deformation from offshore to onshore, nearshore currents induced by radiation stresses, wave set-up, wave set-down, sediment transport, and seabed morphological changes.[27]

Other wind wave models include the U.S. Navy Standard Surf Model (NSSM).[28]

The formulae of Bretschneider, Wilson, and Young & Verhagen

For determining wave growth in deep waters subjected to prolonged fetch, the basic formula set is:

$$\frac{gH_s}{u_w^2} = 0.283$$
$$\frac{gT_s}{u_w} = 7.54$$

Where:

g = gravitational acceleration (m/s^2)
H_s = significant wave height (m)
T_s = significant wave period (s)
u_w = wind speed (m/s)

The constants in these formulas are deduced from empirical data. Factoring in water depth, wind fetch, and storm duration complicates the equations considerably. However, the application of dimensionless values facilitates the identification of patterns for all these variables. The dimensionless parameters employed are:

$$\widehat{H} = gH_s/u_w^2$$
$$\widehat{T} = gT_s/u_w$$
$$\hat{d} = gd/u_w^2$$
$$\widehat{F} = gF/u_w^2$$
$$\hat{t} = gt/u_w$$

Where:

d = water depth (m)
F = wind fetch (m)
t = storm duration (s)

When plotted against the dimensionless wind fetch, both dimensionless wave height and wave period tend to align linearly. However, this trend becomes notably more flattened for more extended dimensionless wind fetches. Various researchers have endeavoured to formulate equations capturing this observed behaviour.

Common Formulas for Deep Water

Bretschneider (1952, 1977):

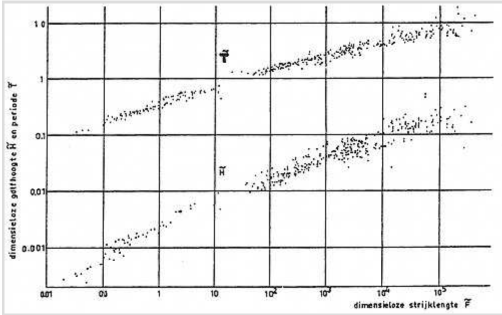
$$\widehat{H} = 0.283 \tanh(0.0125\widehat{F})^{0.42}$$
$$\widehat{T} = 7.54 \tanh(0.077\widehat{F})^{0.25}$$

Wilson (1965):[30]

$$\widehat{H} = 0.30\{1 - [1 + 0.004\widehat{F}^{1/2}]^{-2}\}$$
$$\widehat{T} = 1.37\{1 - [1 + 0.008\widehat{F}^{1/3}]^{-5}\}$$

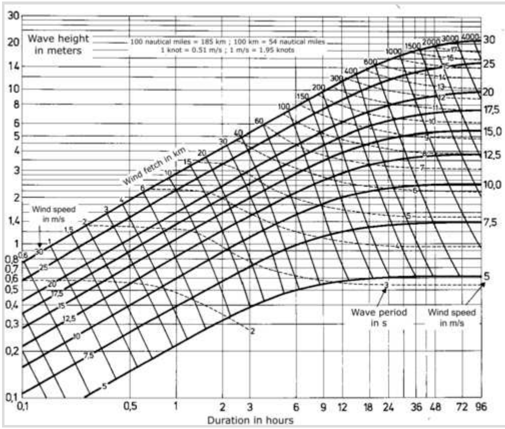
In the Netherlands, a formula devised by Groen & Dorrestein (1976) is also in common use:[31]

$$\widehat{H} = 0.24 \tanh\left(0.015\widehat{F}\right)^{0.45} \text{ for } \widehat{F} > 10$$
$$\widehat{T} = 2\pi \tanh\left(0.0345\widehat{F}\right)^{0.37} \text{ for } \widehat{F} > 400$$
$$\widehat{T} = 0.502\widehat{F}^{0.225} \text{ for } 10 < \widehat{F} < 400$$



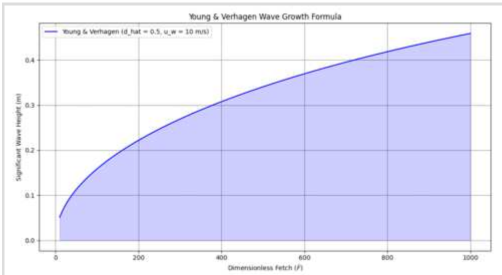
Dimensionless wave height and period against the backdrop of the dimensionless fetch (data courtesy of Wilson, 1965)[29]

During periods when programmable computers weren't commonly utilised, these formulas were cumbersome to use. Consequently, for practical applications, nomograms were developed which did away with dimensionless units, instead presenting wave heights in metres, storm duration in hours, and the wind fetch in km.



Wave growth chart based on the formulas by Groen & Dorrestein[31]

Integrating the water depth into the same chart was problematic as it introduced too many input parameters. Therefore, during the primary usage of nomograms, separate nomograms were crafted for distinct depths. The use of computers has resulted in reduced reliance on nomograms.



Graph depicting the variation of significant wave height with dimensionless fetch based on the Young & Verhagen wave growth formula, set against a specific water depth and wind speed.

For deep water, the distinctions between the various formulas are subtle. However, for shallow water, the formula modified by Young & Verhagen[32] proves more suitable. It's defined as:

$$\widehat{H} = 0.241\left(\tanh A_H \tanh \frac{B_H}{\tanh A_H}\right)^{0.87}$$
$$A_H = 0.493\hat{d}^{0.75} \text{ and } B_H = 0.00313\widehat{F}^{0.57}$$

and

$$\widehat{T} = 7.519\left(\tanh A_T \tanh \frac{B_T}{\tanh A_T}\right)^{0.387}$$
$$A_T = 0.331\hat{d}^{1.01} \text{ and } B_T = 0.0005215\widehat{F}^{0.73}$$

Research by Bart demonstrated that, under Dutch conditions (for example, in the IJsselmeer), this formula is reliable.[33]

Example: Lake Garda

Lake Garda in Italy is a deep, elongated lake, measuring about 350 m in depth and spanning 45 km in length. With a wind speed of 25 m/s from the SSW, the Bretschneider and Wilson formulas suggest an H_s of 3.5 m and a period of roughly 7 s (assuming the storm persists for at least 4 hours). The Young and Verhagen formula, however, predicts a lower wave height of 2.6 m. This diminished result is attributed to the formula's calibration for shallow waters, whilst Lake Garda is notably deep.

Bretschneider Formula: Lake Garda

Based on Bretschneider's formula:

- Predicted wave height: **3.54 meters**
- Predicted wave period: **7.02 seconds**

Wilson Formula: Lake Garda

Utilizing Wilson's formula, the predictions are:

- Predicted wave height: **3.56 meters**
- Predicted wave period: **7.01 seconds**

Young & Verhagen Formula: Lake Garda

Young & Verhagen's formula, which typically applies to shallow waters, yields:

- Predicted wave height: **2.63 meters**
- Predicted wave period: **6.89 seconds**