As part of Kendal and Upper Kent Catchment Flood Risk Management Scheme we have a package of measures that together will reduce flood risk. This includes the delivery of flood storage areas within the Upper Kent catchment, located upstream of Kendal. Flood storage areas are an important element of the overall scheme and will be designed to limit and control the volume of water flowing through Kendal, Burneside, Staveley and Ings during a flood.

Ground investigations and surveys

The design and construction of flood storage areas is complex. Ground conditions need to be fully understood so that the design team can assess the suitability of the combination of measures required to reduce flood risk as part of the Kendal and Upper Kent Flood Risk Management Scheme.

Site surveys and ground investigations are important. Building on a significant amount of desk-based research, they allow engineers to understand the existing natural processes which are occurring in the study area, for example groundwater flow, surface water flow and fluvial activity. They provide detail on the composition of the ground and what impact that might have on the proposals. By looking to characterise the ground we can better understand the needs of structural designs.

The ground investigations also allow engineers to conduct an array of testing both at the time of the survey, and on samples in the laboratory. This enables a deeper understanding of how the ground will behave, and what the potential impact might be on the proposed flood risk measures.

Kentrigg ground investigations and surveys study area is indicated by the red line.

Site location

Kentrigg is located between two river confluences: the confluence of the River Kent and River Mint.

Ground conditions

The ground conditions described below run from youngest to oldest. Although present across the study area, topsoil is not generally considered as a geotechnical unit, as during construction it would usually be removed.

Alluvium

Alluvium is formed during flood events and represents the youngest geological unit present across the study area. It is generally found at its thickest close to the river, thinning out across the study area. Across Kentrigg Alluvium is found as a thin unit of up to 0.8m deep, overlying the glacial deposits. They have generally been found as a mixture of soft clays and silts, and loose sands and gravels.

Glacial deposits

A glacier is a slowly moving mass or river of ice formed by the accumulation and compaction of crystalline ice, snow, rock, sediment and often liquid water. Glacial deposits underly the alluvium across the whole of the Kentrigg study area. The deposits are formed in two different glacial environments, and therefore are found in two very different and distinct units.

The last glacial maximum occurred 20-30,000 years ago, at which point an extensive ice sheet covered much of Britain and Ireland, in places it was up to 1km thick and found at depths ranging

from 2.5m to 25m. As the glaciers flowed across the country, they deposited sediment trapped either in or below the ice, these deposits are called glacial till. These glacial deposits infilled the topography that existed prior to the glaciation, this includes valleys previously formed by palaeo-rivers (rivers which existed prior to the glaciation). Glacial till is found as a compact reddish-brown clay which can contain gravel, cobbles and even boulders, or a reddish-brown gravel.

Following on from the glacial maximum, the glaciers retreated and melted. This resulted in huge volumes of water flowing across the lake district. These river systems deposited thick layers of sands, gravels and cobbles over the exposed bedrock and glacial till. The deposits left by the rivers are called glaciofluvial deposits and are the thickest unit found across Kentrigg.

Lake deposits also formed at the time of the glacial outwash, leaving behind laminated silts and clays which are found within the glaciofluvial deposits.

Bedrock

There are four types of bedrock deposits encountered across Kentrigg, from oldest to youngest these are; the Bannisdale formation, the Kirkby Moor formation, Pinskey Gill formation and the Marsett formation.

Part of the Kendal group, the Bannisdale and Kirkby Moor formations are up to 1700m thick in some places. These units are ~420million years in age. They were encountered as metamorphosed sandstones, siltstones and mudstones.

The Pinskey Gill and the Marsett formation are part of the Ravenstonedale group. The Pinskey Gill formation is the older of the two, and is found as a mudstone, siltstone, sandstone, conglomerate and breccia. It is only encountered in one borehole on the edge of a buried valley, the interpretation is that the deposits formed within lows in the palaeotopography (where the topography is at its lowest geographical point in the geological past), and subsequently eroded out.

The Marsett formation is found overlying the Pinkesy Gill formation and is encountered as a sandstone, siltstone, conglomerate and a breccia. Similar to the Pinkesy Gill formation, the Marsett Formation is generally found in topographic lows of the underlying Kendal group and is likely to have been eroded away by subsequent glacial and fluvial activity.

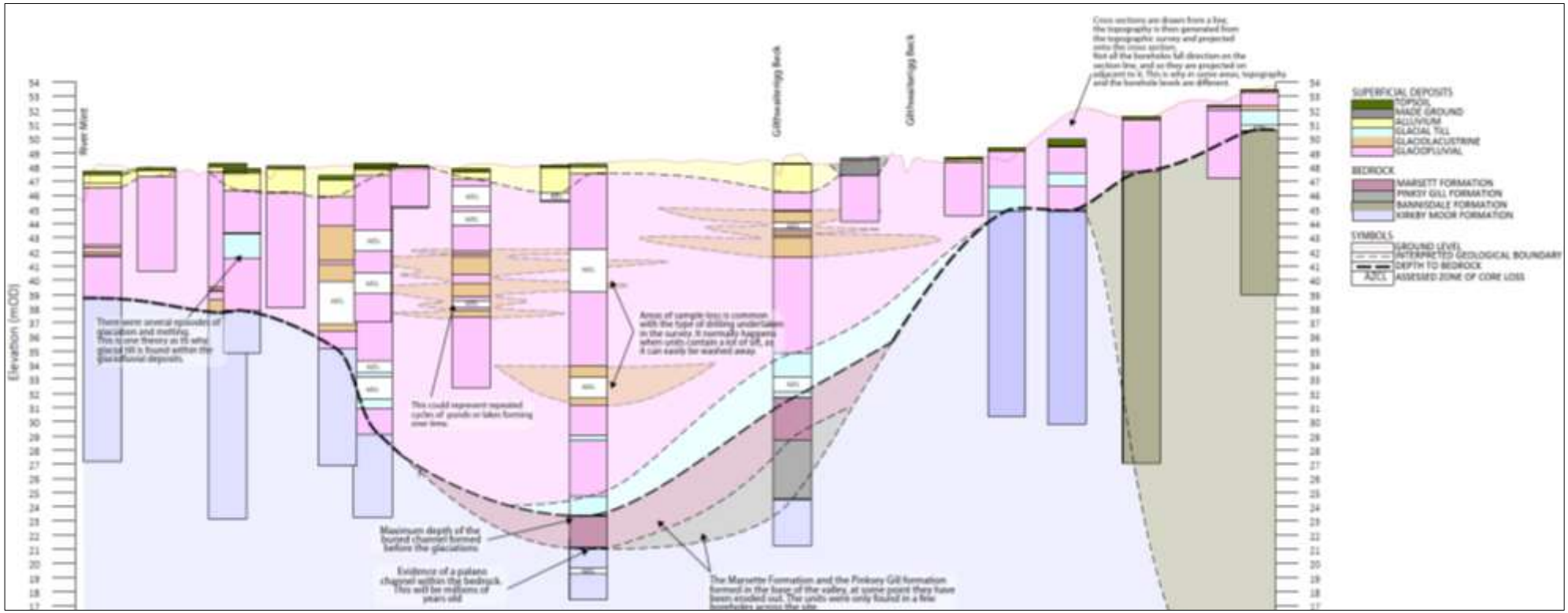
Depth to Bedrock

Depth of bedrock and the nature of the overlying superficial deposits is crucial to the construction of flood defence schemes. The boreholes completed as part of the 2021 ground investigations identified a previously unknown buried channel to the south-east of the study area, approximately 2km wide. Depth to bedrock varies across the study area, ranging from 2.5-25m.

It should be noted that the density of exploratory boreholes improves the confidence and accuracy of the buried valley alignment. Building on the findings of the desk-based work, the ground investigations give us a greater understanding of how the ground conditions and bedrock varies across the study area, at a sufficient density to allow us to make our assessment on the suitability of the site. A smaller number of boreholes were completed within the centre due to the limited need to identify the geological conditions. This is because areas of deeper bedrock may also be present elsewhere.

Indicative cross-section – depth to bedrock

The cross-section illustrates the buried valley is orientated northwest to southeast. Please note the cross-section is indicative and has been produced to illustrate the ground conditions through a cross-section of the buried valley.



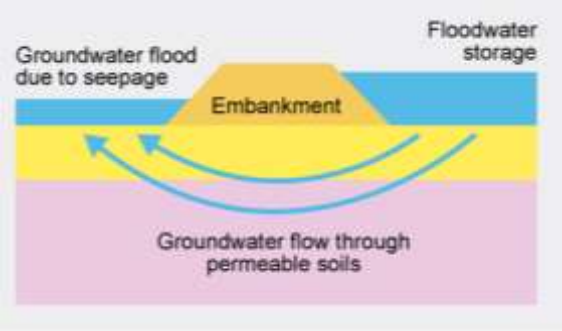
Indicative cross-section

Design and construction of flood storage at Kentrigg

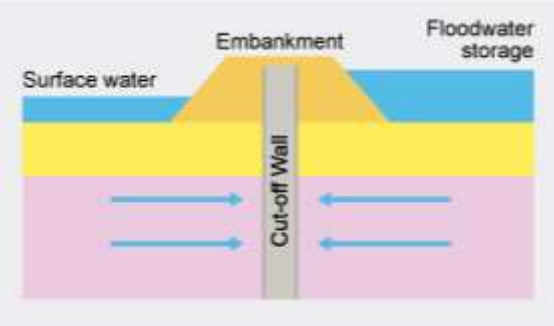
There are two key factors identified through the ground investigation surveys which need to be considered in the design of the flood risk management scheme. The first is the composition of the superficial deposits, the second is the depth to bedrock.

Superficial deposits (glaciofluvial, glacial till and alluvium) are predominantly formed of extremely permeable sand, gravel and cobbles. Permeable ground in the context of flood defences allows a process called seepage to occur. This is when the water level is greater on one side, causing the water to flow through a permeable material to create a flow path beneath the flood defences.

Seepage creates potentially dangerous conditions. It can cause internal erosion of embankments and undermines the integrity of the foundations. To minimise the impact, 'cut-offs' (or barriers) are installed beneath the flood defences to help stop the flow of water.



Seepage

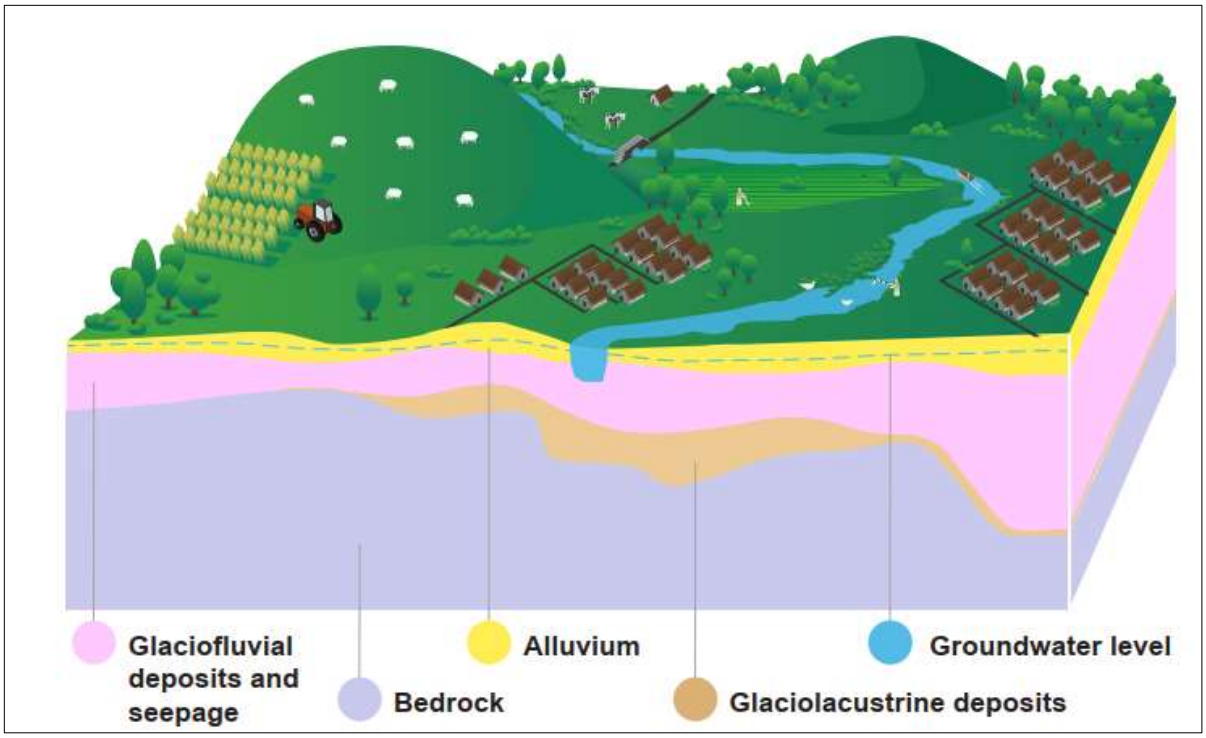


Seepage cut-off

The second issue of depth to bedrock is intrinsically linked to the above. As shown in the contour plan, depth to bedrock ranged from 2.5m-25m. The cut-off in most places needs to extend to an impermeable layer, i.e. some form of clay or bedrock. As Kentrigg does not have any consistent clay layer, this would mean very deep cut-offs would be needed to reach the bedrock.

Kentrigg cross-section - geology findings

This visual illustrates the complexity of the geology within the Kentrigg study area which brings with it additional challenges to the design and construction of flood storage in this area.



Key

River Kent	
Alluvium	deposits formed by rivers. Generally comprises sands, gravels silts and soft clays
Glaciofluvial deposits and seepage	formed from the outwash of glaciers. Generally comprises sands, gravels, cobbles and boulders
Glaciolacustrine deposits	deposited in lakes formed during the retreat of glaciers. Generally comprise soft layers clays and silts
Bedrock	Kirkby Moor Formation – Sandstone

Designing a viable scheme – the Environment Agency's key tests

The suitability of each potential flood risk measure is assessed in more detail against the Environment Agencies key tests: to ensure they are economically viable, technically feasible, environmentally sustainable, socially acceptable, and safe to deliver. Throughout this process multi-criteria analysis is used to evaluate potential risks, opportunities and their likely impact. On completion of the analysis each option is either discounted or progresses to the next stage in the design process.

- **Technical feasibility** – each option is assessed to ensure it is technically achievable, constructable, robust and reliable. This takes into consideration buildability, ongoing maintenance, and health and safety.
- **Environmental sustainability** – potential environmental impact of each option on the natural environment is assessed, together with the appropriateness of any specific land use designations and whether they align with the Environment Agency's strategic environmental goals.
- **Economic viability** – takes into consideration ongoing maintenance, whether the benefits would outweigh the cost, and if the cost is within the scheme's budget. Each option is also analysed to determine any other non-financial benefits they offer to the local community and environment, and/or the potential for this.
- **Social acceptability** – consideration is given to a number of criteria which include landowner constraints, location within designated sites, proximity to recreational areas or public rights of way (PROW), and overall social acceptability. As the scheme progresses we take this out for consultation in order to consider and incorporate feedback from the wider community.
- **Health and safety** – each option is reviewed to check that it can be designed, constructed and maintained safely. Identification of risks and opportunities to the wider community are also assessed and used to inform the design.

This process will ensure we design a scheme that provides a better standard of protection, delivered in the right places, at the time.

Why is Kentrigg not a viable storage area location?

On further investigation the complex geology at Kentrigg suggests that this location is not a viable option to provide flood storage when reviewed against the Environment Agency's key tests. This is because:

- **Technically,** the complex geology of Kentrigg makes the design and construction of flood storage extremely difficult due to the significant depth (varying between 2.5-25m) of bedrock. The bedrock is also highly permeable which means that engineering measures would be required to prevent flow of water through the soil, and under the flood storage embankment (this is called a positive 'cut-off'). The main method used to provide a 'cut-off' is by piling (driving a series of metal piles into the ground until they hit the bedrock to ensure the water cannot seep out).
- **Environmentally,** the extent of engineering works and equipment required to construct such an extensive cut-off would have a harmful impact on the environment and would have a visual impact on the surrounding landscape.

- **Economically,** the cost to insert a deep piling solution of up to 25m, across a distance of 2km would be extremely expensive and therefore is not cost effective.
- **Socially,** the introduction of flood storage at Kentrigg would impact on Carus Green Golf Course and a neighbouring recreation area. When added into the flood modelling assessment this option would also require an increase in the height of linear defences at Burneside. Combined with the other major challenges found at this location, this is not deemed to be acceptable option.
- **Health and safety,** on review the mitigation of health and safety challenges presented at this location outweigh the benefits.