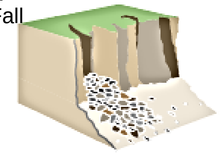
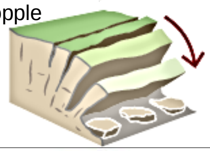
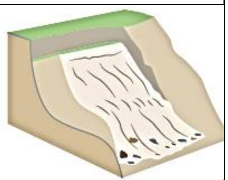
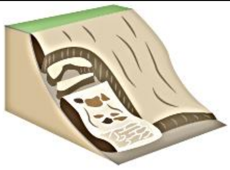
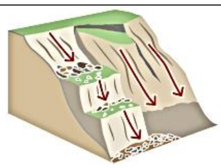
Landslide danger – and climate change
Case studies of how landslides work and the likely effects of climate change

What causes landslides?
Several factors make a landslide more likely to happen, when there is a trigger:

- steepness of slope;
- type of 'rock' – weak rock such as mudstone or tough rock, like limestone
- water – water adds mass, making slopes of more than 45° more likely to slip, and increases pore water pressure which pushes the grains apart – this lowers the strength of the material and reduces friction, making it easier for material to move;
- erosion of the base of the slope;
- human activity altering the slope or the rock strength.

Triggers may include a storm, a flood, coastal erosion an earthquake, an eruption or human activity.

The results can be seen in this diagram:

Falls and topples	Rock breaks off and falls, rolling and bouncing downslope. Topples rotate and falls just drop down. Usually happen very quickly.	Fall  Topple 
Flows	Occur in mud or debris and happen very quickly. Can be wet or dry. Can fail very fast as avalanches.	
Rotational	Sliding of a mass along a roughly circular surface. Steep scarp face at the back, tops of blocks often tilted back.	
Translational	Sliding of a mass along a flat sloping surface. Steep scarp at the back.	
Complex	A mix of landslide types, e.g. starts as a rotation but then has falls at the top and flows further down.	

Use all this information to write the five main factors in the best positions in a copy of this table. There can be more than one factor in each slot:

Importance	Landslide factor
Always important	
Important for most but not so important for falls and topples	
Important only in some places	
Important only at some times	

Adaptation to landslides
Possible ways to adapt to landslide hazards include:

- adapting by not building in the hazard area, or evacuating buildings and moving roads, cables and pipelines and allowing the slope to fail (managed retreat from the area);
- reducing water penetration by improving drainage or planting trees (their transpiration removes water and their roots bind material);
- in areas of rock fall or topple – use rock bolts to bolt unstable rocks to the face; cover weak slopes in mesh or geotextiles; put barriers at the foot to catch rocks; keep people away from the area;
- in actively slipping areas – build a large concrete barrier to secure the toe of the slip;
- in areas where the foot of a slope is being eroded by rivers or the sea – build barriers including walls, gabions, tetrapods or rip rap;
- in areas of earthquake or eruption triggers – avoid building on or near hazardous slopes, if possible.

Landslides and climate change
Climate change impacts such as rising sea levels and in increase in number and power of storms and amounts of rainfall are already being seen in some areas. Add ticks to a copy of this table to show which of the main landslide factors is most likely to be affected by climate change:

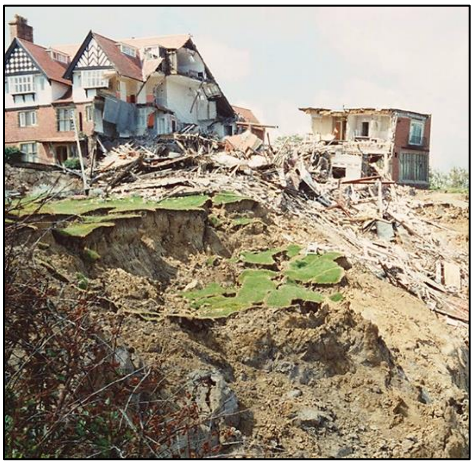
Landslide factor		Tick if likely to be made worse by climate change
slope		
material likely to fail		
pore water pressure		
erosion of slope bases		
trigger	storm	
	earthquake	
	eruption	

The Holbeck landslide
The Holbeck landslide, Scarborough, North Yorkshire, UK, in June 1993, destroyed the Holbeck Hall Hotel, following two months of heavy rainfall.

The Holbeck landslide. (© BGS).

This is the BGS description of the event:
'*The first signs of movement on the cliff were seen six weeks before the main failure, when cracks developed in the tarmac surface of footpaths running across the cliffs. These were filled to stop ingress of water to the cliff, but when the cracks reopened, shortly before the main failure, the council closed the cliff paths below the hotel. At this time a small part of the hotel garden was also observed to have suffered a minor movement.*

There was originally 70 m of garden between the hotel and the cliff edge. At 6 am on the 4 June a guest saw that 55 m of the garden had disappeared. The hotel was evacuated and the landslide continued to develop, culminating in the collapse of the east wing of the hotel by the evening of 5 June.'



Holbeck Hall Hotel after the landslide (© BGS).

- What type of landslide was this?
- Which of the five main landslide factors were important here?
- How could the area be adapted to reduce landslide hazard?
- Is this type of landslide more likely as a result of climate change? Why or why not?

The Pennington Point landslide
These photos capture the event at Pennington Point near Sidmouth, Devon, UK, in February 2009.

Pennington Point landslide (© *Eve Mathews*).

- What type of landslide was this?
- Which of the five main landslide factors were important here?
- How could the area be adapted to reduce landslide hazard?
- Is this type of landslide more likely as a result of climate change? Why or why not?

Your home area
Do you have slopes (including road and rail cuttings or embankments) and rocks and other materials that might fail in your area? If so, your area may be prone to landslides. Many countries produce landslide likelihood maps. Perhaps landslides have happened in your area in the past. If they have, it may mean they will happen again. See an example at: https://www.bgs.ac.uk/geology-projects/landslides/national-landslide-database/ .

Are landslides more likely in your area as a result of climate change?

The back up

Title: Landslide danger – and climate change.

Subtitle: Case studies of how landslides work and the likely effects of climate change.

Topic: An introduction into landsliding processes and the likely impacts of climate change, using two case studies.

Age range of pupils: 14 years upwards

Time needed to complete activity: 45 minutes

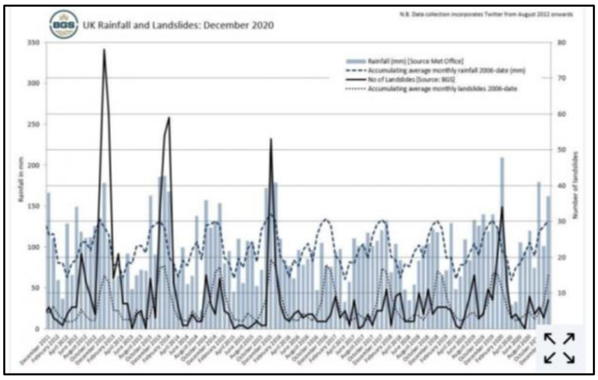
Pupil learning outcomes: Pupils can:
- describe the processes of landsliding;
- explain the main factors in landsliding and their importance in different processes;
- explain the different methods available to reduce landslide hazard;
- discuss which landslide factors might be affected by climate change;
- apply their ideas to case studies.

Context:
This Earthlearningidea explores how landslide risk might be changed by climate change – and what adaptations might be made as a result.

Responses to the first table might be:

Importance	Landslide factor
Always important	• Slopes; steeper stable slopes are possible in more competent (i.e. less likely to deform) materials. • Weak or weakened rocks or other material; the material can be naturally weak, may have weaknesses such as joints or bedding planes, may have weak layers such as clay bands or may have been weakened by weathering.
Important for most but not so important for falls and topples	• Water adding mass and pore water pressure and water lubricating slip planes; the link between rainfall and number of landslides is shown on the BGS graph for the UK below.
Important only in some places	• Erosion of the base of slopes, in sea and river cliffs and human removal of materials in quarries and cuttings.

Important only at some times	• Triggers, including storms (see BGS rainfall/ landslide graph below), earthquakes, eruptions and drought. The 1920 7.8 magnitude Haiyuan earthquake in China triggered 600 landslides, killing more than 100,000 people.



Rainfall (blue) and landslide frequency (black line). (© *BGS).*

Responses to the second table might be:

Landslide factor		Tick if likely to be made worse by climate change
slope		N/A
Material likely to fail		N/A
pore water pressure		increased storms and rainfall
erosion of slope bases		sea level rise increasing coastal erosion; rivers flooding more often due to increase in storms, eroding banks
trigger	storm	increased storms
	earthquake	N/A
	eruption	N/A

Possible responses to the landslide questions:

Questions	Holbeck landslide	Pennington Point landslide
What type of landslide was this?:	The rotated blocks show that this began as a rotational slip but then the material flowed as a mud or debris flow across the beach.	Some blocks fell and others toppled.
Which of the five main landslide factors were important here?:	The slope was steep (see the cliff on the left hand side of the flow and the slumped slope above); the material was weak glacial till, likely to fail; the rainfall of the previous two months, linked to poor cliff top drainage had increased the pore water pressure; the base of the cliff had been eroded by wave activity; there was no other trigger.	The slope was steep; the material is weak – poorly-cemented sandstone and mudstone; there is no evidence that pore water pressure played a part here; the base of the cliff is being steadily eroded by wave action causing regular rock falls; there was no other trigger.
How could the areas be adapted to reduce landslide hazard?	The only option is to demolish the dangerous buildings and leave = managed retreat.	The only option is to stay well away from the cliff base and cliff top.
Is this type of landslide more likely as a result of climate change? Why or Why not?:	Climate change could increase storm rainfall and erosion of the cliff base.	Climate change could increase erosion of the cliff base with rising sea levels, while increased storms are likely to increase weathering, weakening joints and fractures.

Climate change makes landslides more likely in all areas of slopes with materials likely to fail, particularly due to increases in rainfall, bigger storm events, and increased coastal erosion due to storms and sea level rise.

Following up the activity:
Ask the class to find more examples of landslides on the internet and answer the same questions as for the two case studies. For example:
https://www.youtube.com/watch?v=-nx-gYYRu5I , https://www.youtube.com/watch?v=J3amom2Nz_k or https://www.youtube.com/watch?v=5uOiQ__iOmE

Underlying principles:
- Four main types of landslides are commonly recognised, but they can combine together into complex landslides.
- Five main factors affect landslides; they are triggered by a triggering event.
- A range of methods can be used to adapt to landslides, but it is safest not to go there or build there.
- Climate change increases numbers and intensity of storms, making landslides more likely and increasing rainfall events, which is likely to increase pore water pressure and so make landsliding more likely; coastal erosion due to increased storms and sea level rise will also increase landslide likelihood; greater river flooding will erode banks, increasing landslide risk.

Thinking skill development:
Building a picture of landslide processes involves construction and adding the main factors involved enhances the pattern; cognitive conflict is involved when bridging this understanding to real-world examples.

Resource list:
- none

Useful links:
Search for ‘net-zero’ on the Earthlearningidea website to find other Earthlearningideas relating to climate change mitigation or adaptation.

Source: Chris King of the Earthlearningidea Team, with expert guidance from Catherine Pennington of the British Geological Survey.

The ‘How will the ‘net-zero’ target affect your local area?’ series of Earthlearningideas

Topic			**Earthlearningidea title**
Introduction			How will the ‘net-zero’ target affect your local area?
Possible mitigation measures	Use alternative energy sources	Solar	Harnessing the power of the Sun
		Wave	Harnessing the power of waves
		Wind	Farming the wind: through onshore and offshore windfarms
		Tidal	Tidal energy
		Nuclear	Nuclear power - harnessing the energy of the atom
		Nuclear waste	Nuclear waste disposal
		Biofuel	Liquid biofuels: keeping our wheels turning into the future
		‘Blue’ hydrogen	Blue hydrogen: the fuel of the future? *Also:* Hydrogen of many colours
		Geothermal – hot rocks	Deep geothermal power from ‘hot dry rocks’: an option in your area?
		Geothermal – flooded mines	A new use for old coal mines
		Hydro – small scale	Small-scale hydroelectric power schemes
		Heat pumps	Heat from the Earth
		Waste – incineration	Energy from burning waste
		Waste – methane	Energy from buried waste
	Stop fuels releasing greenhouse gases	Carbon capture	Capturing carbon?
	Store energy from sources that give irregular energy supplies	Batteries	Nuclear batteries: the future?
		‘Green’ hydrogen	Green hydrogen used to even out renewable energy supplies? *Also* Hydrogen of many colours
		Hydro – storage	Matching supply and demand using stored water
		Compressed gas	Storing gas underground: What can we store? How can we do it? How will it help?
	Provide raw materials for new technologies	Electric vehicles	Electric vehicles: the way to go?
		Insulation	How do I choose the best insulation?
	Remove carbon form the atmosphere	Enhanced weathering	Speeding up nature to trap carbon dioxide
		Tree planting	Let’s plant some trees
Possible adaptation measures		Coastal flooding	How will rising sea level affect our coastlines?
		Inland flooding	Inland flooding: a Sheffield case study
		Landslides	Landslide danger
		Agriculture	The future for global agriculture