Understanding water and cliff failure at Sidestrand and Trimingham

November 2024

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Contents

1 Introduction

Mott MacDonald has been commissioned by North Norfolk District Council (NNDC) to undertake a focused investigation into understanding water and cliff failure at Sidestrand and Trimingham.

The project is part of Coastwise, an initiative being delivered by NNDC, which is nationally funded scheme, through the Coastal Transition Acceleration Programme, funded by DEFRA and the Environment Agency.

The study area is as per the client request for proposal document which states, “East of Sidestrand Hall School to 100m east of Cliff Farm”.

1.1 Objective

- To draw together existing technical knowledge alongside seeking local knowledge to better inform local understanding of the relationship between water and cliff failures between Sidestrand and Trimingham.
- To summarise and present this knowledge in a clear and accessible way.

This report presents a summary of the relationship between water and cliff failure at Sidestrand to Trimingham. The following pages of this report will cover:

- Summary of existing technical and scientific knowledge, local knowledge from the community members, impact from sewers and drains, and rainfall data.
- An account of the relationship between water and cliff failures between Sidestrand and Trimingham.

1.2 Report format

This report presents a summary of the research undertaken by Mott MacDonald to present the data in a clear and accessible way.

1.3 Limitations

While undertaking research for the project, every external contact has been extremely helpful but there have been some constraints on the information available. Below is a list of the limitations from the research:

- Road drainage – Norfolk County Council S38/S40 historic records solely cover new housing developments which were adopted following Local Government re-organisation in April 1974, prior to most roads at Trimingham. Only files which were live at that date were transferred to Development Control by the relevant Urban/Rural District Councils. An investigatory survey would be required to fully understand the road drainage.
- Historical boreholes – the majority of the publicly available boreholes on BGS GeoIndex were for water wells and not logged in detail so individual superficial layers were not recorded. Therefore, building an accurate 3D ground model could not be undertaken.
- Piezometers and water draining boreholes – a series of boreholes were installed in a rotational cliff failure to try and measure water levels and to drain the water into the underlying aquifer. This information would be useful for understanding water levels within the cliff. However, the records of these boreholes were not recorded and only passed on through word of mouth.

2 Existing technical knowledge on water driven cliff failures

This section of the report will summarise the main areas of research in relation to water and cliff failures in the study area. The general scope of works for the research followed these topics:

- Draw together key existing technical and scientific knowledge of water driven cliff failures at Trimingham.
- Pull together local knowledge from community members on the matter including relevant historic water management at Trimingham.
- If possible, to understand the numbers of properties on mains sewerage and those with soakaways and the nature of highways drainage.
- Assess any changes with rainfall and land use (in relation to water) that may exacerbate cliff losses.

Groundwater and surface water flow significantly impacts the cliff slope stability. Therefore, research into the nature and occurrence of water flow is required. Below is a list of the potential sources of water inflow and water outflow in the study area:

Water inflow

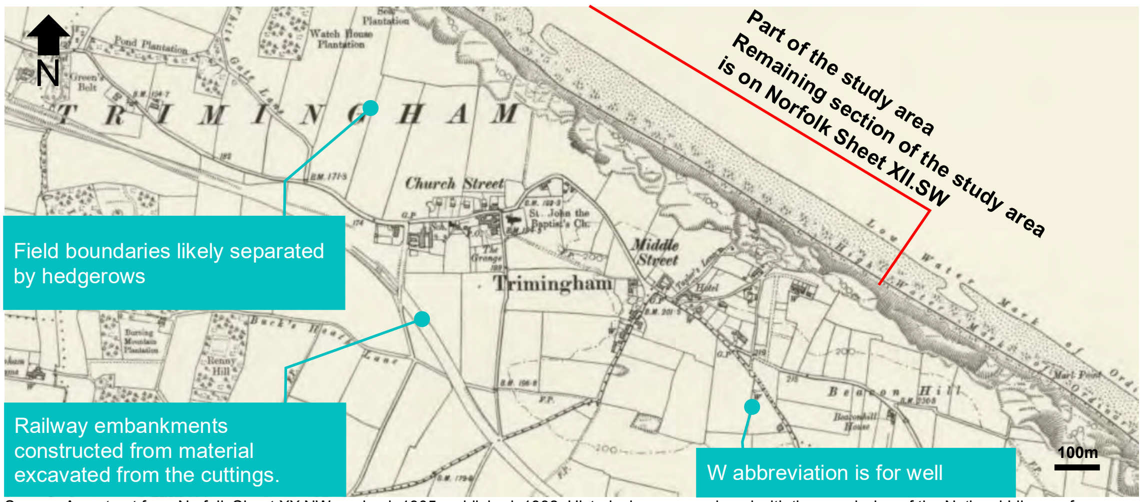
- Rainfall onto:
    - Fields
    - Trees
    - Roads
    - Roofs/gardens
    - Cliff slope
- Domestic water piped into the area:
    - Water or sewer pipe leaks
    - Soakaways
- Groundwater borehole pumping from deep aquifer
    - Water irrigation of fields

Water outflow

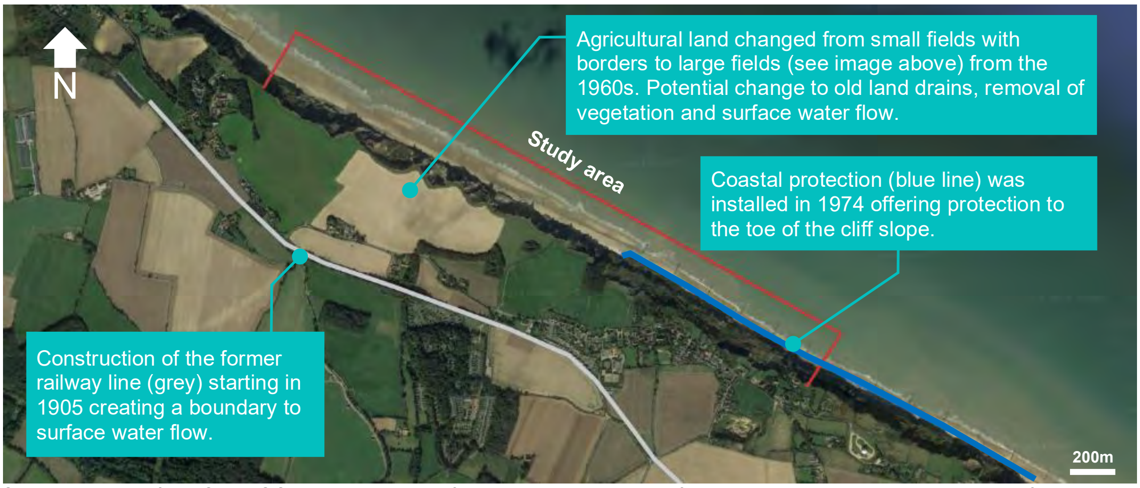
- Water infiltration into shallow and perched groundwater
- Surface water flow onto cliffs
- Underlying deep groundwater chalk aquifer
- Surface water flow to River Mun
- Evaporation
- Transpiration (plants)

The following sections assess the characteristics of these water sources in relation to the ground and environment.

2.1 Summary of change in land use



Source: An extract from Norfolk Sheet XX.NW, revised: 1905, published: 1932. Historical map reproduced with the permission of the National Library of Scotland.



Source: Aerial image from ESRI ArcGIS World Imagery. Date of railway construction estimated from historical maps. Note – only recent and significant land use changes have been highlighted.

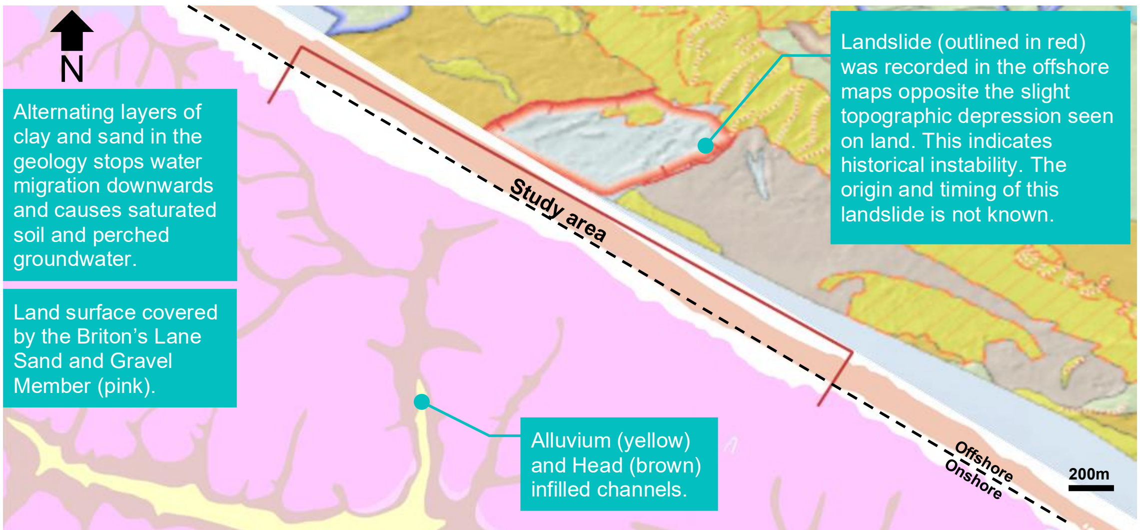
The study area and surrounding land has a long history of farming. Two significant land changes were identified with the construction of the railway line (now disused) starting in 1905 and the coastal protection in 1974.

From the earliest available mapping in 1885, most of the area was used for farming. This was in small, privately owned parcels of land. This continued until the latest available historical map in 1946. Limited resources (maps and aerial photography) were available in the 1960s, but it is likely during this time that the fields were expanded by the combination of multiple small fields into bigger fields (farmland consolidation). Previous field boundaries (e.g. hedgerows and possibly drainage) were lost in farmland consolidation, which would have reduced the flow of surface runoff.

Properties and infrastructure have been lost in Trimingham from cliff regression but development has still occurred with construction of Staden Park estate, Woodlands Holiday Park and more recently with Trimingham Hall.

Further research on changes of land use in the area is being undertaken by the University of East Anglia.

2.2 Onshore and offshore surface geology



Source: Onshore superficial geology reproduced from BGS Geology - 50k (DiGMapGB-50) Bedrock version 8 published by British Geological Survey (BGS). Offshore geology reproduced from Seabed Geology: Offshore East Anglia digital map 10k, released by the BGS in 2024.

A thick sequence of Superficial geology (up to 60m) deposited in the Quaternary Period is controlling the slope stability and groundwater levels.

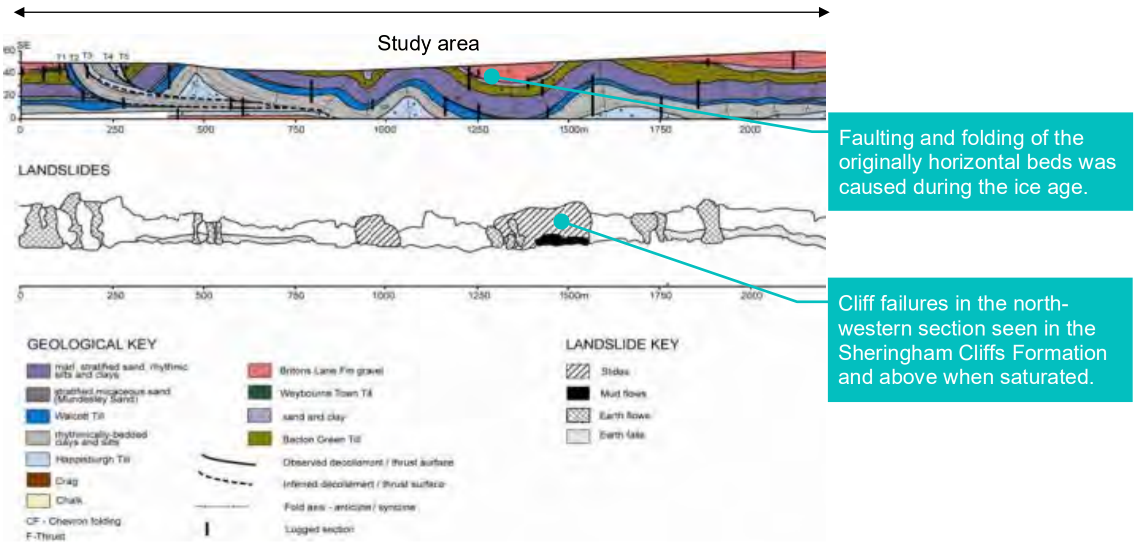
The British Geological Survey (BGS) mapping and borehole log database Onshore GeoIndex has been used to supplement existing technical knowledge (see Appendix A).

The table below presents the Superficial deposits encountered at the cliffs (youngest to oldest) and the underlying bedrock geology. Relative permeability (from low to high) has been included to show potential geological units that stop water migrating down to the chalk.

Stratigraphy		General composition	Relative permeability	Estimated Thickness (m)
Geological unit	Geological name			
Mass movement deposits	Head	Clay, silt, sand, gravel	Low	Unknown
Fluvial deposits	Alluvium	Clay, silt, sand, gravel	Low	Unknown
Briton's Lane Formation	Briton's Lane Sand and Gravel	Sand/gravel	High	4.0
Sheringham Cliffs Formation	Weybourne Town Till	Clay, silt and chalk	Low	2.5
	Trimingham Sand	Sand	High	1.0
	Trimingham Clay	Clay/silt	Low	2.5
	Bacton Green Till	Clay and sand	Medium	6.0
	Ivy Farm Laminated Silt	Marl and silt	Low	13.0
	Mundesley Sand	Sand	High	2.0
Lowestoft Formation	Walcott Till	Clay/silt	Low	1.5
Happisburgh Formation	Ostend Clay	Clay/silt	Low	2.0
	Happisburgh Till	Sand and gravel in clay	Low	5.5
Crag Group		Sand, gravel, silt, clay	High	5.0
White Chalk Group		Chalk	High	>50

Table reproduced from BGS Slope Dynamics Project Report: Norfolk Coast (2000 – 2006). Research report OR/08/018.

2.3 Geological profile of sea cliffs



Source: Reproduced from Lee et al., 2011 (modified from Hart, 1990)

Regional uplift of land and advancing ice sheets has made the geological sequence structurally complex along the cliff faces with faulting and folding.

The land in North Norfolk has experienced uplift, erosion, subsidence and uplift again since the late Cretaceous (when the chalk bedrock was formed). This has generated a geological sequence with no sediments seen from the chalk to the Crag Deposits which represents over 60 million years of time.

The area is dominated by recent glacial and post-glacial deposits from the past 2.6 million years. A well-known feature in North Norfolk is the Cromer Ridge which provided topographic highs points in the area. This ridge was originally created as a south-west to north-east structure by ice pressing from the west to north-west.

A later ice sheet advance from the north generated compression on the existing ice sheets which shortened the Cromer Ridge and this created the folding and thrust fault seen between Sidestrand and Trimingham (shown in the cross section image above), known as glaciotectonics. This large-scale ground movement forced older deposits to break up and be deposited in the more recent deposits, such as chalk rafts (or erratics) seen in the cliff section.

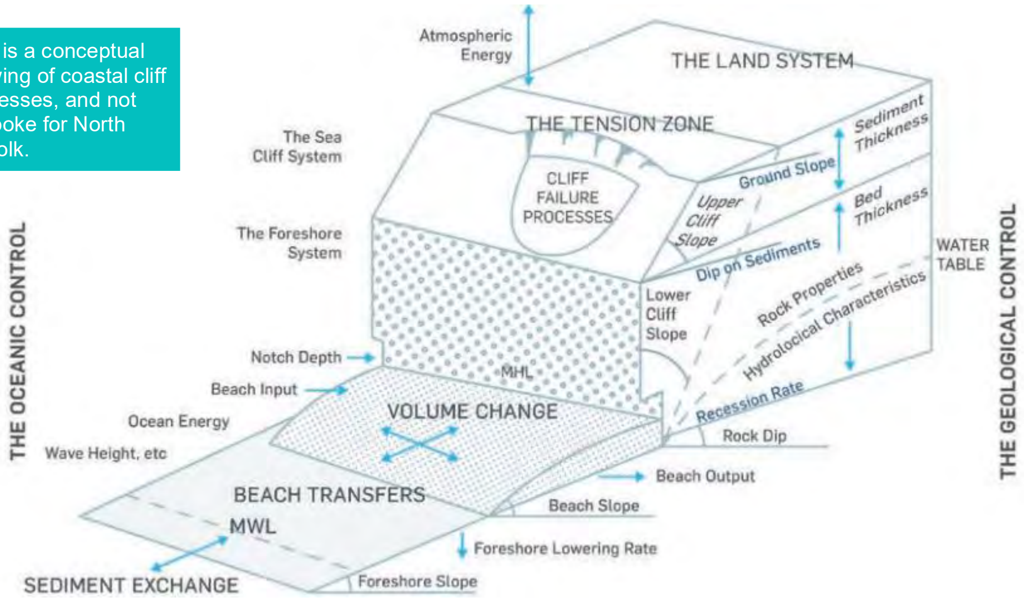
The structurally complex cliffs seen between Sidestrand and Trimingham has a significant influence on the cliff stability and water flow direction.

The large sequence of folding (anticlines and synclines) have created zones for large slides. The syncline folds create topographic low points for water to migrate to lower levels in the cliff sections. High groundwater pressures can cause soils to liquefy and flow.

Geological faults can either generate flow groundwater flow channels (because they contain permeable material) or block water channels (because they contain low permeability material such as smearing of clay soils). Blocked channels will force groundwater to migrate elsewhere or to build up water pressure in that location. The blocking of groundwater channels can happen following landslides, as the channel is cut off by the mass ground movement.

2.4 Cliff slope failure mechanisms

This is a conceptual drawing of coastal cliff processes, and not bespoke for North Norfolk.



Source: Reproduced from Figure 2.6 in CIRIA C810, 2023 (taken from Lee and Brunsden, 2001) Titled "*Process model of forcing functions and system responses around a coastal cliff*".

Slopes are generally formed through erosional, weathering or depositional processes and are affected by both relict and active processes which influence stability.

The stratigraphy of the cliffs between Sidestrand and Trimingham consist of various geological materials that form at different slope angles. Typical stable slope angles for different geological materials are presented in the adjacent table. Generally, if slopes are steeper than the typical slope angles, then they will fail (landslide).

Geological material	Typical slope angles from horizontal (°)
• Glacial till – compacted	30 – 70
• Glacial till – uncompacted	30 – 40
• Sands/gravels	28 – 40
• Clays	8 – 20
• Quick/sensitive clays	0.5 – 8

Soil slopes can have locally high angles due to matric suctions in soils, or weak carbonate cementation common in tills.

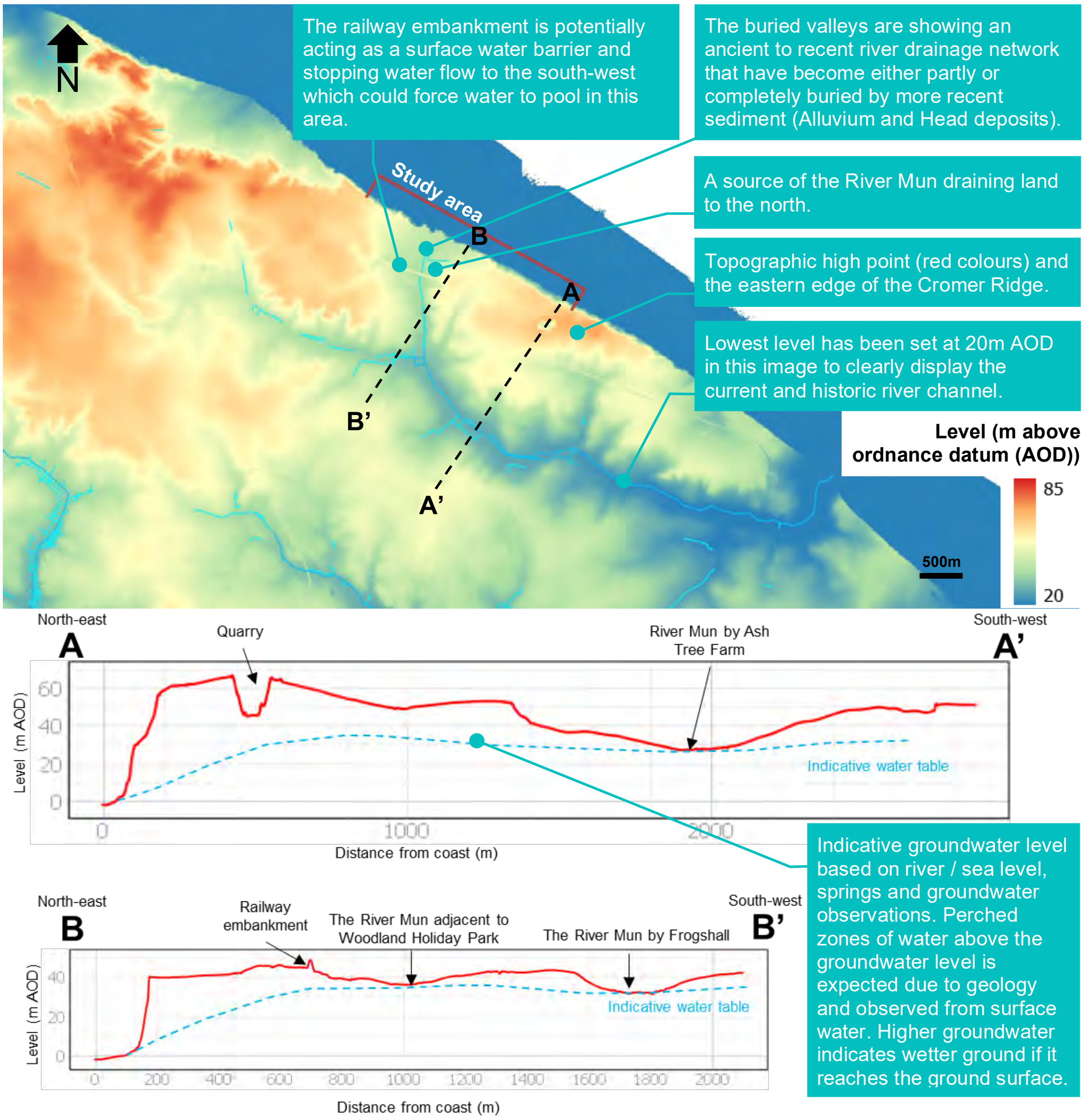
Source: Reproduced from Table 2.3 in CIRIA C810, 2023.

The existing slope angles between Sidestrand and Trimingham vary considerably from different geology and landslides, but generally can be classed as glacial till (compacted and uncompacted). However, most of the cliffs are >50 degrees.

Factors impacting slope conditions (reproduced from CIRIA C810, 2023):

- **External processes on slopes -** Coastal erosion and the removal of material from the base can result in oversteepening leading to changes in stability conditions.
  (Note - the effects of coastal erosion on slope stability is outside of the scope of works for this report.)
- **Internal processes on slopes -** Relates to what happens at a grain-to-grain scale in soils and effects of water flow. Water flow can remove fine material (clay and silt) from soil (suffusion) resulting in a general weakening of the soil slope.
- **Deterioration (weathering) -** The *in-situ* degradation of the minerals that make up the soils. Soils contain significant quantities of minerals prone to alteration or dissolve in water such as mica and glauconite. This can occur from chemical, physical and biological processes.

2.5 Topography and buried valleys



Source: LIDAR Composite Digital Terrain Model (DTM) 1m from 2022 produced by the Environment Agency for tiles TG23ne, TG23nw, TG24se, TG24sw. Watercourse downloaded from OS Open Rivers published by Ordnance Survey.

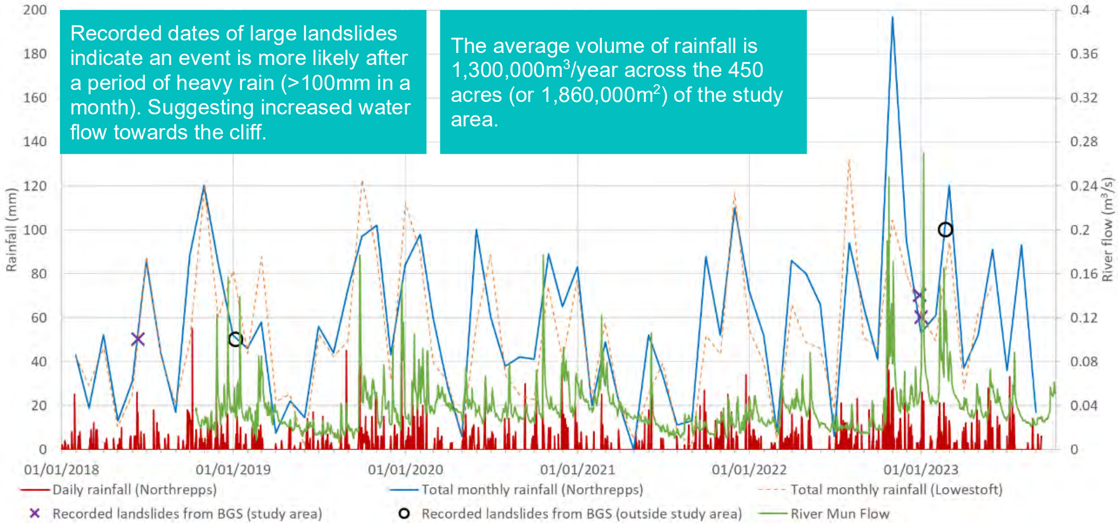
The landscape of North Norfolk has been determined by glaciation, with topographic high points from the Cromer Ridge and low points from ancient river erosion. Both are seen within the study area and dictate groundwater and surface water flow.

Buried valleys are ancient river or subglacial (beneath a glacier) drainage networks that have become either partly or completely buried by more recent sediment (Alluvium and Head deposits). Generally, buried valleys often exhibit little or no surface expression.

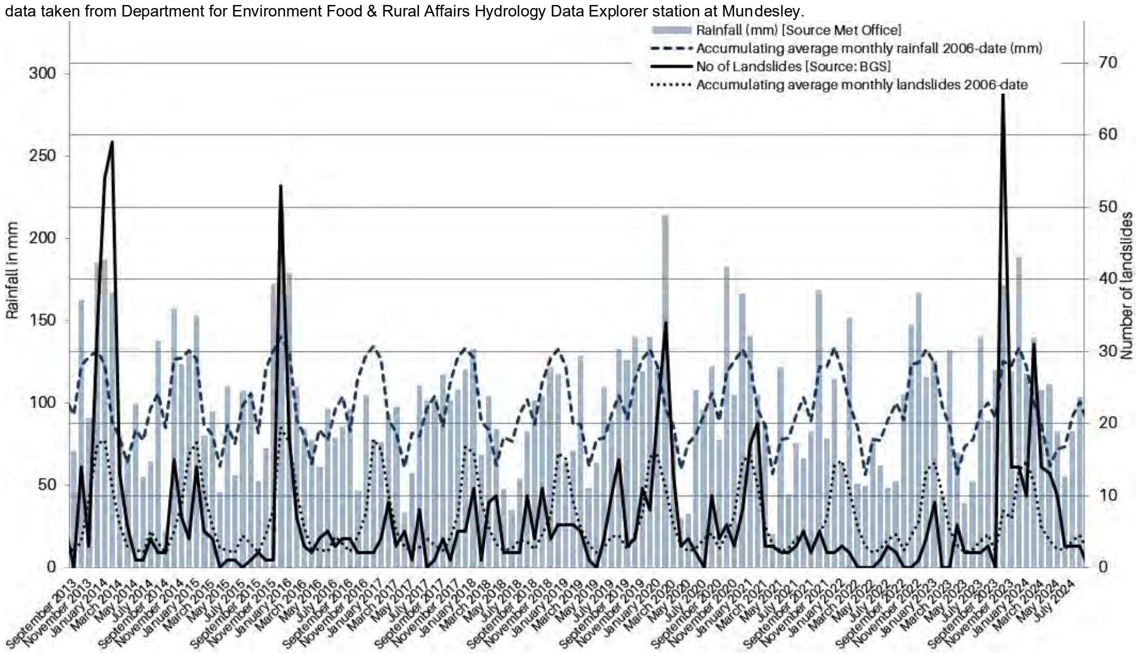
By using satellite imagery (discolouration of agricultural land on Google Earth), geological maps and LIDAR data, buried valleys can be identified. Commonly, the occurrence of buried valleys can have significant and often unexpected implications for groundwater.

The LIDAR data identified the wider catchment for the River Mun (which runs into the North Sea in the village of Mundesley) but also channels near the cliff edge.

2.6 Rainfall



Source: Lowestoft rainfall data downloaded from Met Office. Northrepps rainfall data provided by NNDC with the permission of John Claydon. River Mun flow data taken from Department for Environment Food & Rural Affairs Hydrology Data Explorer station at Mundesley.



Source: Reproduced from the BGS on UK rainfall and landslides. Rainfall sourced from Met Office and landslides sourced from BGS.

Rainfall is a significant factor in triggering landslides.

The processes associated with rainfall (e.g. infiltration, erosion) are considered a trigger of landslides. Generally, when rainfall infiltrates into the ground, this results in an increased pore water pressure in soils which has the effect of reducing the strength of a natural slope and reducing stability (CIRIA C810, 2023).

Short and intense rainfall typically causes shallow landslides and deeper landslides generally require prolonged rainfall events. The graphs above show there is a strong correlation between the average monthly rainfall being >100mm and landslides occurring.

Future predictions indicate that rising air temperatures will make winters wetter (+6% in winter rain by 2050 (UK Climate Risk, 2021)), summers drier, and any seasonal rainfall being heavier.

2.7 Surface water flow

Estimates show around 10% of average rainwater flows down the River Mun. Therefore, understanding where the remaining 90% of rainwater goes is vital for the cliff stability.

Water runoff peak event - a review of the Flood Estimation Handbook (FEH) was undertaken at the study area and this assumes a loamy soil at the surface, which is considered freely draining, allowing for prominent levels of infiltration.

A hydrology calculation was completed through a Revitalised Flood Hydrograph method (ReFH2) for a high level flood estimation for a 1 in 100 year rainfall event (using 1% Annual Exceedance Probability (AEP) and FEH22 rainfall depth-duration-frequency model). The results are shown in the adjacent table.

Model calculation: 1 in 100 year event (FEH22)

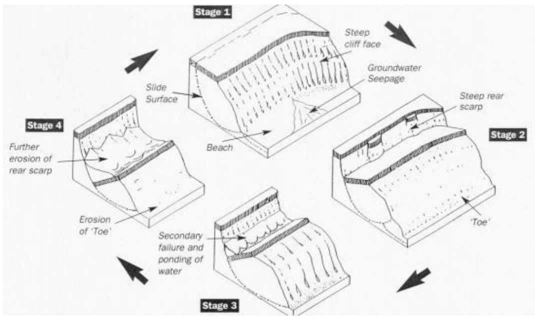
Rainfall – FEH22	63mm (depth)
Total rainfall	40mm (depth)
Peak rainfall	11mm (depth)

Please note that urbanisation and existing sewer network information has been excluded at this stage from the above calculation. A full hydrological study should incorporate this information.

When comparing the (peak rainfall event) total runoff and the total flow results, the proportion of total flow compared to total runoff is around 70%, which suggests there is a high level of infiltration.

Water runoff average - The volume of rain falling on the River Mun catchment area (about 19.4km^2) has been compared to the volume of river water passing the downstream River Mun station per year. The results show only around 10% of rainwater ends up flowing down the river and the rest is lost to the ground (infiltration), evaporation and transpiration. Blocked drains could be contributing to reduced rainfall runoff which will increase infiltration.

Landslide ponds - Sections of the cliff at Trimingham have experienced deep-seated rotational failure which has resulted in back-tilt in the cliff morphology which forms ponds (See Stage 3 in adjacent image). Continuous catchment and seepage from these ponds often leads to the reactivation of landslides.



Source: Reproduced from Peter Frew, Coastal Management Unit NNDC 2009 Document 1 - An Introduction to the North Norfolk Coastal Environment (based on Bromhead, 1979)

Water flow at the base of the cliffs - Numerous water outlets are seen along the beach at the base of the cliffs. The speed of water was slower at cliffs below Trimingham but the outlets towards Sidestrand at the base of the big earth flows was fast flowing. No water flow monitoring data is available.

Rainfall onto houses - Based on an average roof area for a house of 75m^2 and annual rainfall of 843mm in 2023, the volume of water per house in Trimingham would be about 63,000 litres annually.

2.8 Evaporation, interception and transpiration

Evaporation and transpiration from plants (or evapotranspiration) reduces the amount of water that enters the ground.

Evaporation - There are numerous factors that affect the rate of evaporation (water depth, wind speed, humidity, air temperature etc) and the accuracy of monthly evaporation estimates will vary by season, but in general it is estimated to be around 40% of land precipitation (Environment Agency – see Appendix A). The current trend with the UK's climate is showing it is changing, with an increase in winter rainfall and longer dry spells, which could lead to more evaporation in the warmer periods. At this current stage there is not enough data to provide accurate evaporation rates at Trimingham and this would need to be undertaken if a design option was selected that used evaporation.

Interception - The process by which water held on the surface of leaves, branches and trunk during and after rainfall is directly evaporated back to the atmosphere. Often expressed as a proportion of annual precipitation (interception ratio).

Transpiration - Numerous factors affect the transpiration rate (temperature, humidity, light intensity etc). Based off information from Forest Research webpage and the ICE (see Appendix A) it is understood conifers lose 25-45% of annual rainfall through interception, while broadleaved trees lose 10-25%. Conifers also lose 300-350mm of water per year through transpiration, while broadleaved trees lose 300-390mm. Grass loses almost no water through interception, but transpiration rates are higher than for trees.

The below table indicates the typical range of annual evaporation losses (mm) for different land covers receiving 1000mm of annual rainfall.

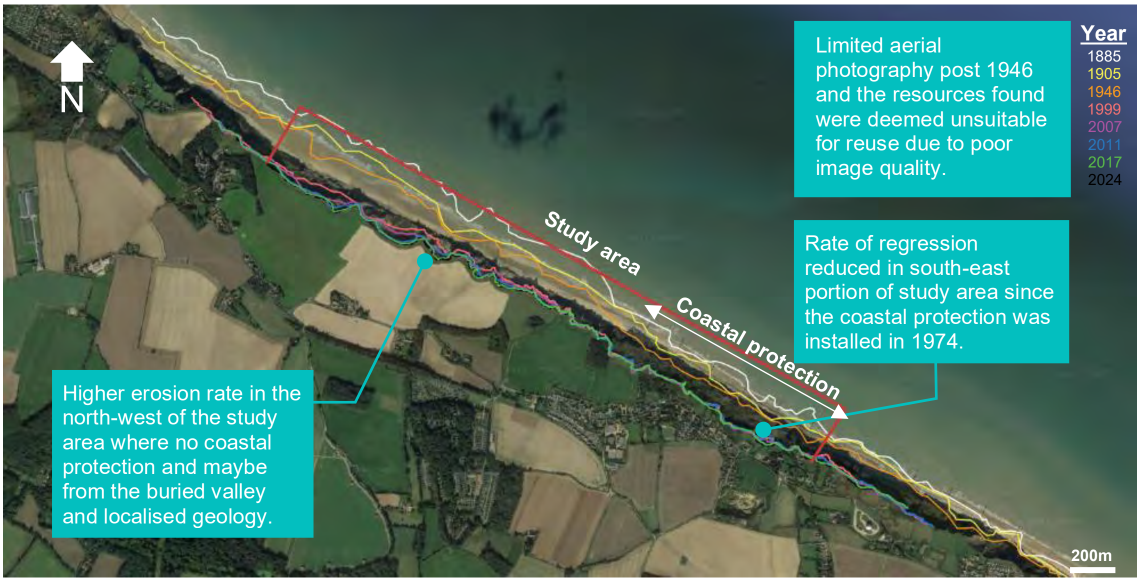
Land cover	Transpiration (mm/year)	Interception (mm/year)	Total evaporation (mm/year)
Conifers	300 - 350	250 - 450	550 - 800
Broadleaves	300 - 390	100 - 250	400 - 640
Grass	400 - 600	-	400 - 600
Heather	200 - 420	160 - 190	360 - 610
Bracken	400 - 600	200	600 - 800
Arable*	370 - 430	-	370 - 430

*assuming no irrigation
Source: Reproduced from 'Water Use by Trees' Forestry Commission Information Note, FCIN065, April 2005.

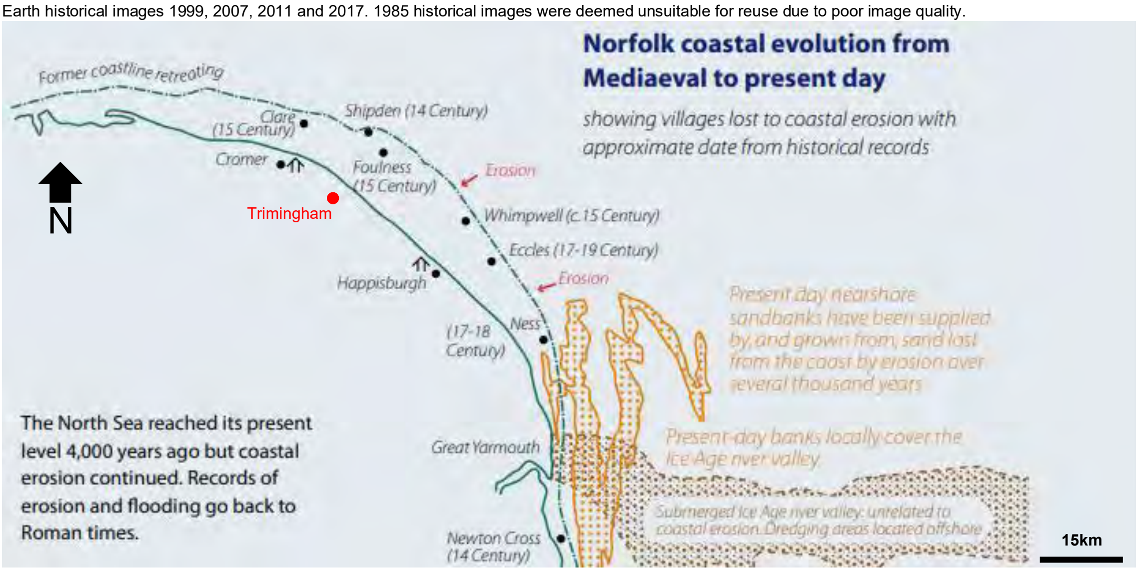
Rainfall and total evaporation are usually expressed as an equivalent depth of water in mm across the land surface. For example, the addition or loss of 1mm of water to/from an area of 1m^2 of ground is equivalent to a total volume of 1 litre. Similarly, 1mm of rainfall or evaporation to/from 1 hectare (ha) is equivalent to 10m^3 or 10,000 litres of water (Nisbet, 2005).

The results indicate that trees and grass are much more effective at reducing infiltration than arable land.

2.9 Cliff regression rates



Source: Aerial image from ESRI ArcGIS World Imagery. Historical coastline taken from maps on National Library of Scotland 1885, 1905 and 1946, and Google Earth historical images 1999, 2007, 2011 and 2017. 1985 historical images were deemed unsuitable for reuse due to poor image quality.



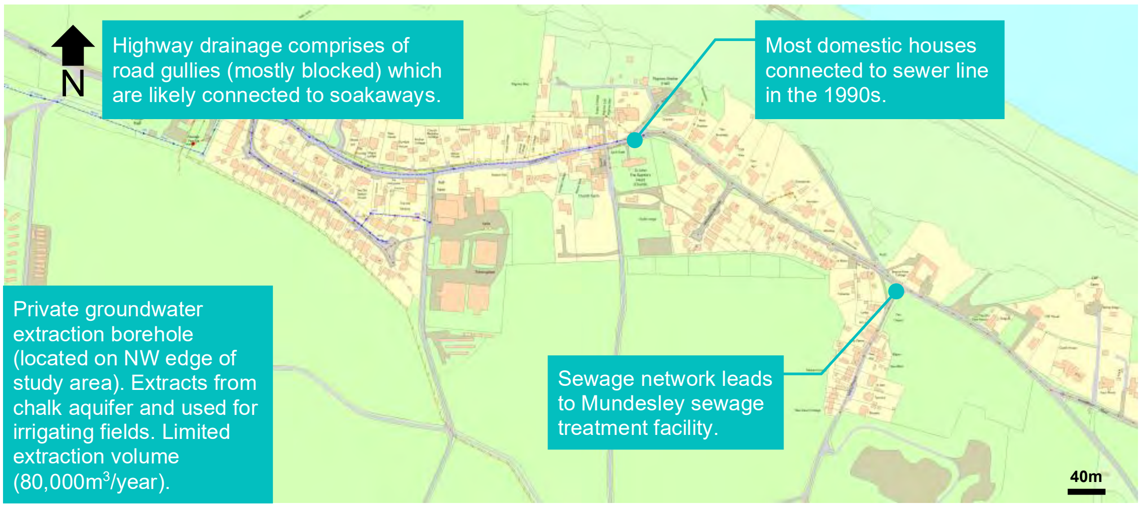
Source: An extract reproduced from Aggregate dredging and the Norfolk coastline by The Crown Estate & British Marine Aggregate Producers Association,

Coastal erosion has been happening for thousands of years in North Norfolk. Rates of recession has been heavily researched but it is still difficult to predict accurately.

The BGS (Hobbs et al., 2008) suggested that the cliffs of North Norfolk have retreated at an average rate of 1 m per year over the past 5000 years. The rate of regression is not uniform across North Norfolk due to numerous factors (wave angle, cliff geology etc) and at Trimingham, cliff regression has been recorded between 0 to 15m per year (Payo et al., 2017). However, as cliff erosion is episodic (from occasional landslides) and not continuous, it is better to express the long-term recession rate at Trimingham as up to 25m every 10 years rather than 2.5m/year.

Recent studies from the BGS have investigated how varying size of the annual beach wedge area contributes to the rate of regression and have found observations that suggest as the beach wedge area increases, the cliff recession rate becomes smaller (López et al., 2020). Further research is ongoing on coastal erosion.

2.10 Water use, sewers and highway drainage



Source: Anglian Water wastewater plan of Trimingham purchased (Oct 2024) through www.digdat.co.uk (reference: 1588778-2). Highway drainage data from Highways, Transport & Waste department of the Norfolk County Council.

The change from private soakaways to a sewer system in the 1990s will have reduced the volume of water entering the ground. However, it is not known whether all the houses are connected to the mains and where the water from road drainage ends up.

Road & Sewers - The Anglian Water utility plans show the western section of Trimingham is drained with gullies that are piped away from the study area. However, there is potential that gullies may not be connected to the public network on the eastern side of Trimingham. This potentially points to the use of soakaways for the publicly owned infrastructure on the eastern side of Trimingham. Unfortunately, Norfolk County Council do not hold any records showing the disposal pipes or outfalls of the roads as these pre-date their transfer of records in 1974.

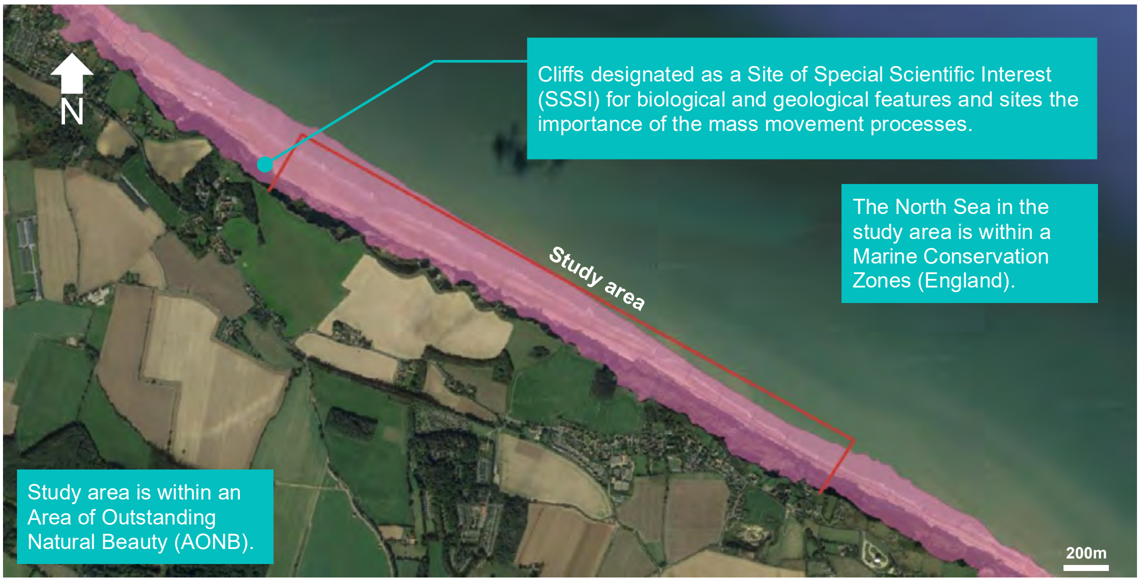
Domestic water/sewage use - The average person uses around 142 litres of water per day (Energy Saving Trust webpage). However, the amount of water used varies depending on the number of people in a household and their personal needs.

The 2021 Census reported a population of 430 in Trimingham, but this will seasonally increase from tourism. The Consumer Council for Water (CCW) report around 114 litres of water per property is lost through leakage every day.

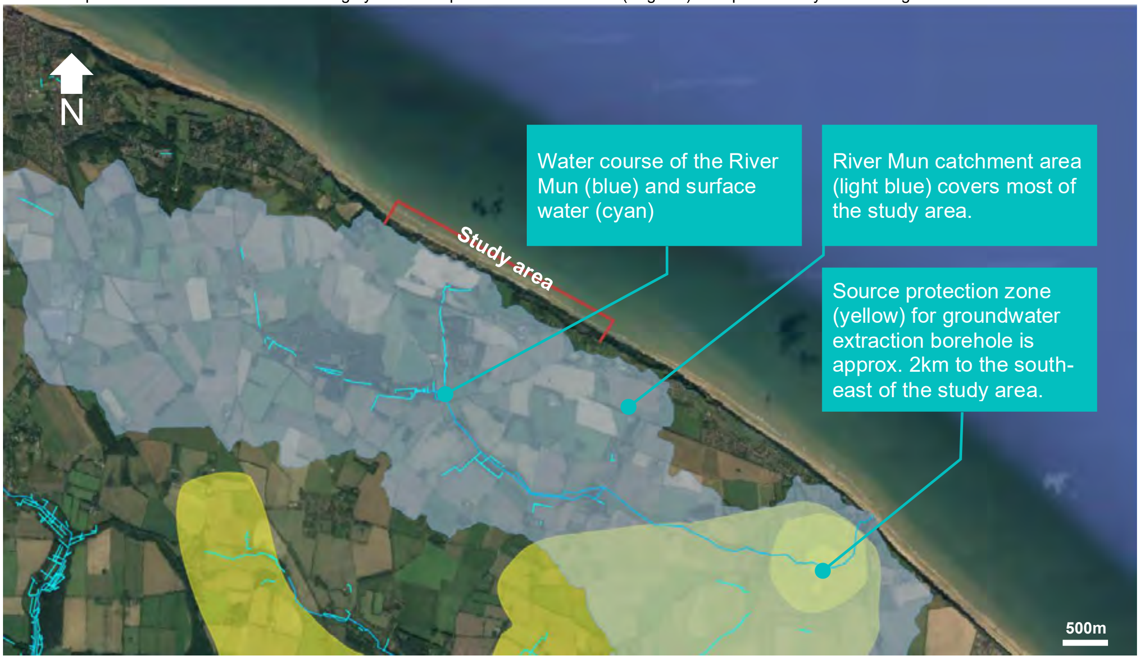
Water extraction - Based on information provided by a local landowner, there is a maximum water extraction licence for agricultural use of 80,000m^3 per year. Around 45,000m^3 has been extracted for irrigating potatoes (high water requirement). Water extracted for irrigation will likely have a minimum to negligible impact on the water entering the cliff.

Unknowns - It is still not clear at this stage if private soakaways for houses are still present and if so, how many there are and the proximity to the cliff edge. This will require further investigation along with the road networks and any potential water leakages.

2.11 Environmental



Source: Map data from ESRI ArcGIS World Imagery. Sites of Special Scientific Interest (England) data published by Natural England.



Source: Map data from ESRI ArcGIS World Imagery. Groundwater source protection zones data and the river catchment for Mun Water Body data both published by Environment Agency. Watercourse and surface water data published by Ordnance Survey.

Understanding the land-based designations is critical for developing potential measures for controlling water flow towards the cliff.

Any potential options will need to consider impact on these environmental designations. With any option, consultation with the respective organisation will need to be undertaken.

3 Relationship between water and cliff failures at Trimingham - Oblique view of conceptual 3D site model

Water ponding and surface runoff

- The corner of Middle Street and Mundesley Road (locally known as "the Pit") often ponds after rainfall. Likely this has been backfilled with cohesive material. However, the connecting drain to remove the water is located higher than the ponded water.
- On the northern side of Mundesley Road at the same location the surface often remains free of ponded water after rainfall.
- Where the former Crown and Anchor pub was located, the ground gently slopes to the cliff. Evidence for surface water flowing over cliff edge and into the cliff failure 'back-tilt' pond on a lower bench.
- The quarry (which is around 20 metres deep) remains dry and free draining. Likely this is located in a thicker section of sand formed from the glacial moraines (Cromer Ridge – see Buried valleys map).
- Initial hydrology calculations suggest, during a heavy rainfall event, around 70% of rainwater infiltrates into the ground.

Cross sections

The two cross sections are presented on the Topography and buried valleys sheet.

Limited impact from properties and roads

- Houses moved from soakaways to private sewerage network in the 1990s. Potentially a few houses on private soakaways. It is believed the community hall is on soakaway system. However, based on normal household water use, this would have a minimal (and only local) impact on cliff stability compared to rainfall and groundwater.
- Road surface drains and gullies have been recorded to be mostly blocked. It is likely that the gullies are connected to soakaways. Again, this is likely to have a minimal (and only local) impact on cliff stability.

Surface water obstructions

Site observations indicate standing water is present in ditches and ponds on the northern side of Cromer Road. The ditches are heavily vegetated and the outlet drain leading under Cromer Road appeared to be blocked, reducing or stopping water flow to the south. Additionally, the railway embankment could be acting as a barrier for surface water migration to the south.

Buried valley and saturated soils

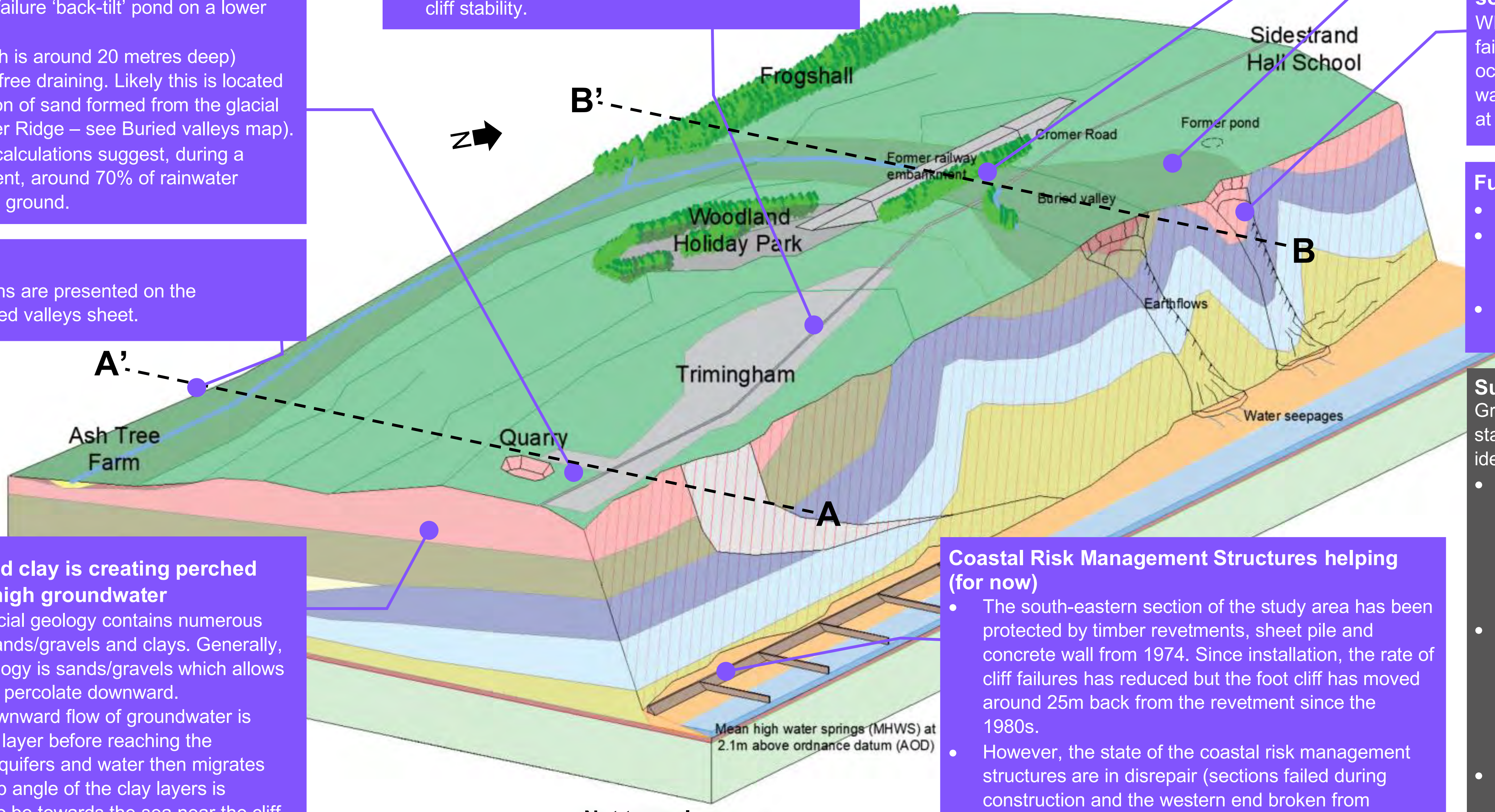
The aerial imagery and Lidar data has identified a buried valley from previous glacial periods. This has been infilled by hillwash and soil creep material known as Head and Alluvium where the River Mun starts. These deposits usually consist of clays and silts and will be saturated and retain water.
The branches of the valley extend across the field towards the cliff and towards Sidestrand school.

Earthflow/Mudflow failures caused by saturated soils

Where the surface geology indicates a buried valley, the failure type is large earthflow and mudflow. Typically, this occurs when clay, silt and fine sand become saturated with water and flow down slope. Water seepages can be seen at the toe of the failures.

Future sea level and rainfall

- Sea level could rise by 3cm to 37cm by 2060.
- Wave height could increase with a predicted 4.30m wave height in a 100 year return period. This could erode more of the slopes base.
- Heavy rain events are predicted to increase and the likelihood of >100mm of monthly rainfall will increase.



Not to scale

Layers of sand and clay is creating perched water zones and high groundwater

The complex Superficial geology contains numerous bands and folds of sands/gravels and clays. Generally, the near surface geology is sands/gravels which allows water to infiltrate and percolate downward. Conceptually, the downward flow of groundwater is intercepted by a clay layer before reaching the underlying bedrock aquifers and water then migrates horizontally. While dip angle of the clay layers is unknown, it is likely to be towards the sea near the cliff edge. This can lead to water flowing out of the cliff, removing finer material which reduces the strength and stability of the cliff.

Coastal Risk Management Structures helping (for now)

- The south-eastern section of the study area has been protected by timber revetments, sheet pile and concrete wall from 1974. Since installation, the rate of cliff failures has reduced but the foot cliff has moved around 25m back from the revetment since the 1980s.
- However, the state of the coastal risk management structures are in disrepair (sections failed during construction and the western end broken from landslides and a storm in 2013) and the current Shoreline Management Plan (SMP6) approach is for no active intervention and for a natural shoreline. This means the protection will not be repaired or replaced.

Summary

Groundwater and surface water has a large impact on the stability of the cliffs. Several sources of water have been identified and presented in this document.

- Water flow from the water channel identified in the north of the study area would normally flow down slope to the south. However, there appears to be barrier to flow by Cromer Road and the former railway embankment, which may cause water to backup and flow to the cliff section causing instability.
- In Trimingham, the interbedded geology may be contributing to water flow towards the cliff. Water will percolate through sands/gravels at the surface and flow down along the top of clay (impermeable) layers. The direction that these layers fall towards is unknown but could be to the cliff.
- There appears to be limited impact from domestic sewers since these were converted to a main sewage network. The blocked road drainage is likely connected to soakaways, but the small catchment area (and therefore small volume of water) will only have a limited and local impact on cliff stability.

4 Glossary

Anticlines	A geological fold in the ground that is arch-shaped and convex upward.
Aquifer	Is a geological formation that stores and provides water by allowing groundwater to flow through it.
AOD	Stands for above ordnance datum and is used to specify heights above mean sea level.
Back-tilt	A feature of a rotational landslide, where the material at the back for rotation is lower than the material at the front of the rotation.
Buried valleys	An ancient river or subglacial (beneath a glacier) drainage network that is now abandoned and has become either partly or completely buried by more recent sediment.
Compacted	A process when material is pressed together over time, reducing the space between the pieces.
Cretaceous Period	A geological period that lasted from 145 to 66 million years ago. This time period is when chalk formed during Earth's warming phase and high sea levels.
Deep-seated	The definition for deeper failure planes. The top of the failure is usually far back from the slope edge and exits the slope beneath or at the base of the slope.
Depositional	The location where sediments are deposited to form soils and rocks.
Evaporation	A process that occurs when a liquid changes into a gas.
Failure plane	Also known as a slip plane, is a surface along which a mass of soil or rock slides.
Farmland consolidation	A process that reorganises land into larger, more efficient farms.
FEH22	Flood Estimation Handbook (FEH). The FEH22 rainfall model is the FEH’s latest UK-wide statistical model for rainfall depth-duration-frequency (DDF) estimation.
Geological fault	The movement of blocks of ground in a different direction relative to each other. Faults are classified by the direction and type of movement that occurs along the fault plane.
Geological formation	A body of rock having a consistent set of physical characteristics that distinguishes it from adjacent bodies of rock, and which occupies a particular position exposed in a geographical region (the stratigraphic column).
Glaciotectonics	Is defined as the glacially induced structural deformation of bedrock or sediment masses due to glacier-ice movement or loading.

Infiltration	The moving of surface water into the soil.
Interbedded	When layers of rock (or soil) alternate with beds of a different lithology (material).
Landslide	The mass movement of material, such as rock, earth or debris, down a slope.
Mass movement	The downhill movement of cliff material under the influence of gravity.
Pore water pressure	The pressure of groundwater held between soil or rocks in the gaps (or 'pores') between soil particles. This can increase when soils become saturated and the pressure increases. When pore water pressure increases the shear strength of the soil reduces.
Post-glacial	The time after a glacial period when large ice sheets melted and the Earth's landscape changed.
Quaternary Period	A geological time period that spans from about 2.6 million years from the present day. The Quaternary Period has seen many cycles of glacial growth and retreat, with ice sheets covering large areas of continents.
Rotational failure	A type of slope failure that occurs when a curved slip surface causes a slope to rotate and move outwards and downwards.
Saturated	A soil that cannot absorb any more water.
Shear strength	A term used in soil mechanics to describe the magnitude of the shear stress that a soil can sustain.
Slope stability	The condition of inclined soil or rock slopes to withstand or undergo movement.
Subsidence	A general term for downward vertical movement of the ground surface.
Suffusion	A process that involves the migration of fine soil particles through the voids between coarse soil particles.
Superficial deposits	Superficial deposits are the youngest geological deposits formed during the most recent period of geological time, the Quaternary.
Synclines	A fold in the ground where the layers of rock curve downward and the younger layers are closer to the centre.
Transpiration	The process by which water is taken up by a plant's roots and evaporated through the stomata, or pores, on the leaves.
Uncompacted	Sediments that are loosely arranged and not compacted or cemented together.
Uplift	An increase in the vertical elevation of the ground surface in response to natural causes (e.g. following removal of glacial ice mass).

Appendix A. References

100120302-0001-P01 - Archive of publicly accessible records - Trimingham

Resources used by Mott MacDonald used during Cliff and Water Assessment project in addition to the resources presented in NNDC's Archive Reference List.

Resources used by Mott MacDonald used during Cliff and Water Assessment project in addition to the resources presented in NNDC's Archive Reference List.

Reference	Title	Author(s)	Tag	Nature	Publication	Date	URL
1	Effect of Soil Strength Degradation on Slope Stability	Chun Li, Yi Cai	Parameters	Paper	International Journal of Design & Nature and Ecodynamics, Vol. 15, No. 4, pp. 483-489	05/06/2020	https://www.iieta.org/download/file/fid/39344
2	Broad Scale Coastal Simulation, New Techniques to understand and manage shorelines in the third Millennium	Robert J. Nicholl, Richard J. Dawson and Sophie A. Day (née Nicholson-Cole)	Stability	Book	Advances in Global Change Research 49 by Springer	26/08/2015	Available on request via the permission of Robert Nicholls
3	Adapting to coastal change in north Norfolk, UK	Peter Frew	Stability	Report	Proceedings of the Institution of Civil Engineers - Maritime Engineering Volume 165 Issue 3, pp. 131-138	25/05/2015	https://www.icevirtuallibrary.com/doi/10.1680/maen.2011.23?mobileUi=0
4	Slope Dynamics Project Report: Norfolk Coast (2000 - 2006)	P.R.N. Hobbs, C.V.L. Pennington, S.G. Pearson, L.D. Jones, C. Foster, J.R. Lee & A. Gibson	Stability	Report	British Geological Survey Research Report, OR/08/018. 166p	2008	BGS Report, single column layout (nerc.ac.uk)
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14	A Method to Extract Measurable Indicators of Coastal Cliff Erosion from Topographical Cliff and Beach Profiles: Application to North Norfolk and Suffolk, East England, UK	Pablo Muñoz López, Andrés Payo, Michael A. Ellis, Francisco Criado-Aldeanueva and Gareth Owen Jenkins	Erosion	Paper	Journal of Marine Science and Engineering	02/01/2020	293753495.pdf (core.ac.uk)
15	Managing Coastal Change: Use of the Defra Coastal Change Fund in North Norfolk	Peter Frew and Alexandra Schofield	Erosion	Report	Innovative Coastal Zone Management: Sustainable Engineering for a Dynamic Coast	07/07/2015	Managing Coastal Change: Use of the Defra Coastal Change Fund in North Norfolk | Innovative Coastal Zone Management: Sustainable Engineering for a Dynamic Coast (icevirtuallibrary.com)
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21	UK and Global extreme events – Heavy rainfall and floods	Met Office	Rainfall	Webpage article	Met Office		UK and Global extreme events – Heavy rainfall and floods - Met Office
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Footnote - publicly available data not included in the records but used during Cliff and Water Assessment project
EA Lidar, rainfall data, tide data, historical maps and CIRIA C810, Natural slopes and landslides – condition, assessment and mitigation, 2023, was used by Mott MacDonald through their licence but this guide is not available for free to the wider public.