SEA LEVEL RISE

What is the Sea Level Rise and what can we expect?

The main causes of Sea Level Rise (relative to the land surface) are:

- melting of ice (polar ice caps, land ice, permafrost, glaciers, etc);
- increased fresh water input by rivers;
- decrease of the fluid density due to increase of temperature (volume expansion, about 0.02 m expansion for a layer of 100 m due to an increase of temperature of 1 degree Celsius);
- sinking of the land surface.

Sea levels varied over some 150 m during the last 4 glacial periods, see Figures 1 and 2. Sea level was about 10 to 15 m higher than present at about 130 000 years ago.
Some 15,000 to 20,000 years ago during the last glacial period the sea level was about 120 to 140 m lower than at present, see Figures 1 and 2.
Initially, the sea level rise was about 8 mm per year until approx. 7,000 years ago when it slowed down to about 2 mm per year until present.

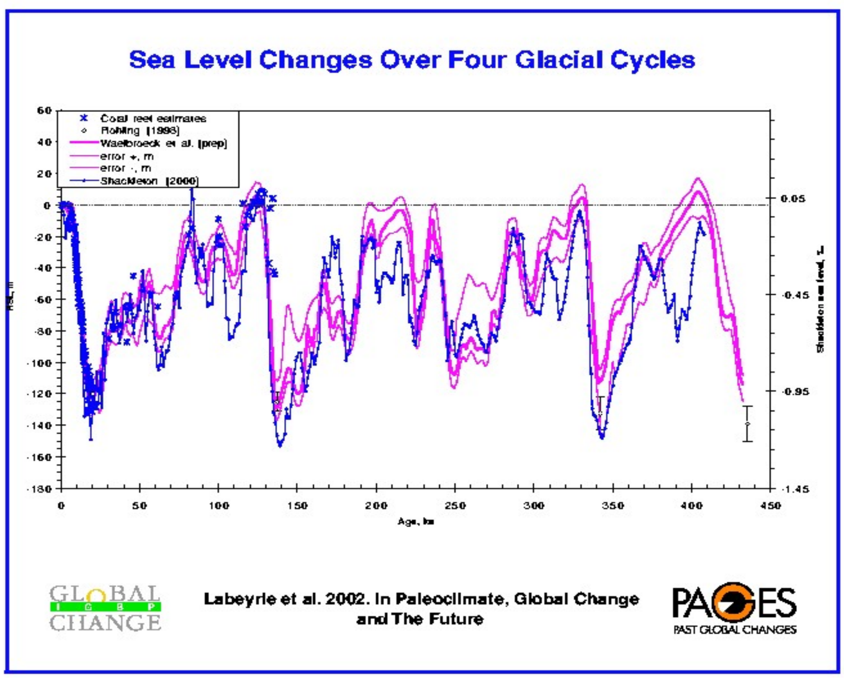

Figure 1 *Sea level variations on geological time scale (450,000 years); www.geo.uu.nl/fg/paleogeopgraphy*

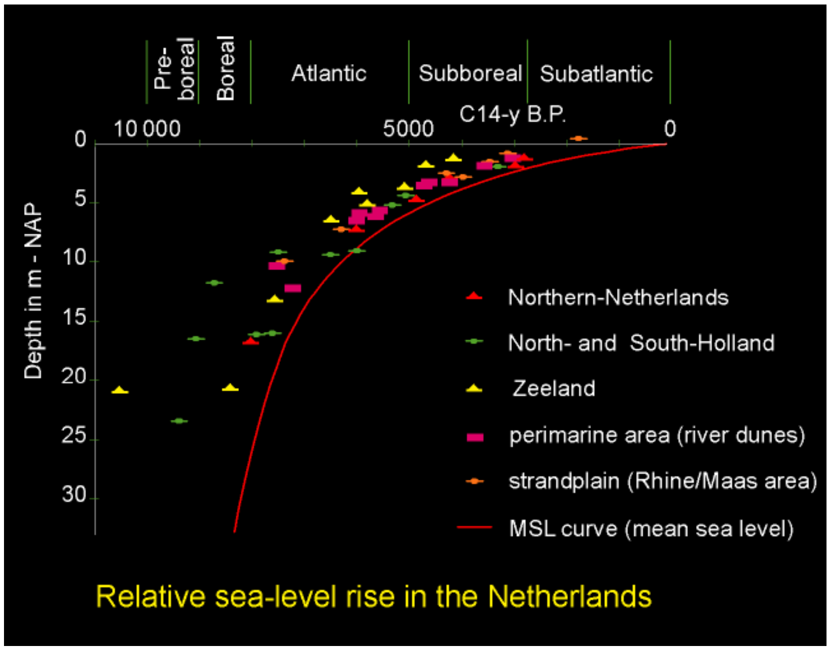

Figure 2 *Sea level rise during last 10,000 years; www.geo.uu.nl/fg/paleogeopgraphy*

Recent long term data (last 300 years) of Mean Sea Level based on tidal gauges are available for several stations in Europe (Amsterdam, Liverpool, Stockholm); see Figure 3 (IPCC 2001 report).
Analysis of these records shows a Sea Level Rise of about 0.2 m for the period between 1900 and 2000. Effects of accelerated Sea Level Rise during the last decade (1990-2000) of the previous century cannot be detected.

At present (2013) the sea level rise for the countries along the North Sea still is about 2 mm per year.

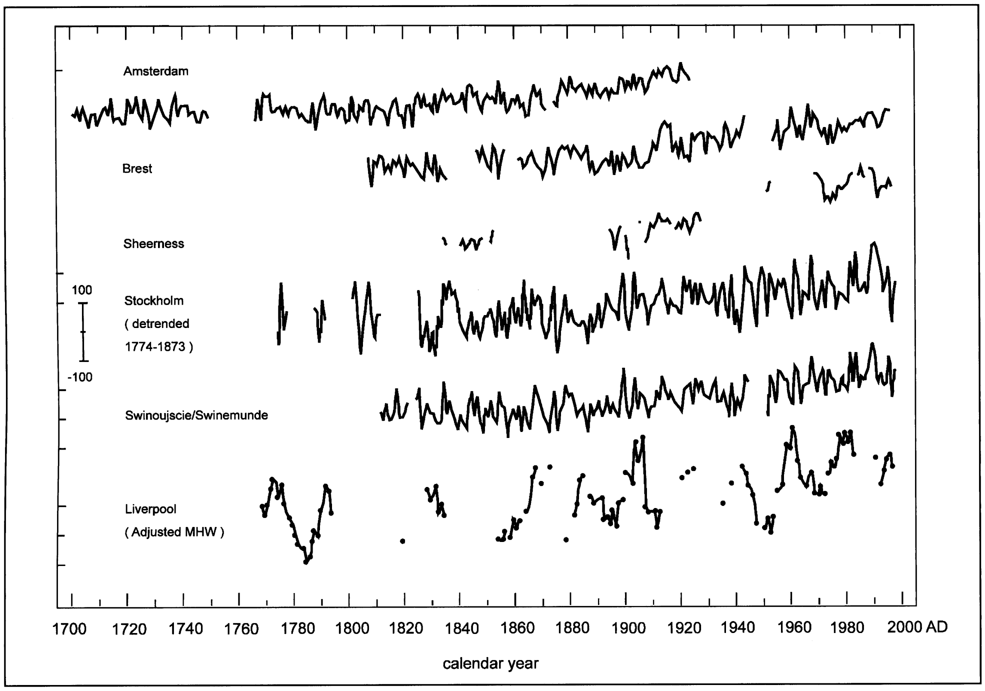

Figure 1. Time series of relative sea level for the past 300 years from Northern Europe. The scale bar indicates ±100 millimeters. Source: IPCC, 2001.

Figure 3 ***Sea Level Rise in Europe between 1700 and 2000 (IPCC, 2001)***

At present the total amount of ice accumulated in Ant-Arctica, Greenland and the main glaciers on earth (Alaska, Iceland, Scandinavia, etc) is about **30 millions cubic kilometers** (KMNI, The Netherlands, see www.knmi.nl). The total volume of Greenland land ice is about 2.5 miljoen cubic kilometers. Recent publications (Nature 2006) show an annual melting rate of Greenland ice of 250 cubic kiliometers per year. At this rate it will take about 10,000 years for complete melting of the Greenland land ice.

Further melting of this reservoir of ice results in a Sea Level Rise of about:

- glaciers: 0.5 m (time scale of 0 to 100 years),
- Greenland: 5 m (time scale of 100 to 1000 years),
- Ant-Artica: 50 m (time scale >> 1000 years).

The expected Sea Level Rise for this century (up to 2100) is between 0.2 and 1.0 m (IPCC report 2001), mainly due to expansion of the water volume and melting of the glaciers. Extrapolation of present values (2013) yields 0.2 m in 2100.

What can we do about Sea Level Rise?

Accelerated Sea Level Rise on short term time scale due to human interference (global warming) is a direct threat to low-lying countries bordering the seas and oceans.

Mitigating measures are (see also Figure 4):

- construction of (new) higher and wider barriers, dunes and dikes along the coast and lower river sections;
- elevation of existing land surface by large-scale sand suppletion to outraise Sea Level Rise;
- evacuation of the low-lying areas.

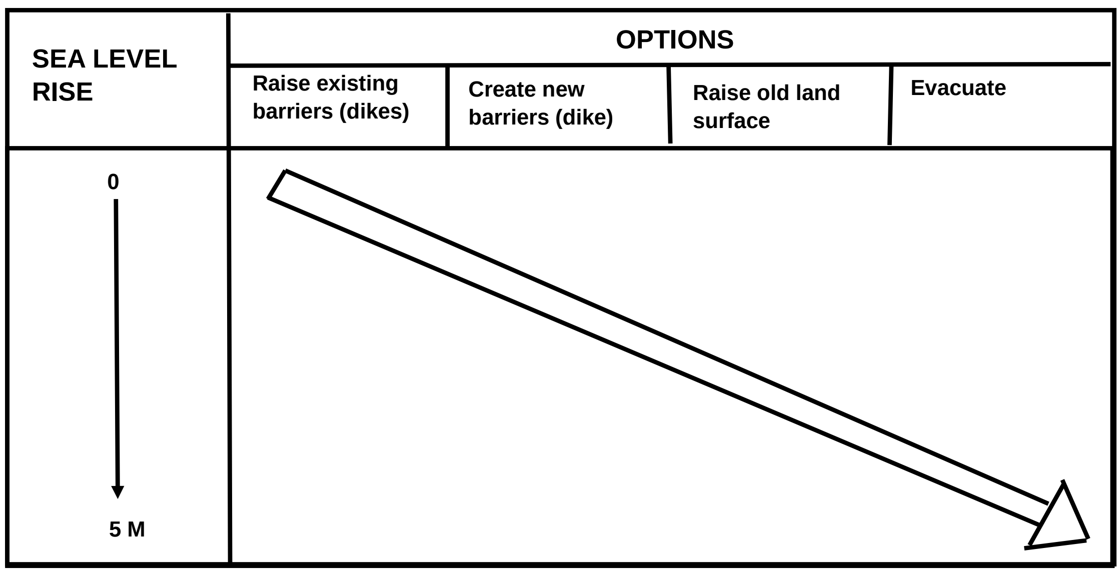

Figure 4 ***Sea Level Rise and counter measures (options)***

<u>Limited Sea level Rise</u>

As long as Sea level Rise remains of the order of 1 m, the most realistic option is to strengthen the existing dune and dike (levees) systems.
The maximum Storm Surge Level during a superstorm in the North Sea is of the order of +7 m above Mean Sea Level (tide level of 3 m, wind setup of 4 m). Based on this, the minimum required crest level of dunes and dikes is of the order of +15 m above MSL.
The maximum dune erosion volume of a natural sand dune facing the sea during a superstorm (assuming an increased wave climate) is of the order of 300 m^3/m above MSL (based on data of Vellinga, 1986; beach and dune erosion during storm surges, Delft University of Technology; see Figure 5) resulting in a dune base width of the order of 50 to 100 m.

When open rivers are present, the sea penetrates into the lower river reaches over considerable distance due to tidal flow (flood and ebb). Hence, the river dikes in the lower river sections will also be affected by Sea Level Rise. Furthermore, global warming may also lead to increased river discharges (increased rainfall).
China has shown that the major river flood discharges of the Yellow River can be regulated by a system of massive dikes with a base width of the order of 100 m (Practice of Yellow River Control, Yellow River Conservancy Press, 2004). The annual sedimentation in the lower Yellow River is so large that the dike levels have to be raised every 20 years ('hanging' river system with the river bed above the surrounding terrain).

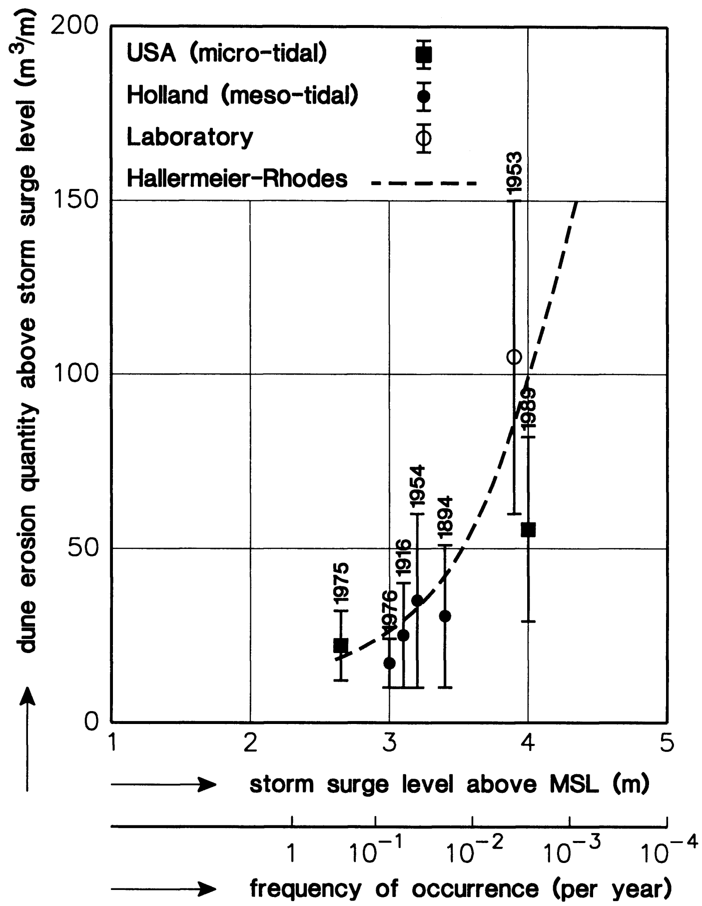

Figure 5 ***Dune erosion volume as function of storm surge level (Vellinga, 1986)***

The construction costs of massive dunes and dikes (levees) are of the order of 10 to 30 millions of Euros per kilometer. The overall costs will be large when the dikes along hundred’s of km’s of river sections have to be strengthened. However, the annual construction costs are not very high for most industrial countries with strong economies, given the relatively large time scale of the order of 100 years for a Sea Level Rise of about 1 m.

Excessive Sea level Rise

In the case of excessive Sea level Rise exceeding several meters (up to 5 m), one may consider three very drastic and very expensive options:

- evacuation of low-lying land;
- elevation of the existing land surface by large-scale suppletion of sand (assuming that sufficient amounts of sea sand are available);
- construction of a new massive offshore seadike.

To raise a square kilometer of land by a layer of sand with a thickness of 10 m, a volume of 10 millions m^3 of sand is required at a price of 30 to 50 millions of Euros depending on the availability and transportation distance of sand. Furthermore, the infrastructure of the old land has to be rebuild completely. On the scale of The Netherlands it would mean that a total area about 50,000 square kilometers of the western part of the country has be raised by 10 m at a price of about 2,500 billions of Euros. The annual construction costs of this option (about 2 to 3 billions of Euros per year) are still feasible considering the time scale of 1000 years.

Figure 6 *Offshore seadike in the case of excessive Sea Level Rise > 5 m (sluice systems and offshore islands for ports/airports are included)*

A rather drastic option for the Northwestern Europe would be to build a massive offshore seadike (width of 300 m, height of 50 m; length of about 600 km; see Figure 6) to protect the coastline. This requires 10 billions m^3 of sand. The overall costs (including sluices for shipping) are of the order of 300 to 500 billions of Euros, which is still feasible if the costs are spread over 100 years.
The offshore water level may go up to +5 m above Mean Sea Level. The area inshore of the dike will become a large fresh water lake due to the input of river water. The total pumping capacity to deal with river water input and seepage flows through/under the dike may be as large as 100,000 m^3/s requiring a continuous energy input of about 10,000 Megawatt (energy required to raise 1 m^3 of water per sec over a vertical distance of 5 m is about 0.1 megawatt or 150 horsepower).
The scale of such a project requires an international cooperation between France, Belgium, The Netherlands, Germany and Denmark to construct a new defence line between the high cliffs of Northern France and Denmark.