SEA-LEVEL CHANGE – IMPACTS AND CONSEQUENCES

by Keith Metcalfe

SEA LEVELS are rising, and have already risen by about 20 cm over the last 100 years (Figure 1). The annual rate is still relatively slow – the most recent satellites have measured it at approximately 3 mm per year – but this rate of rise seems to be increasing: predictions are that this annual rise may increase to anything up to 8 mm per year over the next century. In 2007, the Intergovernmental Panel on Climate Change (IPCC) forecast a rise of 18 cm to 59 cm by 2100 (Figure 2).

What are the implications?

Sea-level rise of this magnitude may not seem a lot to many of us, but it is a significant worry for the 600 million people who live on coastal plains and in low-lying areas in danger of flooding. Although an increase of just a few centimetres may make little difference to average sea levels, this could mean that an extreme spring high tide or a major storm surge could break through existing coastal defences and flood the area behind.

Vast areas of the world's land masses are only just above sea level and are becoming more and more likely to be inundated by salty water. The consequences would not only be social, with people's lives, homes and belongings at risk from flooding or the collapse of coastal cliffs due to increased erosion; but also economic, with vast amounts of wealth potentially lost as industry and agriculture are submerged; and also environmental, as vast areas of coastal wetlands and estuaries are submerged under salt water.

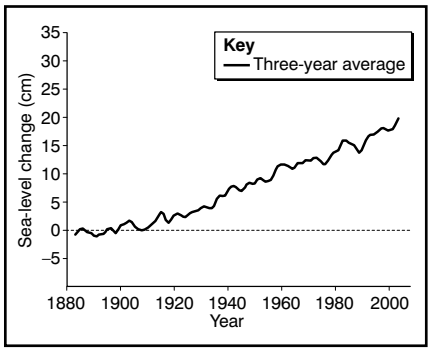

Figure 1: **Sea-level rise since 1880**

Source: Wikipedia (Data prepared by Robert A. Rohde/ Global Warming Art)

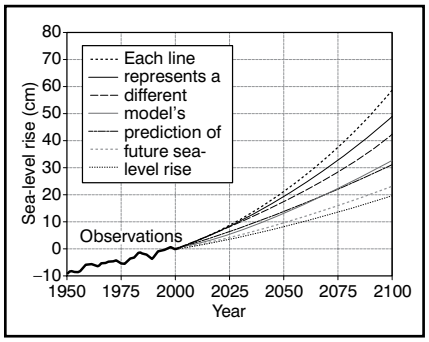

Figure 2: **Some scientific agencies' predictions for sea-level rise over the next 90 years**

Source: Wikipedia (Data prepared by Robert A. Rohde/ Global Warming Art)

What are the causes?

The main cause of this sea-level rise is the increase in average global temperatures over the last 130 years. Humans seem to have played a major role in this, with ever increasing injections of greenhouse gases trapping more heat in the atmosphere. However, sceptics argue that global temperatures have constantly fluctuated without human intervention over millions of years as we have gone through a regular cycle of ice age followed by inter-glacial, followed by ice age.

Higher temperatures across the globe cause sea levels to rise due to two main processes:

1 Thermal expansion: a process in which increases in temperature cause the volume of water to expand. For every 1°C rise in temperature, sea levels rise by between 0.1 and 0.7 metres, depending on the depth of ocean.

2 Melting of ice caps, ice sheets and glaciers: means that less water is stored on land as ice and more is back in the oceans.

So far, thermal expansion has proven to be the more significant of the two processes, as much of the recent melting has only been of ice that is already floating in, and therefore already displacing, large areas of oceans. For example, the Arctic ice sheet is really just a frozen ocean; when it melts sea levels do not rise because the water from the melted ice just fills the gap where the ice was. This is the same as when you have a glass of drink filled with ice cubes: as it warms up the ice cubes melt, but your drink does not overflow.

What other factors cause sea levels to change?

Short-term changes in sea level can be caused by various factors:

- Tides (twice daily), because they are so regular, do not cause a threat by themselves to the coastal environments or to people, who have adapted to them.
- Atmospheric pressure – low pressures experienced during storms can cause sea levels to rise by up to 1.5 metres, and when combined with the strong winds associated with hurricanes can cause storm surges, raising sea levels temporarily by up to 5 metres, which is what happened during Hurricane Katrina in 2005.
- Seasonal variations – during the summer months more ice and snow is melted than is added to continental ice sheets and mountain glaciers, so more water is added to the oceans in that hemisphere.

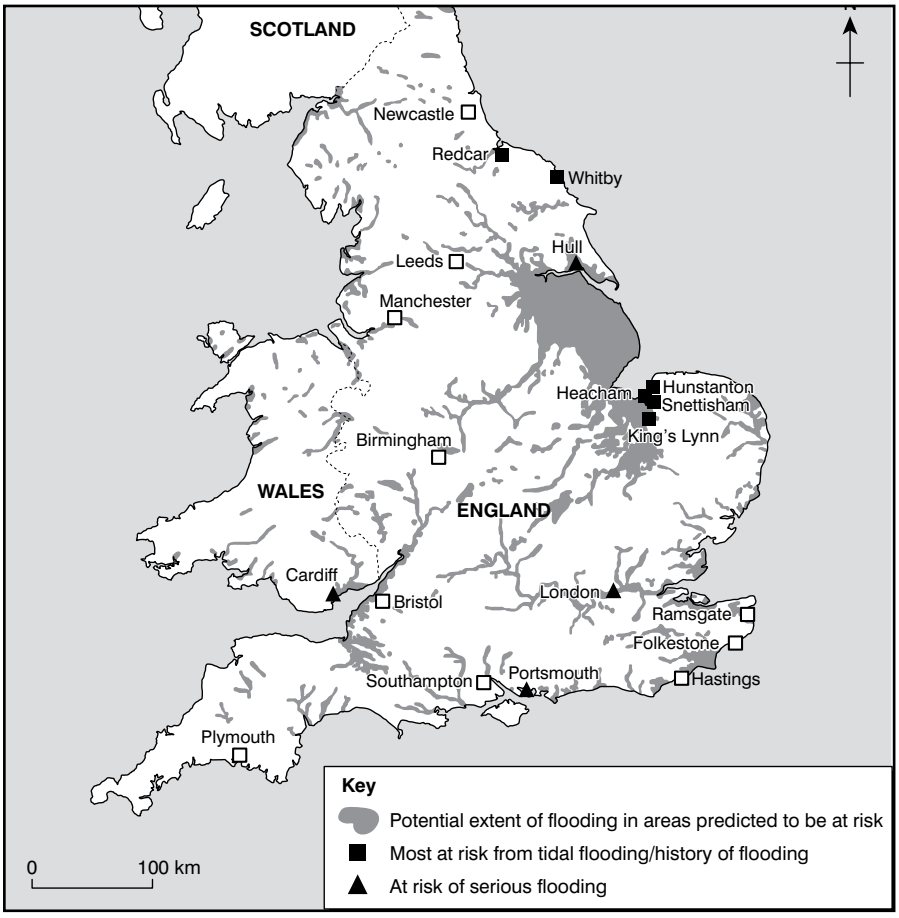

Figure 3: **Areas of England and Wales most likely to flood should sea levels rise**

Sources: Environment Agency

- Tectonics – movements of plates can cause:

  – sea-floor spreading so that ocean basins become larger (sea levels fall) or at subduction plates the ocean floor disappears (sea levels rise)

  – mid-ocean ridges, fold mountains and volcanic islands can all displace water, causing sea levels to rise

  – tilting of the land so that sea levels *seem* to rise or fall.

What about the future?

Although thermal expansion is currently the main cause of sea-level change, if temperatures continue to rise then the ice in the middle of the world's ice sheets may also begin to melt. If this happens then sea levels could rise:

- by 7.2 metres if the Greenland ice sheet melts
- by a further 61 metres if the Arctic ice sheet disappears.

There is also a considerable time lag between temperature change and sea-level responses. This is thought to be between 10 years for shallow areas of water and up to 1,000 years for deeper oceans – that is, sea levels today may have been caused by the levels of carbon dioxide in the atmosphere at least 10 years ago.

Evidence from 3 million to 3.5 million years ago, when carbon dioxide levels were similar to now, suggests that, if the link between carbon dioxide and sea levels is a strong one, sea levels could still rise by up to 25 metres!

The long-term future of the world's sea levels largely depends on people and our willingness or ability to restrict global warming.

Solving the problems?

The most obvious way to solve the problem of future sea-level rise is to stop global warming. The Copenhagen Climate Conference in 2009 set a target to prevent global temperatures rising by more than 2˚C above pre-industrial levels – but, as we know, even if this is achieved sea levels may still continue to rise for several years.

One of the other aims of the Copenhagen agreement was to predict the likely consequences and the ways to reduce the vulnerability of areas at risk. The main options to reduce the risks are:

- **Coastal management:** hard engineering techniques such as sea walls and tidal barriers like the Thames Barrier can be used, as well as soft engineering techniques to protect coastal towns and cities to some degree against sea-level rise.
- **Hazard mapping:** with projection models and the use of GIS (Geographical Information Systems), maps can be produced that predict which areas will be at risk with each extra centimetre of sea-level rise (Figure 3).
- **Building and planning regulations:** planning offices can block developments in high-risk areas or can insist that buildings and infrastructure are built several metres above sea level, as they have done for the new developments in Thames Gateway in London, where the ground floor has been left empty.
- **Monitoring and prediction:** computer modelling can constantly assess a large number of factors to produce accurate up-to-the-minute predictions of potential coastal floods.

In some areas it is hoped that natural processes will respond in such a way that areas are still protected. In areas where the land has been created by deposition, such as the massive delta that makes up Bangladesh or the salt marshes of East Anglia, just as areas flood, the extra layers of deposition and plant growth may be able to keep pace with sea-level rise, keeping the land above sea level – just.

Case Study

Maldives

The present situation

The Maldives is a tiny country located in the Indian Ocean off the south-west coast of India. It is made up of 1,200 islands, 80% of which are no more than 1 metre above sea level (Figure 4). Therefore if sea levels continue

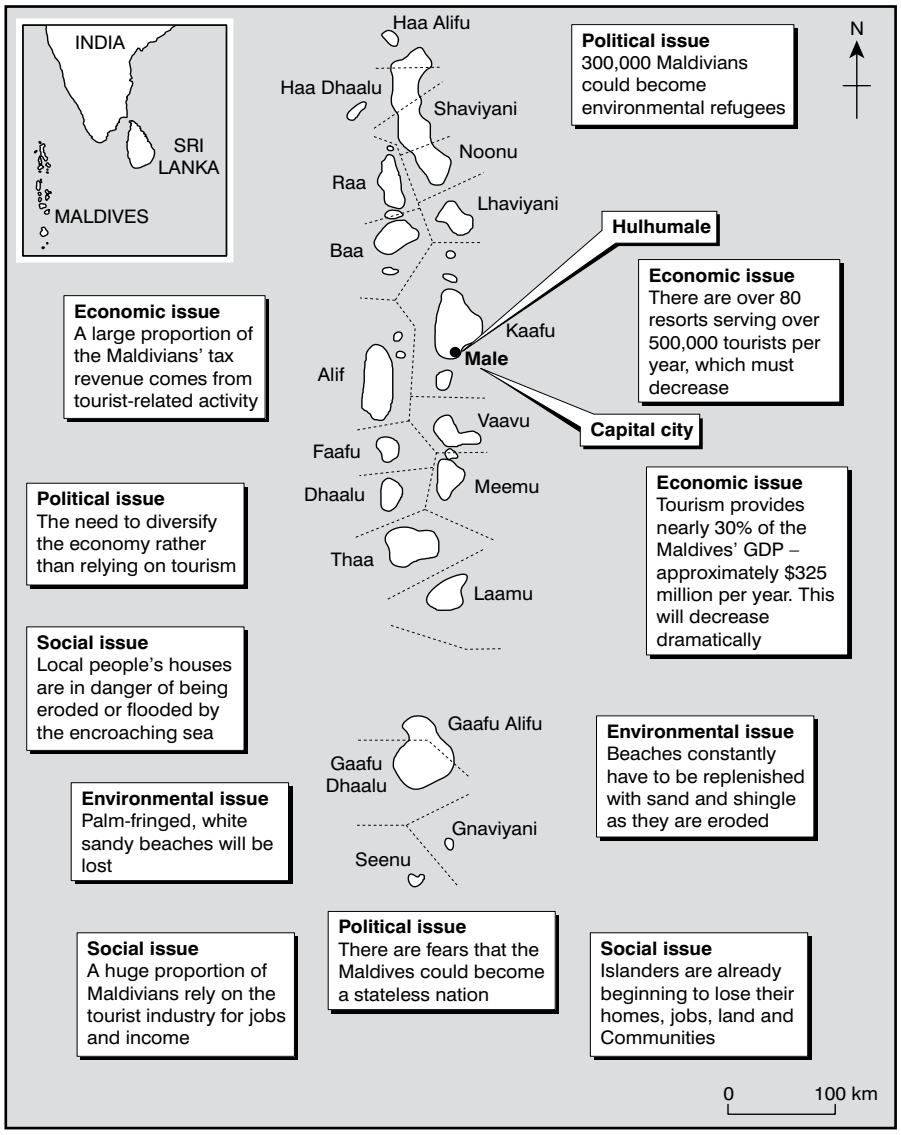

Figure 4: **Issues that will be faced by the Maldives if sea levels continue to rise**

to rise at 3 mm per year, within 300 years many of them will be under water, along with their beautiful beaches, elegant resorts and the homes of the country's 360,000 people. They stand to lose everything – literally.

Solutions

The Maldives were the first to sign up to the Kyoto Protocol and made sure that their plight was in the headlines before the Copenhagen round of talks, with ministers holding an underwater meeting as a publicity stunt (Figure 5).

In 2009 the Maldivian president announced that the Maldives hoped to become the world's first carbon neutral country, meeting all its energy needs from renewable sources. This could cost up to US$1 billion to implement – a vast amount for a country of this size – but it is hoped that this might prompt the rest of the world to sit up and take action.

More practical solutions that are being explored:

- Building higher artificial islands – the island of Hulumale has been enlarged by reclaiming land from the sea, and raised using sand, concrete and shingle. The aim is eventually for seven islands like Hulumale, each up to 3 metres high, that will provide enough space for the entire Maldivian population (Figure 6). Male (the capital city) and the neighbouring international airport have already been enlarged and raised in this way, along with strong sea walls and breakwaters built around their coasts.
- Raising money from tourism to create a 'sovereign wealth fund' with which to buy land in India or Sri Lanka where Maldivians could rebuild their lives should the worst happen.

Figure 5: **World's first ever underwater cabinet meeting concludes in the Maldives**

Source: www.presidencymaldives.gov.mv 17-10-2009

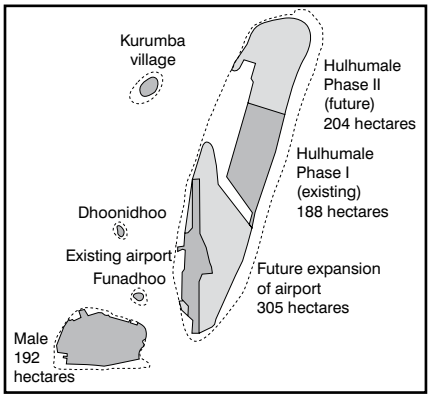

Figure 6: **Male and the new island of Hulhumale**

Source: hulhumalé.com

- Coastal management – offshore breakwaters and beach nourishment have to be used more and more as beaches are slowly eroded.
- Encouraging growth of the natural coral reefs that already offer a significant natural defence system – a much more sustainable and environmentally friendly method than building artificial sea walls.

The Green Resort Award is presented each year by the President to the resort most clearly aiming at 'encouraging tourist resorts to adopt and embed green policies in their development and operation' (Ministry of Tourism Arts and Culture for the Republic of the Maldives).

The Maldivian government is worried that it could become a nation without a land – and this is not something they are just going to allow to happen.

Activities

1 Look at Figure 1.
(a) Describe what the graph shows about average sea levels since 1880.
(b) Explain why it is sensible to look at a three-year average of sea levels rather than at every individual reading.

2 Look at Figure 2.
(a) Calculate the difference between the highest and lowest sea-level rise predictions for 2100.
(b) Suggest reasons why most of these predictions show a curved line that gets steeper throughout the century.

3 Approximately 600 million people live in low-lying areas that are potentially at risk from coastal flooding, should sea levels rise as predicted.
(a) From your own knowledge, or using Figure 3, list two cities in the UK at risk from serious flooding.
(b) From your own knowledge, or using Figure 3, describe two other areas of the UK that are likely to flood.
(c) Name one other country or region from around the world that you suspect is in danger of flooding.
(d) Explain why tides do not usually pose a coastal flooding threat.

4 Find out about another country or area, other than the Maldives, that is at risk from sea-level rise. Produce a similar map to Figure 4, highlighting the main economic, social, political and environmental issues should sea levels continue to rise.

5 Study Figure 6.
(a) Describe how the islands of Male, Hulhumale, and the existing airport, differ from the other islands such as Dhoonidhoo, Funadhoo and Kurumba Village.
(b) What attractions draw tourists to the resorts found in the Maldives?
(c) New islands such as Hulhumale have been designed first and foremost to give local people somewhere to live.
Do some further research on the new island of Hulhumale and suggest the implications (both positive and negative) for tourism on these new islands.

6 Look at Figure 7.
(a) Write an article for a London newspaper describing the possible implications should current flood management schemes prove to be inadequate in the future.
(b) The Thames Barrier is being used more than was ever expected, and is going to have to be replaced by the end of the century. Suggest what the main considerations will be when the decision makers meet to discuss its replacement.

7 Go to the Environment Agency's website: www.environment-agency.gov.uk/homeandleisure/floods/default.aspx
(a) Enter your postcode to see if your area is at risk from flooding.
(b) Read the section 'How can I be prepared?'. What do you think is the most important action that you should take from the 'flood plan'?
(c) If you do live in an area that is at risk from flooding, read through the section on: 'What should I do when it floods?'

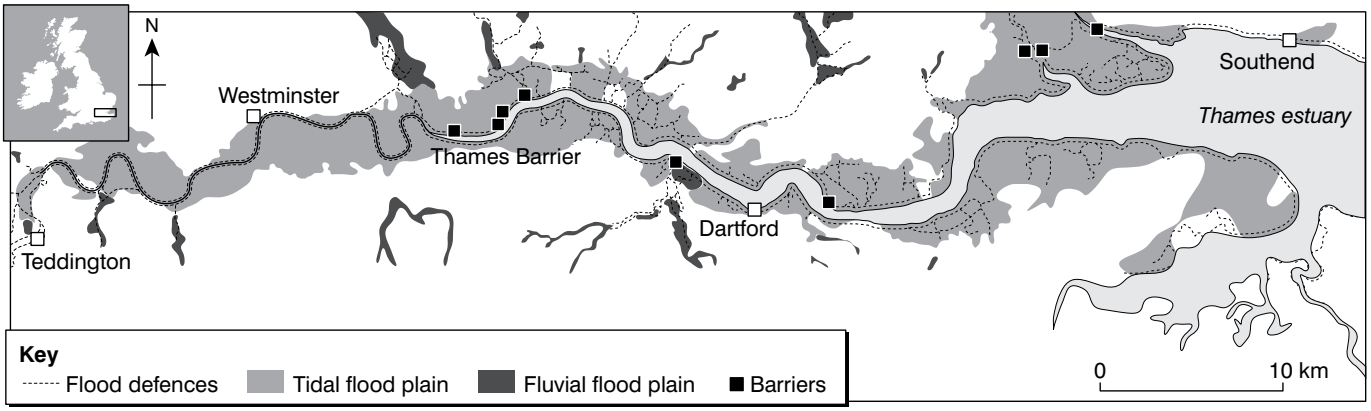

Figure 7: **The Thames flood plain and present-day coastal and river management structures**

Source: Environment Agency