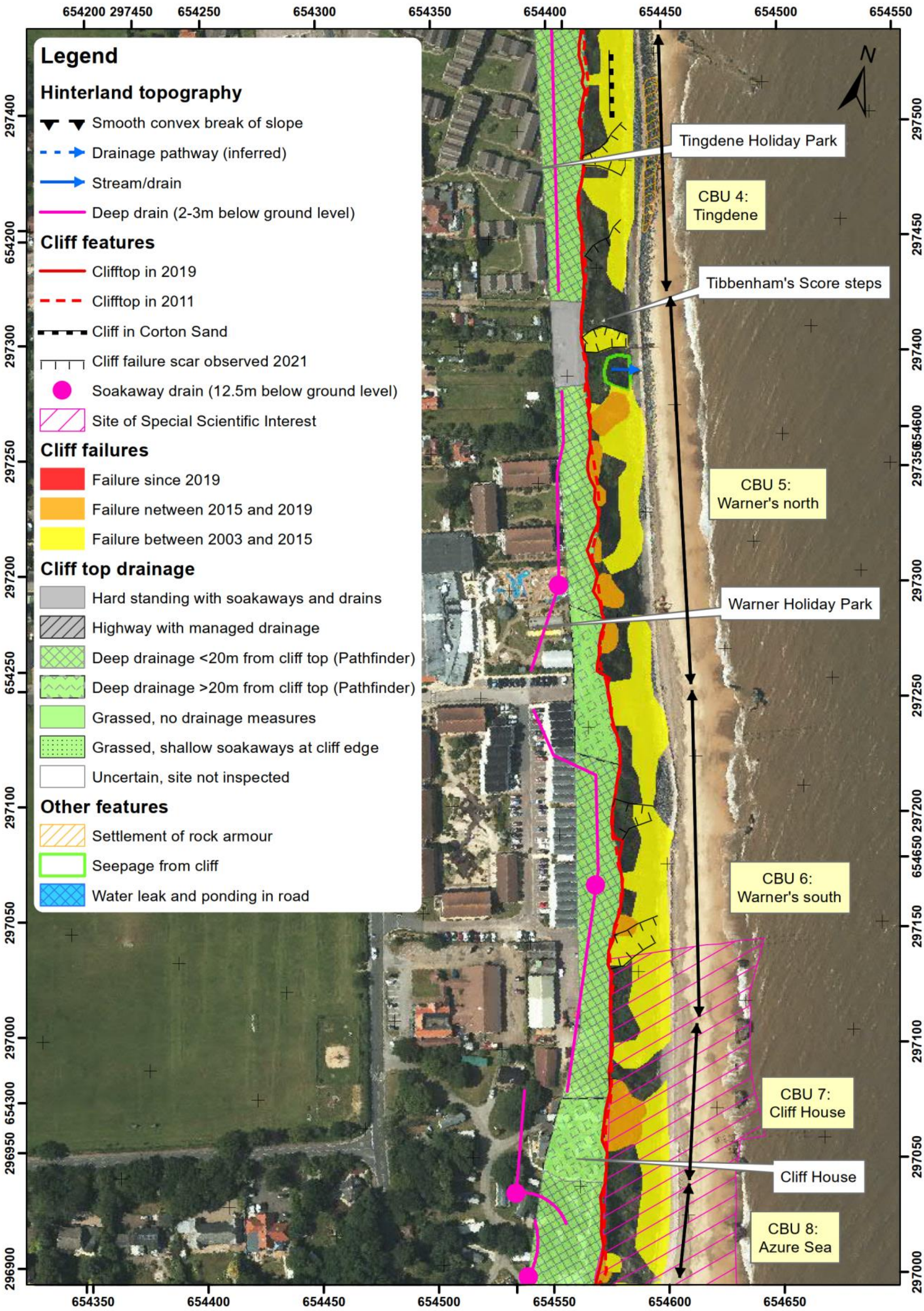

Figure 2.5b. Geomorphology, cliff activity and drainage, Tingdene Holiday Park to Cliff House. Note: section is divided into Cliff Behaviour Units (CBU)

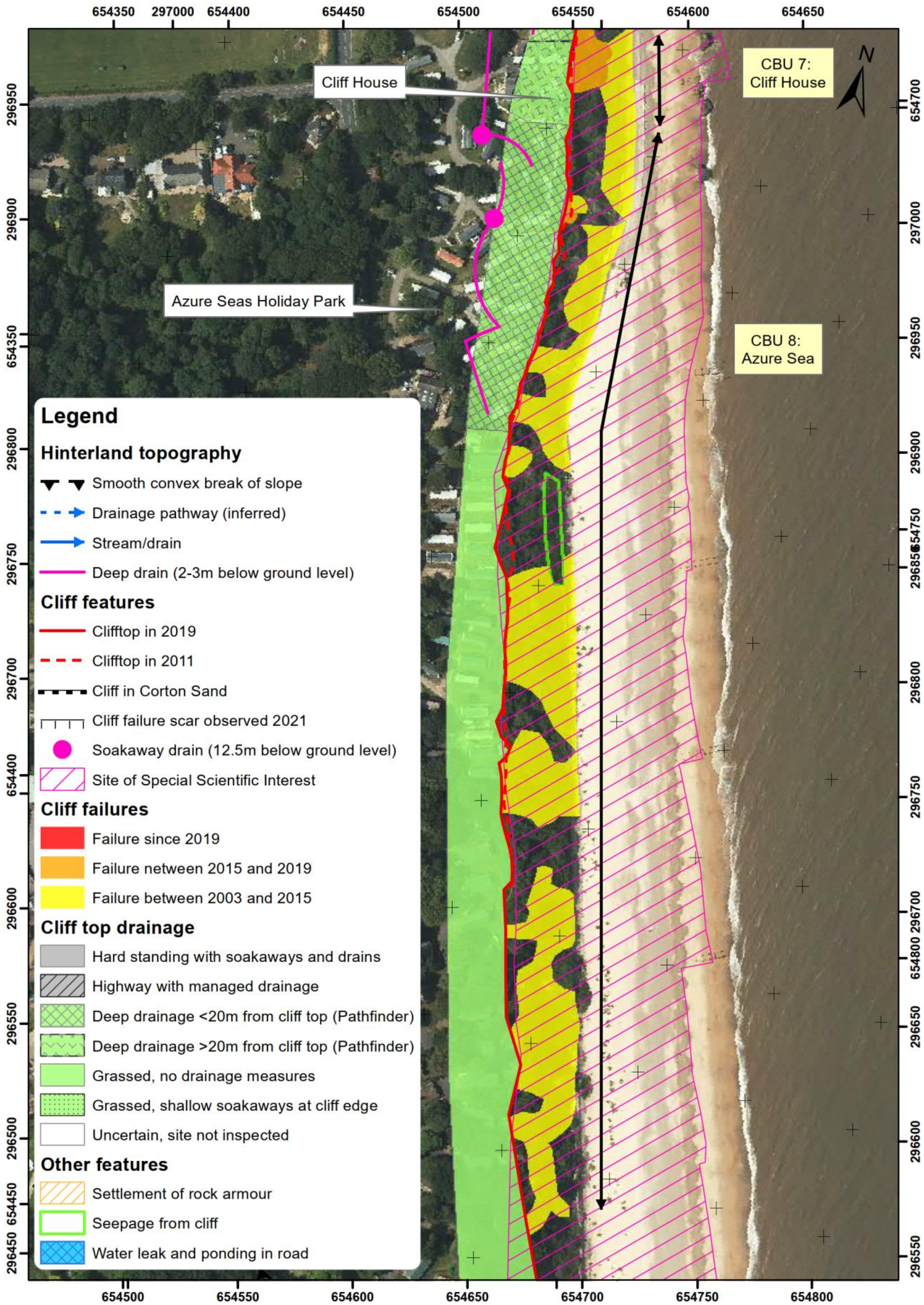

Figure 2.5c. Geomorphology, cliff activity and drainage, Cliff House to Azure Sea Caravan Park. Note: section is divided into Cliff Behaviour Units (CBU)

The LiDAR data indicate that despite the presence of toe protection measures, most of the Corton cliff shows evidence of change in the period since 2003 (Figure 2-5). The data confirms widespread and repeated reactivation of the debris apron that mantles the cliff with losses in the upper to middle part of the cliff, and accretion in the lower cliff, often with runout that extends over the promenade and rock armour. As shown by the review of aerial imagery, clifftop retreat rarely occurs. This implies an increase in the cliff angle, since the toe has retreated but the clifftop has been stable. This reflects erosion of the debris apron mantling the cliff rather than erosion of the in situ cliff materials (see Figure 2-4).

Clifftop locations shown on Figure 2-5 where activity is indicated to be particularly widespread and persistent comprise:

- The area north of Baker's Score steps fronting the caravan park and adjacent grassland. Runout of debris (sediment from the cliff) over the rock protection on the lower cliff face has occurred and much of the upper cliff has experienced cliff failure through slumping and mudslides prior to 2019, but no recent activity was observed during the site inspection. This reflects localised failure of the debris apron that mantles the cliff.
- Cliffs fronting the Wy Wurry caravan park have experienced widespread erosion immediately above the rock protection prior to 2015, and large cliff failures of the upper cliff have occurred since 2015, including recent retreat of the clifftop and slumping of the debris apron that was observed during the site inspection.
- Most of the length of cliff fronting the Tingdene site has experienced erosion immediately above the rock prior to 2015, with reactivations occasionally extending to the clifftop. Activity since 2015 has been limited to small areas of the middle and lower cliff. This indicates most activity relates to slumping of the debris apron.
- The northern part of the Warner site and Tibbenham's Score steps show evidence for erosion immediately above the rock prior to 2015, with reactivations generally only affecting the debris apron that mantles the lower cliff. There is also widespread evidence for more recent cliff activity with erosion of the upper cliff. Cliff activity is particularly associated with an area of very boggy ground and a drainage outfall pipe, where elongated slumps have affected the whole cliff face. The pipe has saturated the debris apron, making it unstable and particularly susceptible to slumping and erosion from overtopping waves during storms.
- The southern part of the Warner site shows evidence for erosion immediately above the rock protection prior to 2015. Reactivations generally affected the debris apron that mantles the lower cliff, but scars on the cliff face show some erosion and retreat of the clifftop has also occurred. There is very limited evidence for activity since 2015.
- The area below Cliff House shows widespread slumping of the debris apron mantling the lower cliff prior to 2015 and a large slump of the mid to upper cliff since 2015.
- Cliffs below the Azure Sea holiday park show widespread evidence for cliff instability and erosion prior to 2015, with these reactivations occasionally extending to the upper cliff. There is limited evidence for activity since 2015 due to the growth of a substantial beach across this section. The site visit showed this pattern of change reflects a large incipient slump of the debris apron that mantles the lower to middle part of the cliff, which is likely to be periodically active in response to wet weather. Movement of the debris apron is likely to trigger localised retreat of the clifftop.

2.4 Review of Drainage Records

Holiday park and housing developments on the clifftop can influence cliff behaviour due to inadvertently surcharging ground water. An example is surface water runoff from soakaways, hard standings and drainage outfalls which concentrate discharge over the cliff edge, locally saturating materials, causing seepage erosion and forming gullies down the face. The effect of groundwater is evident from the records of on-going cliff top retreat and runout of debris to the concrete walkway, despite toe protection measures being in place since the 1960s.

A Defra-funded Community Resilience Pathfinder project was undertaken by the council in 2010-11 to investigate the reasons for ongoing cliff retreat and to recommend cliff stabilisation options. Ground investigation demonstrated the presence of an impermeable clay layer 2 to 3 m below the ground surface (Lowestoft Till) that was underlain by a thicker, permeable sand (Corton Sand). The Pathfinder project concluded that poor drainage, due to the presence of the Lowestoft Till close to the ground surface, was causing on-going cliff instability and recommended construction of a deep drainage scheme close to the cliff top.

The scheme was constructed along the frontage between the Wy Wurry caravan park and the northern part of the Azure Seas caravan park during 2011-12. It comprised a series of vertical drains that intercept shallow groundwater and direct it through the impermeable Lowestoft Till to gently sloping drains at a depth of 2 to 3 m below ground level. These discharged to five deep soakaway drains in the Corton Sand 12.5 m below ground level (8 to 9 m above OD) (Figure 2-6). The drains were typically constructed within 20 m of the cliff edge and in front of all cliff top assets, but the presence of cliff top assets at the Warner Holiday Park, Cliff House and Azure Seas Holiday Park meant short sections of drain had to be constructed 20 to 40 m inland of the cliff top. In these locations there are assets between the deep drains and the cliff top.

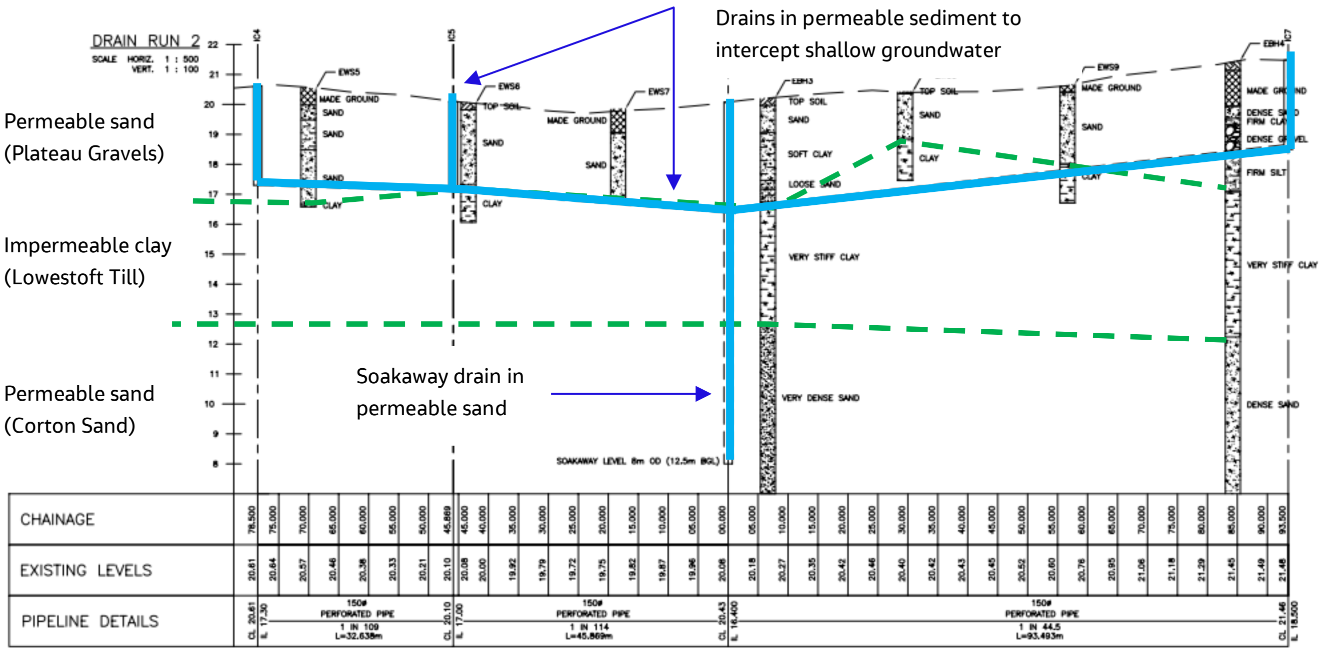

Figure 2-6: Typical design of the deep-drainage scheme, which conveys surface water and shallow groundwater through the impermeable clay layer (Lowestoft Till) into the underlying permeable sand (Corton Sand). Note: dashed green lines indicate boundaries between the main geological strata

The site inspection (Section 3) has provided additional details on surface water drainage and highlights different management across the site, particularly in areas where the deep drainage scheme is absent, or where there are assets between the deep drain and the cliff top. Details of cliff behaviour units recognised on site are summarised in Table 2-2 and shown in Figure 2-5, which also shows cliff activity and hinterland drainage measures.

Table 2-2. Summary of cliff activity, defences and drainage

Cliff behaviour unit	Location	Defences	Cliff activity	Hinterland context and surface water management
1a	Hopton to North Corton	Timber revetment, now derelict and seaward of cliff line.	High	None. Caravan park is inland at this location – rainfall infiltrates arable fields
1b	Hopton to North Corton	Rock revetment replacing original seawall that has collapsed	Moderate	None. Rainfall infiltrates arable fields and amenity grassland.
2	Bakers Score	Rock armour fronting concrete and steel sheet piled (SSP) seawall and gabion basket protection of cliff	Low	Surface water piped to shoreline.
3	Wy Wurry	Rock armour fronting concrete and SSP seawall	Moderate/high	Deep-drainage scheme. Caravan soakaways seaward of the drain discharge directly to cliff edge.
4	Tingdene (to Tibbenham's Score)	Rock armour fronting concrete and SSP seawall	Low	Deep drainage of 10 to 20 m wide vegetated strip between cliff and chalets.
5	Warner's north (parking area and central complex)	Rock armour fronting concrete and SSP seawall	Moderate/high	Car park hard standing with a single gulley pot drain, connected to deep soakaway.
6	Warner's south (chalets)	Rock armour fronting concrete and SSP seawall	Low	Deep drainage of 15 to 20 m wide vegetated strip between cliff and chalets. Short section of car park does not benefit from deep drainage.
7	Cliff House	Rock armour fronting concrete and SSP seawall	Moderate/high	Deep drainage inland of the property and hard standing. Unclear if hard standing drainage is connected to mains network.
8	Azure Seas	Concrete and SSP seawall.	Moderate	Deep drainage only for northern section of the CBU. Drain is typically over 20 m from the cliff top and is fronted by caravans with soakaways, some of which discharge directly to cliff edge.

3. Site Inspection and Observations

A photographic record of the site inspection is provided in Figure 3-1, which shows characteristic cliff forms along the relatively freely degrading Hopton to Corton coastline, and the defended frontage of Corton. The discrete sections of coast are described below. The locations of the inspected cliffs are shown in Figure 2-5. The weather on the day was dry and warm. The previous week had been characterised by warm and dry conditions with occasional rain showers. Except where stated, the cliffs were dry and seepage was not commonly observed.

3.1.1 Hopton on Sea to Corton

The clifftop lies at between 15 and 17 m OD and the hinterland comprises arable fields and a holiday park. The Cromer Till was observed to have an undulating upper surface. Up to 2.5 m is sometimes visible at the base of the cliff while at other locations it is below the level of the beach. Reference to LiDAR data suggests the elevation of the top of the Cromer Till ranges from around 5 m OD to 2 m OD. When exposed, the Cromer Till forms a vertical cliff or a raised platform that affords relative resistance to coastal erosion. The majority of the cliff is formed of Corton Sand, which forms a subvertical cliff up to 10 m high that is often incised by rills caused by surface water runoff erosion. The upper cliff is formed from Lowestoft Till that ranges in thickness from around 1 to 3 m.

The cliff is very active, with widespread evidence for toe erosion and collapse to form a debris apron and numerous fresh to degraded slump scars in the upper cliff. Where the Cromer Till is absent, the debris apron is larger (Figure 3-1a-c) than locations where the till is present (Figure 3-1d), reflecting the increased protection this material affords to the cliff base. Some debris apron slopes are well-vegetated (Figure 3-1a), suggesting that toe erosion only occurs periodically. The upper part of the cliff is generally sub-vertical and degraded, often with a drape of Lowestoft Till that has been mobilised by rainfall (Figure 3-1d).

Cliff failure occurs through two processes:

1) Erosion by the sea at the toe of the cliffs, which causes undercutting and cliff collapses that may extend up to the clifftop.

2) Sustained wet weather saturates the clay-rich Lowestoft Till, causing mudslides to displace down the cliff. Wet weather also remobilises the debris apron that results from past cliff failures. The debris affords little protection to the cliff toe, and is rapidly reworked by waves during storms that acts to steepen the cliff.

3.1.2 Corton, Wy Wurry Caravan Park to Warner Holiday Park

The defended section of the Corton coastline between the Wy Wurry Caravan Park and the Warner Holiday Park is protected by a concrete slab revetment and rock armour. Access to the walkway is via steps at Baker's Score and Tibbenham's Score. The beach is narrow, and the high water mark corresponds with the base of the rock armour defences. The clifftop is at around 16 m OD at the subtle valley at Baker's Score but rises to 20 to 21 m for the majority of the frontage. The surface of the promenade lies at 2 to 3 m OD and the concrete revetment/ replacement rock protection extends to 5 to 6 m OD. The hinterland is well-developed with a series of static caravan parks and holiday camps present. Some caravans are situated immediately at the cliff edge, other areas have amenity grassland or hard standings for car parking. Most of this section of coast benefits from a deep drainage scheme.

The cliffs are at a lower angle than the freely eroding frontage north of Corton and are mantled with a debris apron. This reflects a lower overall level of erosion and slumping (Figure 3-1e, f). Most of the cliff is mantled with a well-vegetated debris apron, but there is widespread evidence for erosion and slumping, and locally steeper sections at the base of the cliff where the debris apron has been eroded and the in situ geology can be seen (Figure 3-1I, j and k). The Cromer Till is rarely visible above the defences, but was observed at two short sections of cliff below the Tingdene Holiday Park and Warner Holiday Park, where its upper surface lay at around 7 m OD (Figure 3-1k and l). Most of the cliff is formed from Corton Sand with a 2 to 3 m thick cap of Lowestoft Till. The upper cliff formed in clay-rich till, lies at a lower angle than the lower cliff and is characterised by numerous degraded mudslide scars (Figure 3-1f). Seepage from the cliff was observed immediately south of the Tibbenham's Score steps (Figure 3-1j) where the vegetation on the cliff comprises species tolerant of marshy conditions. East Suffolk Council has installed catch boards on the concrete apron to manage the flow of water issuing from the cliff, which is reported by the council to be constant. The source of the water is uncertain, but the cliff hinterland at this location is a tarmacadam surfaced car park that does not benefit from deep drainage.

Cliff failure typically comprises saturation of the clay-rich Lowestoft Till following sustained wet weather, which causes mudslides to displace down the cliff, mobilise the Corton Sand and form a debris apron. The debris has accumulated behind the wave return wall, which shows evidence of deformation (Figure 3-1h, j). Wet weather also remobilises this debris apron causing runout to the promenade. In places the debris apron is absent, and the geology is exposed. This reflects periodic wave splash or overtopping of the defences, causing erosion and localised reactivation of the lower cliff. Occasionally larger cliff failures occur which have led to reactivation of the whole cliff and retreat of the clifftop.

3.1.3 Corton, Cliff House to Azure Sea Holiday Park

The defended section of the Corton coastline at the Azure Sea holiday Park is protected by a concrete revetment that is at an elevation of up to around 5 m OD. The clifftop lies at an elevation of 21 to 23 m OD and the hinterland is well-developed with a static caravan park and a small hard standing car park at Cliff House. Caravans tend to be situated immediately at the cliff edge.

The beach at this location is wide and the defences are rarely reached by waves. This section of cliff is notified as a SSSI because of the glacial geology. The cliffs are very degraded, with a shallow angle debris apron that is thickly vegetated with mature shrubs and small trees. The cliffs are at a lower angle than those to the north, reflecting a lower overall level of erosion activity (Figure 3-1m, n). The cliffs are mantled with a debris apron and the geology is rarely exposed. Seepage is commonly seen draining over the seawall, and debris runouts to the beach are observed periodically.

Cliff failure comprises reactivation of the debris apron in response to sustained wet weather. Ongoing failure of the debris was observed, suggested periodic movement and debris runout to the beach occurs.

Figure 3-1a to n. Site photographs (taken 7 July 2021)

Figure 3.1a. CBU 1a. Degraded, partially-vegetated cliffs fronting caravan park. Vegetation has established at the cliff toe suggesting wave erosion has not occurred for several months at this particular location. The Cromer Till is below the level of the beach and the Lowestoft Till is thin, meaning most of the cliff is formed of Corton Sand.

	Figure 3.1b. CBU 1a. Active cliffs south of Hopton. The Cromer Till is below the level of the beach. The cliff is formed of Corton Sand with a 2 m capping of Lowestoft Till and Plateau Gravel. Note the darker silt/clay beds in the upper part of the Corton Sand that create local perched water tables. Cliff failure comprises collapse of the whole cliff and retreat of the clifftop.
	Figure 3.1c. CBU 1a. Active cliffs south of Hopton. The Cromer Till is below the level of the beach. The cliff is formed of Corton Sand with a thin (<1 m) capping of Lowestoft Till and Plateau Gravel. Cliff failure comprises collapse of the cliff formed in Corton Sand with limited retreat of the clifftop.
	Figure 3.1d. CBU 1a. Partially active cliffs north of Baker's Score. 1 to 2.5 m of Cromer Till is present above the beach. The cliff is formed of Corton Sand with a thin cap of Lowestoft Till that has slumped over the upper part of cliff. Erosion of the base of the cliff has caused collapse of the Corton Sand Cliff. The upper cliff is degraded and probably experiences slumping in wet weather. Note the rills and gullies eroded by surface water runoff down the cliff face

	Figure 3.1e. CBU 2. Defended cliffs at Baker's Score. This section of cliff has rock armour below and above a concrete walkway. The cliff has been regraded and protected with gabion baskets.
	Figure 3.1f. CBU 3. Degraded cliff fronting the Wy-Wurry Caravan Park. This section of cliff experience headscarp retreat and slumping of debris in the storm surge of 3rd April 2021. The Cromer Till is below the level of the rock armour, with the cliff formed of Corton Sand with a thin cap (<1 m) of Lowestoft Till.
	Figure 3.1g. CBU 4. Degraded, locally active cliff fronting the northern part of the Tingdene caravan site. The Cromer Till is below the level of the rock armour and the cliff is formed of Corton Sand with a thin cap (<1 m) of Lowestoft Till and made ground. Note the bricks in the debris that mantles the cliff. Recent activity comprises small slumps of this debris on the lower cliff. The upper cliff is well-vegetated and degraded.

	Figure 3.1h. CBU 4. Degraded, locally active cliff fronting the northern part of the Tingdene caravan site. The cliff is formed of Corton Sand with a thin cap (<1 m) of Lowestoft Till. Recent activity comprises slumps over the concrete apron and toe protection. Note damaged sections of concrete apron have been infilled with rock. Sheet piles have been used at the edges of the concrete slabs to stop water washing beneath.
	Figure 3.1i. CBU 4. Degraded, locally active cliff fronting the south of the Tingdene site, near Tibbenham's Score. The cliff is formed of Corton Sand with a thin cap (<1 m) of Lowestoft Till. The cliff is mantled with slumped and vegetated Lowestoft Till that has locally remobilised. The cliff base in Corton Sand is locally free of debris, suggesting recent wave overtopping and erosion. Note the wave return wall has been dislodged by fallen debris.

Figure 3.1j. CBU 5. Seepage from drainage outfall from upper cliff at the northern part of the Warner holiday camp, south of Tibbenham's Score. The cliff is degraded and well-vegetated. It is mantled with debris that is saturated with water and which has pushed out the wave return wall. A car park is present on the cliff top, which is not covered by the deep drainage scheme.

Figure 3.1k. CBU 6. Warner holiday camp. The cliff is locally active, showing areas that are degraded and well-vegetated, and others that show evidence for recent slumping of debris and toe erosion from wave overtopping. The sediments exposed at the base of the cliff comprise 1 m of banded and gravelly Cromer Till. The majority of the cliff is formed of Corton Sand.

Figure 3.1l. CBU 6. Warner holiday camp south. The cliff is locally active, showing areas that are degraded and well-vegetated, and others that show evidence for recent slumping of debris over the upper rock, and erosion from overtopping waves. The sediments exposed in the base of the cliff comprise around 1 m of banded and gravelly Cromer Till overlain by Corton Sand and a thin cap of Lowestoft Till and Plateau Gravel.

Figure 3.1m. CBU 7. Cliff House to Azure Sea. The cliff is degraded and well-vegetated with a mantle of debris apron. Periodic activity comprises slumping of debris apron in response to wet weather.

Figure 3.1n. CBU 8. Azure Sea north. The cliff is degraded and well-vegetated with a mantle of debris apron that is marginally stable. Periodic activity comprises slumping of debris apron over the toe protection measures in response to wet weather. Seepage is often observed draining over the concrete apron along this section of coast. Note the particularly wide beach at this southern extent of Corton, which monitoring shows has accreted in the last 5 years.

4. Cliff Behaviour Assessment, Causes and Instability Potential

4.1 Natural Processes and Coastal Defence

The cliffs at Corton were formed by coastal erosion as sea-level rose over the last ten thousand years and the cliff line is a natural feature which has progressively retreated over time. The rate of cliff recession has historically responded to fluctuations in beach level and movement of offshore banks and channels, which affect the amount of wave energy reaching the toe of the cliff and the ability of tidal currents to transport sediment away.

Reference to the more freely-degrading cliffs towards Hopton provides a relevant analogue of how the Corton village frontage would have evolved had it not been protected by coastal defences and cliff drainage. These cliffs reveal the mechanism of cliff retreat is twofold: toe erosion by wave attack undercuts the sandy lower cliff leading to collapse of the mid and upper cliff; and saturation of the clay-rich upper cliff by extreme rainfall, run-off and groundwater causes mudslides that form debris aprons on the lower cliff, which are rapidly eroded from the lower cliff by wave attack. By contrast, the defended cliffs at Corton do not experience the same toe erosion, due to the coastal defence structures, but the upper cliffs remain exposed to weathering and mass wasting processes that deposit debris aprons on the lower cliff.

When cliff protection measures were constructed in the 1960s, toe erosion was effectively halted and the cliff line fixed by the presence of the revetment. However, the rates of clifftop retreat responded differently as the cliff face remained exposed to weathering and mass movement processes caused by rainfall, wind and runoff. Over time this has led to development of a debris apron on the lower cliff, which became vegetated, reducing the overall angle of the cliffs. Despite the coastal protection measures preventing cliff toe erosion, periodic failures of the debris apron and upper cliff still occurred. A Community Resilience Pathfinder project in 2010-11 investigated the reasons for ongoing cliff retreat. The study recommended a deep drainage scheme be installed along most of the cliff top between the Wy Wurry and Azure Seas caravan parks to extend the life of cliffs, which was constructed in 2011/12 (see Section 2.4).

The debris apron is periodically active due to wave overtopping and undercutting during storm events. Localised cliff failures and mudslides from the upper cliff also occur in response to extreme rainfall, run-off and ground water drainage, which saturates the ground, causing it to lose strength and fail. These causes and mechanisms can occasionally lead to localised retreat of the clifftop that threaten clifftop development.

The localised cliff instability of the upper cliff is caused by groundwater, which is well-managed across much of the site with the deep drainage scheme. The groundwater originates from rainfall, but is also influenced by the hinterland developments, which act to concentrate flows from soakaway drains or by uncontrolled runoff from hard surfaces. Despite deep drainage, headscarp retreat and slumping of debris on the cliff have recently occurred at Wy Wurry, where caravans with soakaways are located seawards of the drainage scheme; at Tibbenham's Score, where there is gap in the deep drainage scheme and a cliff top car park with poor drainage and potential for run off; at Cliff House, where the deep drainage scheme was routed inland to avoid existing properties and hard standings; and at Azure Seas, where the deep drainage scheme only covers the northernmost part of the site, and caravans with downpipes and soakaways are located seawards of it.

There are widespread areas where the debris aprons are absent and fresh cliff exposures are observed, particularly between Baker's Score and Cliff House, indicating that periodic storms overtop the defences and undercut the debris apron and lower cliff. This is much less frequent south of Cliff House because the much wider beach affords protection from the sea.

Therefore, despite the toe protection and deep drainage, the debris apron that mantles the cliff still shows evidence of local movement due to the effects of local groundwater, overtopping and toe erosion during storms.

4.2 Cliff Drainage Issues

Drainage outfalls and soakaway drains from caravans or hard standings at car parks act to focus rainfall in a particular area of ground. Leaking water mains, stormwater overflows and sewerage systems can also contribute water to the slope and lead to instability. While the topography of the hinterland slopes gently inland (i.e., away from the cliff edge), the shallow geology is permeable sand and gravel and silty sands that overlies impermeable clay-rich Lowestoft Till. It is therefore likely that rainfall rapidly infiltrates into the ground and then naturally drains towards the cliffs, where a large proportion is intercepted by the Pathfinder drainage scheme and transmitted to deep soakaways below the Lowestoft Till. Outfalls and shallow soakaway drains will direct water in a similar direction. This hydrogeological influence is likely to affect a relatively small hinterland area landward of the cliff and extending to the main road (Figure 5), a distance of approximately 200 m.

The nature of the hinterland, and particularly the land drainage system, were assessed from council records of the Pathfinder drainage scheme and site visit observations (Figure 5; Section 2.4). Static caravans were observed to generally use soakaways to discharge rainwater directly to the ground. Wastewater from caravans was observed to be connected to the mains sewerage system. Brick-built chalets at the Tingdene site discharge rainwater into drains, but it was unclear whether these drains were connected to a combined public drainage system. Similarly, the tarmac hard standing and car park at the rear of the Warner site, south of Tibbenham's Score, appears to be drained with a small number of gully pots, but it is unclear to what these are connected and most likely an outfall pipe in the upper cliff (Figure 6i). The southern part of the Warner site has a grassed strip 20 to 30 m wide above the cliff. Inspection covers in this area relate to the Pathfinder deep drainage scheme were opened and observed to be clear of debris.

Despite the presence of toe protection measures and narrow beach in the area between Baker's Score and Cliff House, there are variations in the level of cliff activity, with notable hotspots at the Wy Wurry, part of the Warner Holiday park immediately south of Tibbenham's Score steps and at Cliff House. The geology at these locations is very similar, with the cliff above the toe protection measures comprising Corton Sand with a 2 to 3 m thick cover of clay-rich Lowestoft Till and more-permeable Plateau Gravels. These locations all benefit from the deep drainage scheme. However, the site inspection showed the Wy Wurry site has caravans located immediately above the cliff edge, seaward of the deep drain, and that rainwater downpipes concentrates roof water drainage at the cliff edge. The area of the Warner site that experiences most cliff activity is a car park with an impermeable surface that is not included in the deep drainage scheme. A single road drain was observed, but it is unclear whether it is connected to mains drainage or discharges via a cliff outfall pipe. A proportion of the runoff from the carpark is likely to flow over the cliff edge. The cliffs below the car park are saturated and seepage is reported to be continuous. Cliff House is in private ownership and was not observed in detail, but the deep drainage scheme extends inland of the property and its carpark. Aerial imagery shows the clifftop car park has an impermeable surface and it is likely that concentrated runoff is directed towards the cliff edge.

5. Management Approaches

The observations from site and historical records of cliff activity confirm that cliff activity along the defended frontage of Corton is driven by two processes:

- Semi-natural shallow groundwater flows that are locally enhanced by runoff from hard standings and soakaway drains, which lead to failure of the upper cliff and debris apron mantling the slope and occasionally lead to retreat of the clifftop.
- Erosion of the debris apron that mantles the cliff during periodic storms that overtop the defences. This also sometimes leads to retreat of the clifftop.

At present, these processes have resulted in very limited clifftop recession, but as the debris apron is progressively eroded by storm waves and the cliff is undercut and steepened, clifftop retreat could be triggered, and assets will be at increasing risk. Both of these factors leading to cliff recession can be managed.

Control of land drainage and early detection and repair of water leakages on the clifftop and hinterland area are important measures to prevent adverse effects on cliff stability and erosion.

Management of groundwater at the clifftop can be controlled by ensuring all land drainage is connected to the mains network. Soakaways should be prohibited for assets at the clifftop and avoided at other locations. Runoff from hard standings should be managed to ensure connections with the mains drainage system and does not enter the ground or discharged over the edge of the cliff. All mains water supplies and drainage connections should be checked to ensure that there are no leaks. Particular attention should be paid to swimming pools and ornamental ponds to ensure no water leaks into the ground. This will likely be the responsibility of the cliff top property owners to address, who are also the parties most immediately affected by not doing so. Based on the findings of this report and experience elsewhere (i.e., Undercliff, Isle of Wight), guidance on the control of surface and ground water for property owners, developers and utilities could be prepared and distributed to stakeholders to ensure this aspect is understood and appropriately addressed in future.

Engineered interventions to stabilise the cliff could also be considered. These would be considerably more expensive to implement but have the advantage of stabilising and fixing the clifftop position. Options include:

1. Regrading the cliff face to a more stable angle. This would be achieved by cutting back the clifftop to a shallower slope, but that requires a swathe of clifftop area to be sacrificed which may not be feasible where private property and assets are located immediate along the clifftop.
2. Minor improvements to the Pathfinder cliff drainage scheme to resolve local groundwater problems where deep drainage is absent, or existing drains are located inland of assets of risk (such as Cliff House). This would require additional inclined gravity-fed drains to intercept groundwater and direct it to the existing deep soakaways.
3. Cliff stabilisation measures, such as soil nails and meshing, which would prevent slumping of the cliff face and failure of the debris apron. This option also encourages vegetation to establish and will form a stable green cliff.

Any engineered interventions should also be considered in conjunction with options being considered for the coastal defence works, to protect the toe of the cliff; erosion of the lower cliff face by waves will continue as long as the beach is narrow and storm waves are able to overtop the defences. Sea-level rise will mean that overtopping events will occur more frequently in the future. Construction of a new larger sea wall for example could significantly reduce wave overtopping and erosion of the lower cliff face. Conversely, if works are not being undertaken at the base of the cliffs, any interventions dealing with upper cliff instability (either in terms of additional drainage and/or cliff stabilisation) should be designed with recognition of their likely short-lived benefit. Given the increased frequency and severity of defence overtopping and erosion of the lower cliff face due to sea-level rise, upper cliff interventions on their own will have limited cliff stabilising effect in the long-term.