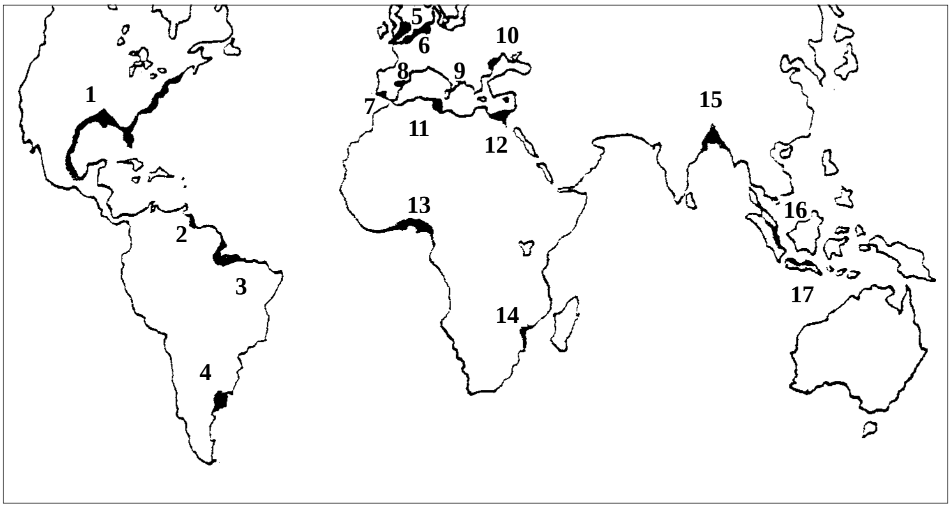
Geo Factsheet

Number 29

Sea Level Change

More than 60% of the world's population lives on or within 60km of coasts. Rising sea levels are therefore high on the political agenda. Sea level change has been a naturally occurring phenomenon for millions of years. Now with the enhanced greenhouse effect playing a contributory role, advancing seas seem set to engulf many of the world's low lying coastal environments (Figure 1). This Factsheet summarises the causes and consequences of rising sea levels.

Fig 1. Areas threatened by rising sea level



1. Gulf and Atlantic coast, Mexico and United States
2. Orinoco delta
3. Amazon delta
4. Gulf of La Plata, Argentina
5. Southern and eastern England
6. Northern Germany, The Netherlands, Belgium and France
7. Guadalquavir delta, Spain
8. Ebro delta, Spain
9. Northern Adriatic from Rimini to Venice and Grado
10. Danube delta, Romania
11. North-east Tunisia
12. Nile delta
13. Nigerian delta and coast
14. Zambezi delta
15. Ganges-Brahmaputra delta
16. Eastern Sumatra
17. Northern Java

Oscillations in sea level occur on local, regional and global scales, variations being either eustatic or isostatic in nature.

Eustatic changes occur where there is an increase or decrease in global water volume.

Isostatic changes are changes in the height of the land relative to the sea. Any uplift or subsidence of a land mass, for example, will result in an apparent change in sea level.

Past sea levels
Prior to the beginning of the first ice age approximately two million years ago, changes in sea level were related to **tectonic** activity. The subsidence and uplift of great land masses, along with sea-floor spreading were responsible for major isostatic changes in sea level.

The ice ages brought **eustatic** change. Sea levels fell as huge volumes of water were transferred to glaciers and ice caps. Subsequent melting would then cause an increase in sea level. Such changes are termed **glacio-eustatic.**

Evidence of past sea levels
Accurate measurements can be made of past sea levels and the rates of sea advance and retreat (marine transgressions and regressions respectively) by observing one or more of the following features.

1. Shoreline deposits such as shells, wood and peat found in marine cores.
2. Exposed rock outcrops containing marine fossils.
3. Vegetated tidal flats above the high water mark.
4. Exposed coral reefs.
5. Marine rocks displaying evidence of wind-borne erosion

Such evidence has made it possible to establish past sea levels as being up to 200m above present during interglacials and 100-150m below present during glacials. Establishing dates of past sea levels is possible through radiocarbon and uranium series dating. The detailed evidence of past sea levels will be the subject of a future Factsheet.

Causes of sea level change
Changes in sea level occur as a result of one of the following:

- Tectonic activity
- Climatic changes
- Human impact

Tectonic activity
The most important aspect of tectonic activity is **isostatic readjustment**. This is the way land naturally rises or subsides according to overlying and underlying forces.

1. Ice
Land in Europe and N. America which was covered by ice subsided during periods of glaciation by up to 300m causing a relative rise in sea level. As the planet subsequently warmed the ice melted and the land would **isostatically rebound**, effectively lowering the sea level. This process is known as **glacio-isostacy**. **Scotland**, **Scandinavia** and much of the **Northern Hemisphere** are currently experiencing sea level drops of up to 1cm/year as they gradually rise and readjust following the last ice age. **Greenland** is still isostatically depressed by approximately 1000m.

2. Uplift
Underlying tectonic forces, including uplift through folding and faulting, can result in isostatic drops in sea level on regional scales. In the **Huon peninsula of Papua New Guinea** tectonic uplift resulted in a stairway of successively-formed coral terraces representing previous sea levels. Mountain building, plate tectonics and spreading ridges may dramatically alter the volume of ocean basins with a resultant change in sea level.

3. Seismic activity
Earthquakes can cause both uplift and depression of land as a result of movement along fault planes. This was observed in **Alaska** in 1964 when an earthquake caused parts of the **Homer spit** to sink by as much as two metres.

Climatic changes

1. Global Temperatures
As temperatures drop globally towards glacial conditions, ice caps and glaciers grow through abstraction and storage of seawater. Such **glacial accretion** results in eustatic drops in sea level. As the planet subsequently warms and swings back towards interglacial periods, the ice melts returning water to the oceans, raising their levels once again.

2. Steric effect
Steric effects refer to the expansion or contraction of water as a result of heat loss or gain. As temperatures increase, ocean volume and therefore sea level increases. It is estimated that 0.4mm/year of the current sea level rise is due to this process.

Human impact

1. River and wetland modification
Heavy sediment loading in deltas can cause compaction and subsidence, which lowers the land surface, a process known as **downwarping**. This effectively causes an increase in sea level and such effects can be seen in parts of many major deltas including the **Mississippi**. Large quantities of sediment are needed to offset such subsidence. Upstream dam building may trap vast quantities of sediment, which effectively increases the risk to coastal areas (see Case Studies).

2. Extraction of resources
Extraction of groundwater, fossil fuels, minerals and other valuable resources from low-lying coastal areas may lead to compaction of land followed by subsidence. This makes these areas more susceptible to erosion and the effects of sea level rise. At **Long Beach** in **southern California** extraction of oil resulted in subsidence of 9.5m in a 50-year period.

3. Emission of greenhouse gases
Human activity has dramatically increased the concentration of greenhouse gases in the troposphere. By delaying the release of long wave radiation, this has increased global temperatures. Sea level will therefore rise as a result of both thermal expansion and ice melt.

Table 1. Mechanisms of sea level change

MECHANISMS	Time Scale (years)	Order of Magnitude
1) Ocean Steric Volume Changes		
Shallow (0-500m)	0.1-100	(0-500m)
Deep (500-4000m)	10-10,000	(500-4000m)
2) Glacial Accretion and Wastage		
Mountain Glaciers	10-100	0.1-1m
Greenland Ice Sheet	100-100,000	0.1-10m
East Antarctic Ice Sheet	1000-100,000	10-100m
West Antarctic Ice Sheet	100-10,000	1-10m
3) Crustal Deformation		
Lithosphere Formation and Subduction	100,000-10^8	1-100m
Glacial Isostatic Rebound	100-10,000	100-10,000
Continental Collision	100,000-10^8	10-100m

The major mechanisms of sea level change and their relative importance is summarised in Table 1.

Consequences

Rising sea levels will lead to:

- Accelerated erosion of cliffs and beaches
- Flooding of urban areas through inundation and storm surges
- Salinisation of agricultural land
- Salinisation of freshwater sources
- Widespread destruction of habitats, especially coastal marshes

The consequences of rising sea levels will be discussed in a future Factsheet on the enhanced greenhouse effect.

Responses

There are two types of response. Firstly, efforts can be made to slow down or stop global temperature increases i.e. to tackle the enhanced greenhouse effect. Much of the developed world has now enforced restrictions on emissions of greenhouse gases. However, the major risk lies within the developing world where many countries are far from reaching their peak emissions and strategies for monitoring output are not established. However, some developed countries - UK, USA and Japan, for example have failed to meet their internationally agreed cuts to carbon dioxide emissions. If the developed countries do not take a lead, it seems unlikely that their developing counterparts will take the problem seriously.

The second approach involves responses to rising sea level (Table 2). These range from long-term, highly expensive and often unsuccessful attempts to protect the land to the increasingly accepted approach of strategic retreat - all of these will be discussed in detail in a future Factsheet.

Table 2. Possible responses to the threat of a rise in sea level

- Boulder ramparts (embankments and dykes) to reduce cliff erosion
- Sea walls *(e.g. **Charleston, S. Carolina**)*
- Artificial raising of land behind walls *(e.g. **Galvaston, Texas**)*
- Groynes
- Construction of undercliff promenades *(e.g. **Christchurch Bay, S. England**)*
- Soft engineering e.g. artificial beaches
- River Barriers *(e.g. **Thames barrier**)*
- Retreat - abandon land to sea *(e.g. **parts of Norfolk coastline**)*
- Rock tetrapods to prevent beach erosion *(e.g. **Niigata, Japan**)*
- Increased investment in coastal defence including embankments, refuge mounds and sea walls
- Introduction of multi-cropping, maximising the use of available land
- Upstream draining of dammed lakes to allow increased sediment supply to deltas
- Artificially raising the land by pumping in sand dredged from the sea floor
- Land reclamation projects/artificial beach emplacement

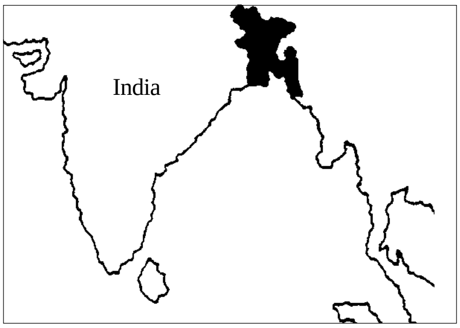
Case study: Bangladesh

The threat from advancing seas in the case of Bangladesh is more serious as the country is very densely populated. Areas particularly at risk are the south-western city of Khulna and the eastern port of Chittagong. The Bengal delta has been created by the Ganges, Brahmaputra and Meghna rivers and represents 80% of the country's 144,000km^2. Although there is little industry along the coast, many fresh water fishing resources are under threat. Fishing generates substantial income and any intrusion of salt water would disrupt the economy. Storm surges are also a threat; cyclonic storms occur frequently and with devastating effects. The storm surge of November 1970 claimed the lives of 250,000 people. Unlike Egypt, the Bengal delta is relatively stable; sediment supply from the rivers appears to be just offsetting natural subsidence and coastal erosion and must continue to do so to protect the threatened coastline. Consequences of predicted sea level rise can be seen in Table 3.

Table 3. Sea level threats to Bangladesh

	1m (2050)	3m (2100)
Bangladesh		
Total sea level rise	0.83m	3.4m
(Global)	(0.13m)	(2.2m)
(Local subsidence)	(0.70m)	(1.2m)
Loss of habitable land	7%	26%
Population	5%	27%
GDP	5%	20%

Bangladesh location



Responses

Relocation of low lying agricultural regions, particularly in Bangladesh, would prove difficult as the country already has 90% of its available land cultivated. Multiple cropping (to increase productivity from any individual piece of land) has been suggested and both embankments and refuge mounds have been constructed to protect heavily populated areas and some of the fishing resources. Inter-governmental investment and risk sharing schemes have proved essential - India, China, Bhutan and Nepal all influence the rivers that terminate in the Bengal delta.

Case Study: Egypt

The Nile delta in Egypt is a low-lying area currently at risk from sea level rise. The population is predominantly centred around the fertile banks of the Nile and along the delta which stretches from Alexandria in the west to the entrance of the Suez Canal in the east. The area is densely populated, heavily cultivated and home to many large industrial centres. Much of the coastal area in this region is threatened by advancing seas and local subsidence, the only protection being a series of sand dunes along the delta's coast, backed up by brackish lakes. The primary cause of the subsidence is insufficient new sediment input to the delta which is needed to compensate for the downwarping effect of the weight of sediments. Upstream entrapment at the Aswan dam has reduced annual sediment input by hundreds of tonnes. At the same time the sea level is rising eustatically. Consequences of predicted sea level rise and subsidence rates can be seen in Table 4.

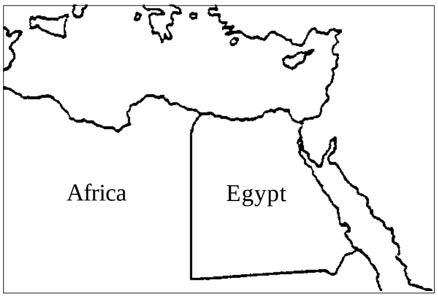
Responses

Coastal defences or land reclamation projects, although costly, are seen as more practical solutions than relocation. The sand dunes and brackish lakes are unlikely to provide protection for any length of time and refuge mounds and embankments may be considered.

Table 4. Sea level threats to Egypt

	1m (2050)	3m (2100)
Egypt		
Total sea level rise	0.78m	3.4m
(Global)	(0.13m)	(2.2m)
(Local subsidence)	(0.65m)	(1.2m)
Loss of habitable land	12%	20%
Population	14%	21%
GDP	14%	20%

Egypt location



Upstream river management should allow for greater sediment transfer to the delta to offset the natural compaction and subsidence.

Exam hint - The strongest candidates will be expected to show that, for a named coastline, they understand how different factors contribute to the overall problem. Isostatic and eustatic factors often interact but many candidates cannot distinguish between the two.

Acknowledgements;

This Geo Factsheet was researched and written by Dominic Light

Geo Press, 10 St Pauls Square, Birmingham, B3 1QU

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