place will be different and the typical **neap tide** (MHWN) timing is about six hours earlier or later than the MHWS timing. When planning work on structures it is useful to know the timing of the most extreme low waters and whether or not they occur during daylight.

For a detailed description of sea level fluctuations and tidal phenomena, see Pugh (1987).

4.2.2.3 *Storm surges*

Meteorological phenomena, namely atmospheric pressure and wind, may also affect the sea level in particular during storm events. This section focuses on atmospheric pressure effects while wind effects are considered in the next section. Pressure and wind effects are often combined during storms generating long waves, called **storm surges**, with a characteristic time-scale of several hours to one day and a wavelength approximately equal to the width of the centre of the depression, typically 150–800 km. These storm surges produce significant variations of the sea level, up to 2–3 m at the shore depending on the shape of the coastline and the storm intensity. In practice, the term **storm surge level** is sometimes used loosely to include the astronomical tidal component and other meteorological effects.

Local low atmospheric pressures (depressions) cause corresponding rises in water level. Similarly, high pressures cause drops in water levels. This is the so-called **inverse barometer effect**.

For open water domains, Equation 4.9 gives the relationship between the **static** rise in water level z_a (m) and the corresponding atmospheric pressure:

$$z_a = 0.01(1013 - p_a) \tag{4.9}$$

where p_a = atmospheric pressure at sea level (hPa) and 1013 hPa is the pressure in normal conditions (see Section 4.2.1.2).

NOTE: Equation 4.9 results from simple equilibrium between the atmosphere and the ocean in static conditions. Where the atmospheric pressure is higher than the mean value of 1013 hPa, the sea level decreases, provided that it can increase at another place where the atmospheric pressure is lower than the mean value. This simple relationship does not apply for closed domains of small dimensions such as lakes. Indeed, if the atmospheric pressure is the same over the whole water domain there is no change in static water level.

Dynamic effects can cause a significant amplification of the rise in water level, however. When the depression moves quickly, the water level rise follows the depression. The height of these long waves may increase considerably as a result of shoaling in the nearshore zones. Along the coasts of the southern North Sea, storm surges with a height of 3 m have been recorded.

4.2.2.4 *Wind set-up*

Shear stress exerted by wind on the water surface causes a slope in the water surface (see Figure 4.11), as a result of which wind set-up and set-down occur at downwind and upwind boundaries, respectively.

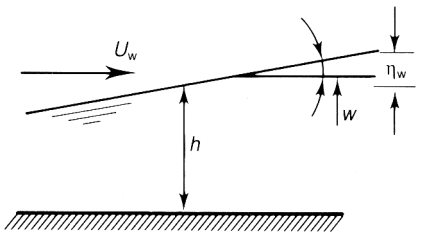

Figure 4.11 *Wind set-up*