

## Knowing your boat means knowing its wake

This is an illustrated guide to wave wake that expands upon the basics outlined in the low wake guide “Wake up? Slow Down”, which is available at:

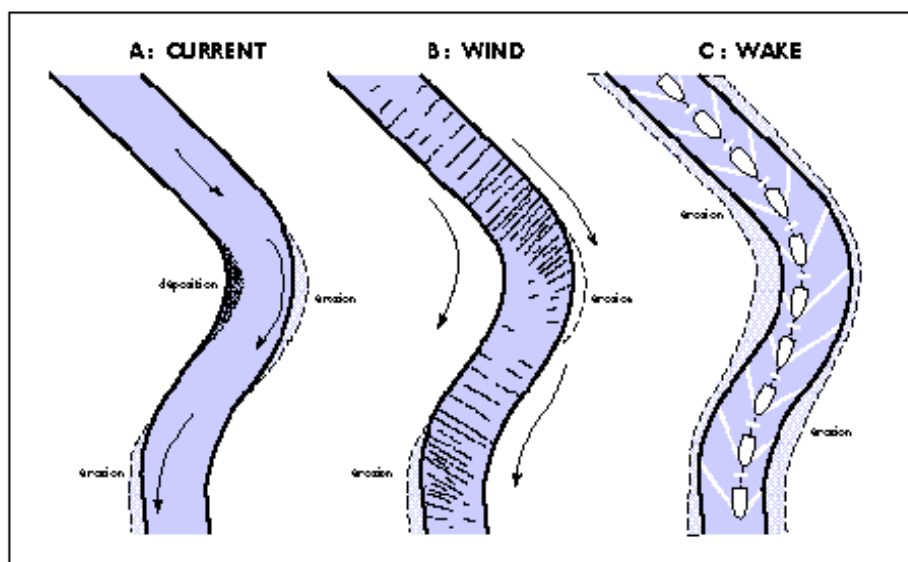
<http://dpi.wa.gov.au/Documents/Guide-to-Low-Wave-Wake-Boating.pdf>

We all know ‘stow it – don’t throw it’ but what about what Bryce Courtenay’s Yowie said to the Dirty Rotten Rubbish Grumpkin: “*not thinking is the same as not caring*”? Here are 18 illustrations to help boaters think about their wake and its potential erosive impacts in sheltered, restricted or shallow waters.

### Environmental effects of wave wake

In the open sea wave wake is likely to have little environmental effect since the waves are small compared to those that might occur naturally. It’s a very different matter in sheltered waters like riverine estuaries. The soft banks and beds of many Tasmanian waterways are vulnerable to damage from boat wake and prop wash. Typical easily-affected landforms include estuaries, inlets, lakes and lagoons; places where natural wave energy tends to be low. Banks of peat or mud, shallow lagoons or lakes with muddy beds and sandy deposits in upper estuaries are all areas of risk.

Wake striking the banks can cause rapid and severe erosion, exposing the roots of vegetation and causing the banks to collapse. Wake impact and prop wash can also churn up fine bed sediments – the impact on bed and banks degrades the aquatic environment for plants and animals. In some popular boating and cruising areas, the effects of wake damage have been severe – for example, on the lower Gordon River, long stretches of bank have been washed away, with mature Huon pines and myrtles toppling into the river.



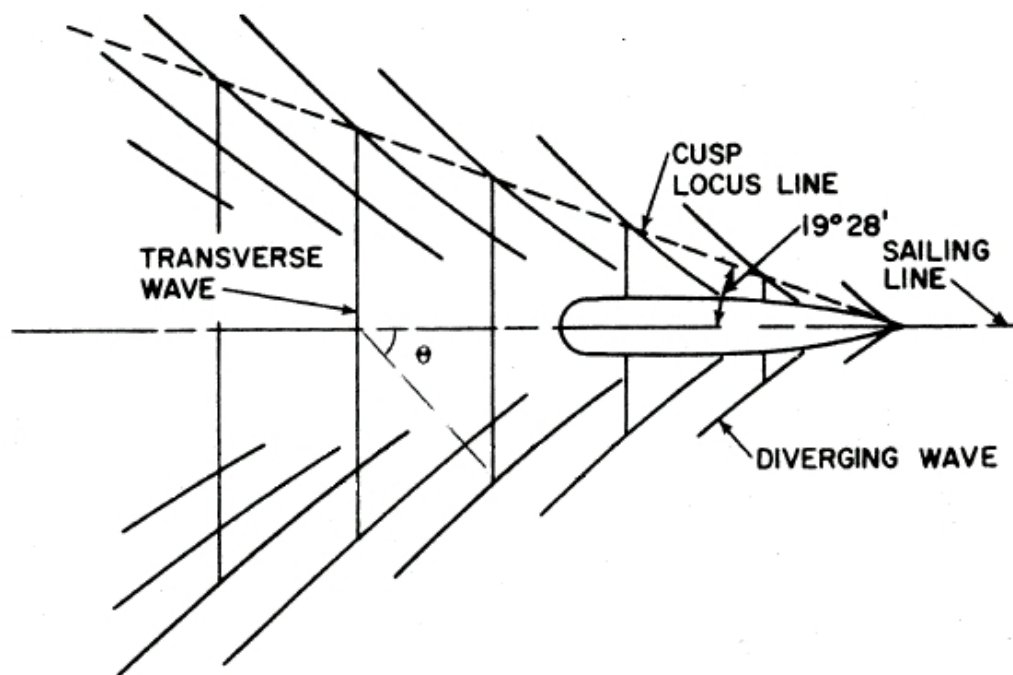
The above diagram shows why wave wake can have such an impact on river and estuarine banks. A) River currents impinge mostly on the outside of bends, where current driven erosion is most active, whereas inside bends are typically areas of deposition. B) Wind driven waves also only attack the outside of bends. C) Wave wake however may attack all banks and is often focused on the soft sediment on the inside of bends.

## What is wave wake?

There are three relevant laws of nature:

- power is required to move a vessel
- energy of propulsion is lost to wavemaking
- a moving vessel creates a wake

A typical boat wake looks something like the figure below. The wavelength (distance between crests) of the transverse waves is equal to the natural length of a wave travelling at the same speed as the vessel. The diverging waves contain a mixture of wavelengths that gradually separate because in water longer waves travel faster than the slower ones. The diverging wave crests therefore curve outwards, not because there is any acceleration away from the boat but because they have had more time to disperse.



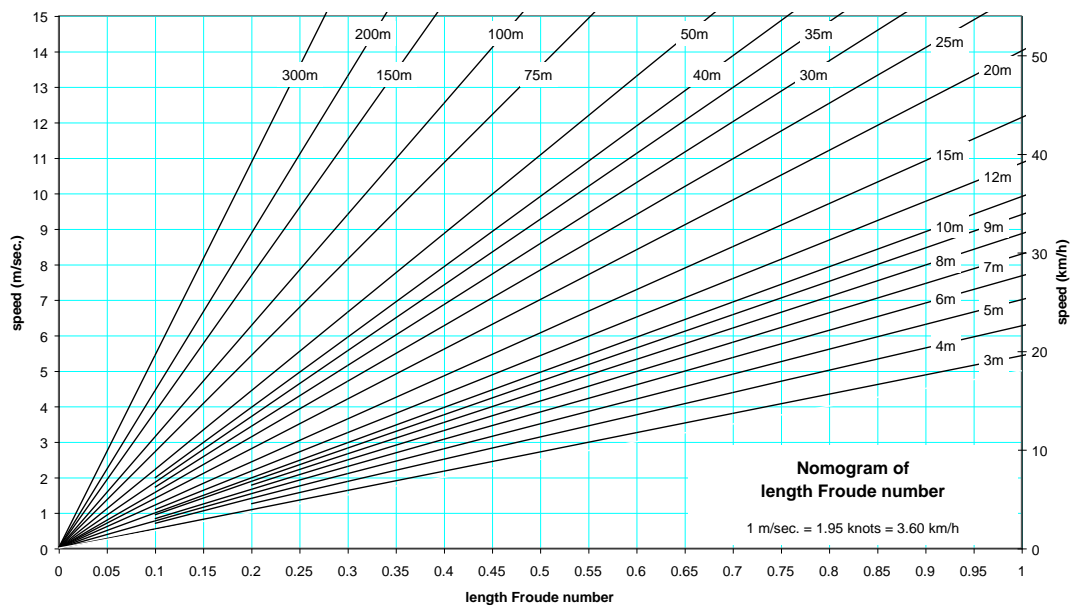
The difference between the wake of a supertanker in the ocean and a toy boat in the bath is really only one of scale. In the late 19<sup>th</sup> century William Froude invented the method of towing model ships in a tank to assess their performance and power requirements. He realised that a vessel's resistance to movement could be divided into two types – that due to friction (viscosity) and that due to other causes, of which wavemaking is the most important. This opened up a whole new field of science (hydrodynamics) to naval architecture, much of which is still concerned with minimising wave resistance; to either reduce power requirements or increase speed or fuel economy. Froude's name is remembered as two special ratios that are the simplest way to describe a vessel in motion with useful accuracy and regardless of scale.

Many thousands of towing tank experiments subsequently conducted as part of routine ship design have shown that wave wake patterns vary in a predictable manner. In deep water all that must be known to gain a first approximation of the wake pattern is vessel length and speed. In shallow water the depth is also important. As far as waves are concerned water is considered shallow when orbital motions extend to the seabed and deep when the bed is more than half a wavelength below the surface.

Much of the information presented here is a classification of wave wake patterns expressed in terms of length Froude number so that the important points can be recognised for any vessel regardless of size. Length Froude number,  $F_L$ , is a ratio of speed (V) to waterline

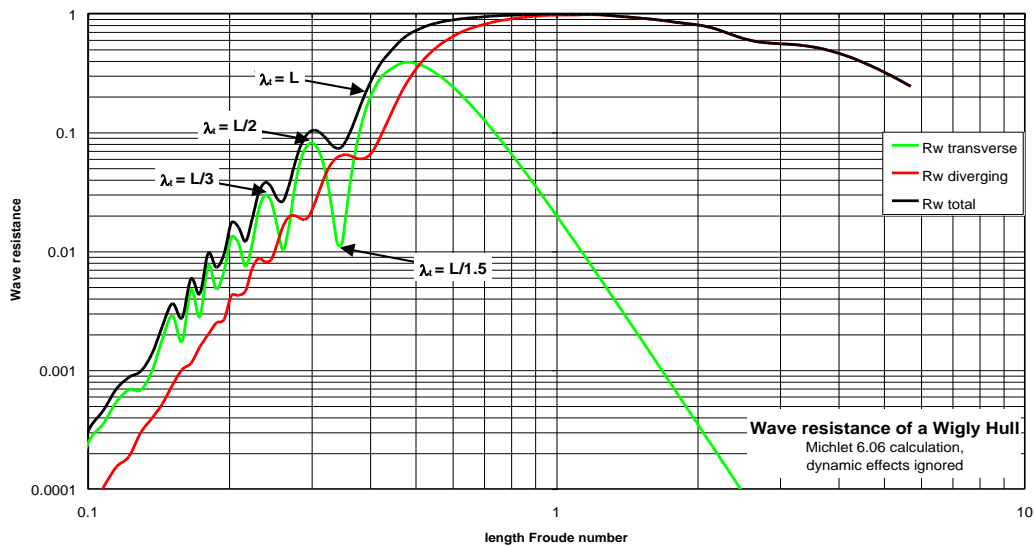
length (L) calculated from the formula  $F_L = \frac{V}{\sqrt{gL}}$  where g = acceleration due to gravity.

For people uncomfortable with formulae length Froude number may also be determined from a graph, like the one below. This shows that a 6 m vessel, for example, is operating at a length Froude number of approximately 0.325 at 5 knots and approximately 0.65 at 10 knots.

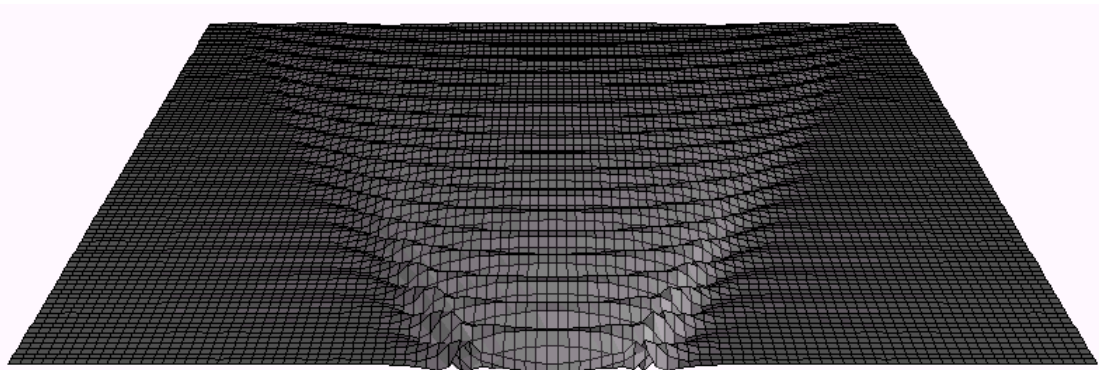


It can be seen from the plot above that a small vessel may be capable of realistically operating at a wider range of Froude numbers than a large ship. In fact, while a large cruise ship is unlikely to exceed a length Froude number of 0.25 it is not uncommon for a small, high powered planning hull boat to operate at 2.5 or beyond.

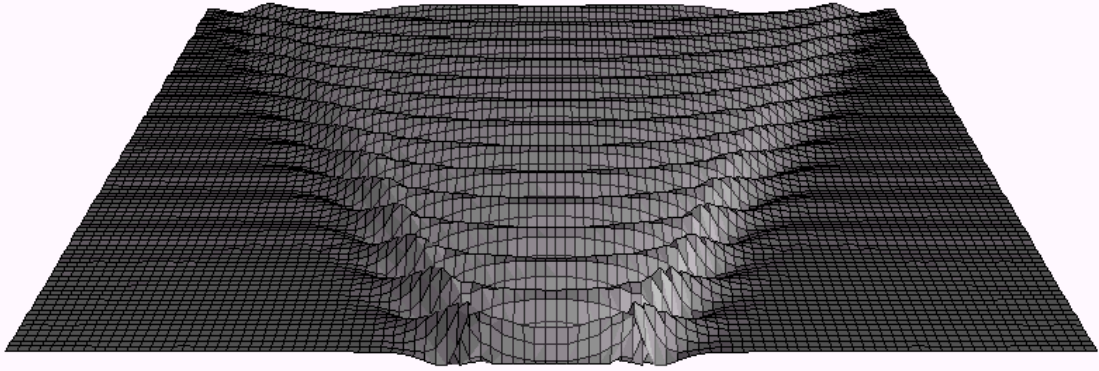
Wave resistance is a measure of how much propulsive energy is expended upon generation of the wake. When wave resistance measurements obtained in the towing tank are plotted against length Froude number a series of peaks and troughs can be seen, as in the next graph. This is largely due to the interactions of the transverse waves in the bow and stern wakes and is controlled by the ratio of hull length to wavelength. In the plot L once again refers to vessel waterline length while  $\lambda$  = wavelength and  $R_w$  is wavemaking resistance.



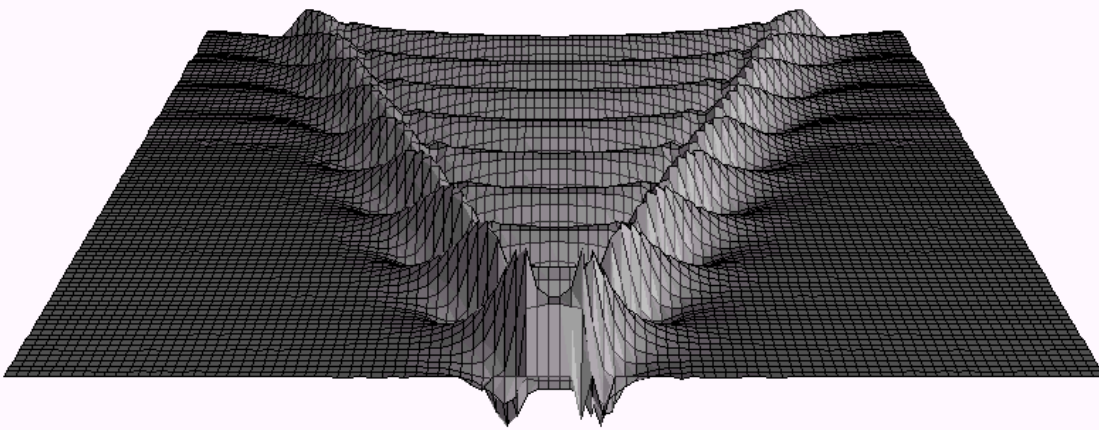
In the next few pages a series of 3D wake plots show how the wave pattern changes as speed increases. They are derived using a theory developed in 1898 by the Australian mathematician John Henry Michell and calculated by a computer program more recently written by Leo Lazauskis at Adelaide University. The wake from a 5 m transom stern planing hull dingy is modeled as an example of the wave patterns produced by most monohulls. The plots represent a square of water 10 boat lengths on a side with the leading edge one boat length behind the vessel. The viewpoint is higher than that from the boat and the light source is over the observer's right shoulder. Wave heights have all been equally exaggerated to assist visualisation.



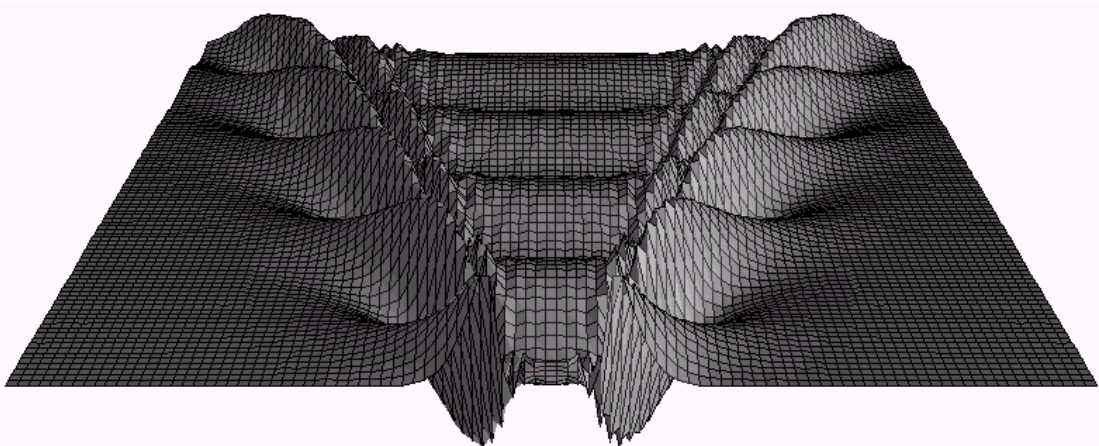
At very low speeds there are several transverse waves along the hull but as speed increases their number decreases as the waves become longer. At a length Froude number of 0.3 (above) the transverse waves are half as long as the vessel, meaning there is a wave crest amidships. The crests of waves generated at the bow coincide with stern wave crests, creating relatively high waves for the total wave resistance, which is about 10% of the maximum possible for a given hull type and displacement.



At a length Froude number of 0.35 the bow and stern wave patterns partly cancel as crests from the bow coincide with troughs from the stern. For most small recreational vessels this represents the best compromise between speed and a low impact wake in sensitive areas. This is a rationale for the 5 knot speed limit imposed in many places, ranging from harbours to nature conservation areas. However it does assume that the typical vessel is about 5.5 m long. Smaller boats have this sweet spot at a slightly lower speed and larger ones slightly faster but consideration of such nuances is overly complex for practical regulatory purposes.

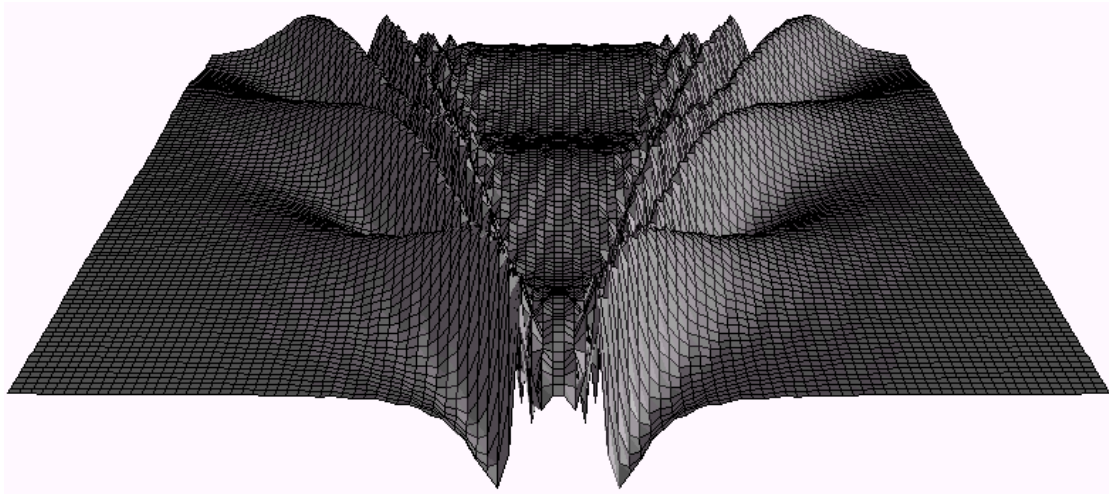


At a length Froude number of 0.4 the wavelength of the transverse waves equals the length of the vessel, bow and stern wakes are reinforcing. This is also known as 'hull speed' and for most yachts and many other conventional commercial vessels is pretty much the top speed.

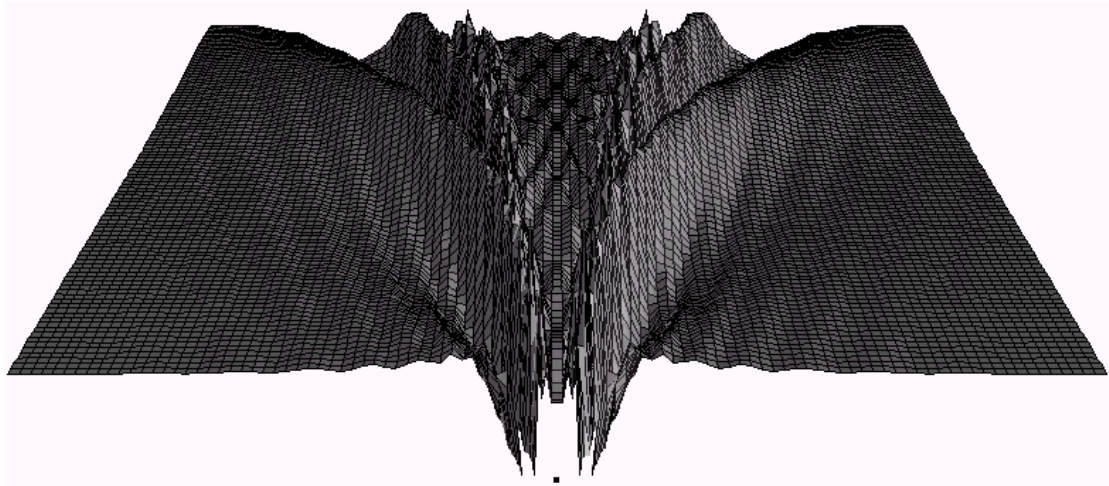


At a length Froude number of 0.6 the transverse waves are longer than the hull length so pronounced changes in trim occur as the bow is on the crest of a wave and the stern sinks into the trough. These longer waves would naturally travel faster than the vessel and their generation is reduced, with the diverging waves becoming more prominent.

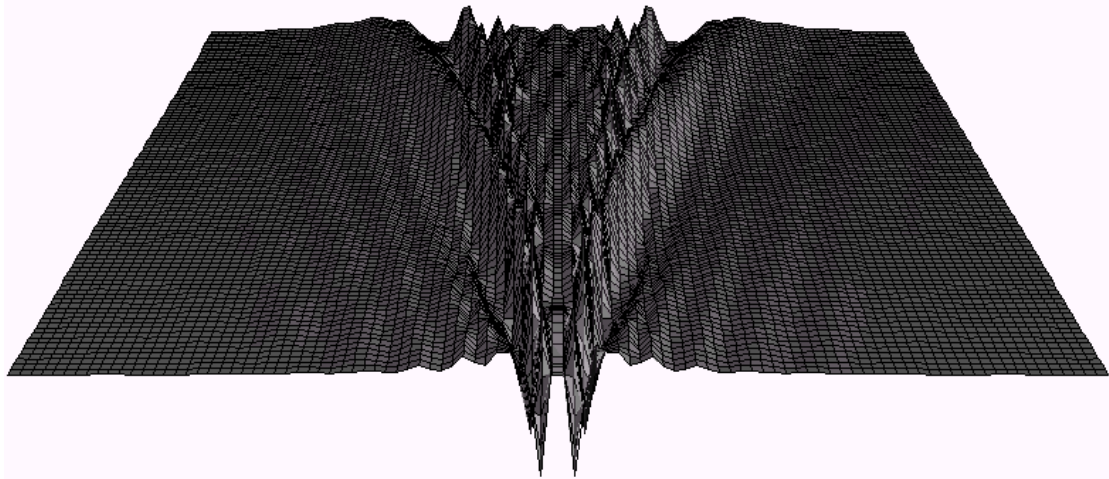




At a length Froude number of 0.8 the diverging waves become very steep and are probably breaking (not shown here). A range of different wavelengths are generated, with each wave travelling at a speed proportional to its length. This is known as dispersion, which means the longer, faster waves leave the slower ones behind and diverging wave crests curve outwards from the sailing line.



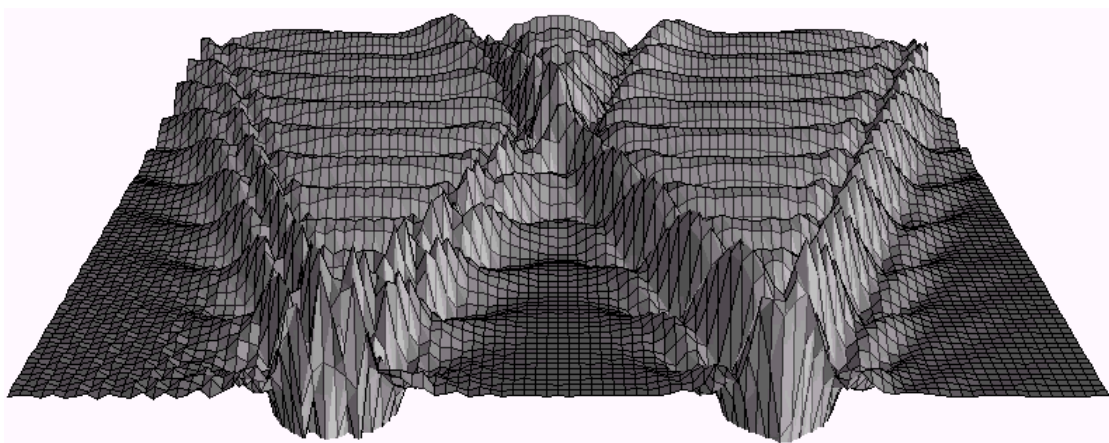
At a length Froude number of 1.0 the transverse waves have almost died out but wave resistance is pretty much at its maximum because of the large diverging waves. This means high fuel consumption and a high chance that the waves may cause erosion in restricted or sheltered waterways.



At a length Froude number of 1.5 planing has more or less begun. Hydrodynamic lift reduces the vessel's active displacement. This in turn reduces the height of the waves, but they are still very energetic. As these fast, long waves enter shallow water their height increases in the same way a swell becomes surf and they may have a very obvious impact on a relatively sheltered shoreline.

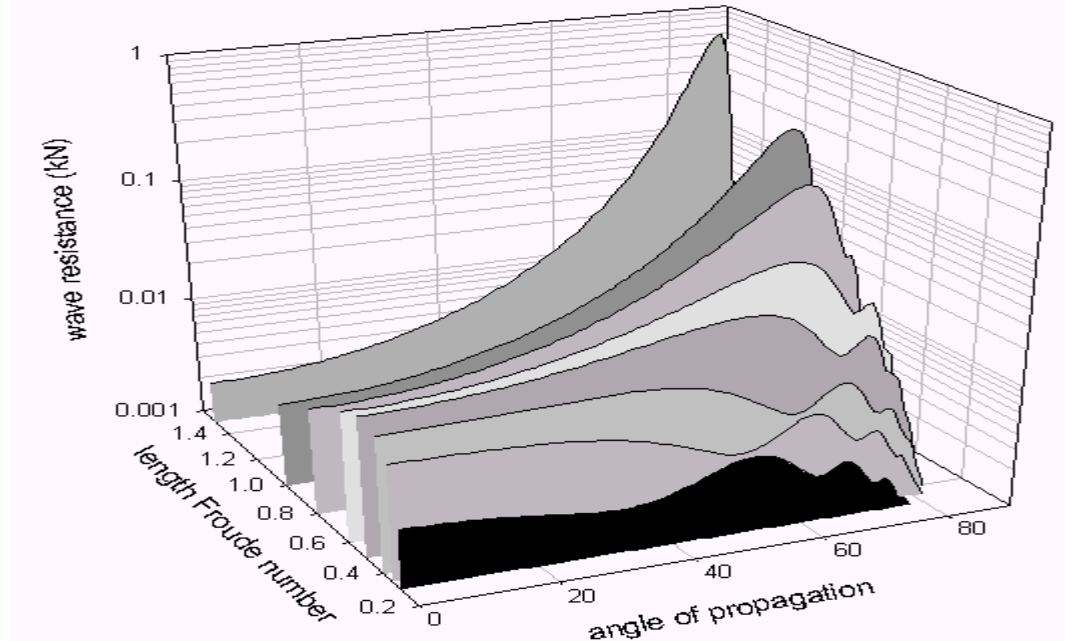
Hull form has relatively little influence on the pattern of wake waves because to a certain extent all commercially successful hulls are more or less low wake designs, in order to reduce fuel consumption. The main effect on wake pattern is associated with the number of hulls, with multihull vessels causing more complex wakes. The waves produced by each hull interact in much the same way as the bow and stern wakes of a monohull but because the sources are side by side the diverging waves are also subject to reinforcement and suppression.

Modern vessels that have been designed to a low wake specification tend to be multihulls only partly in order to utilise interference wave suppression. The principle wave resistance advantage of catamarans is due to the very slender waterplane area of each hull. This has been proven by evolution of designs where propulsive efficiency is the ultimate criteria; kayaks and rowing shells.



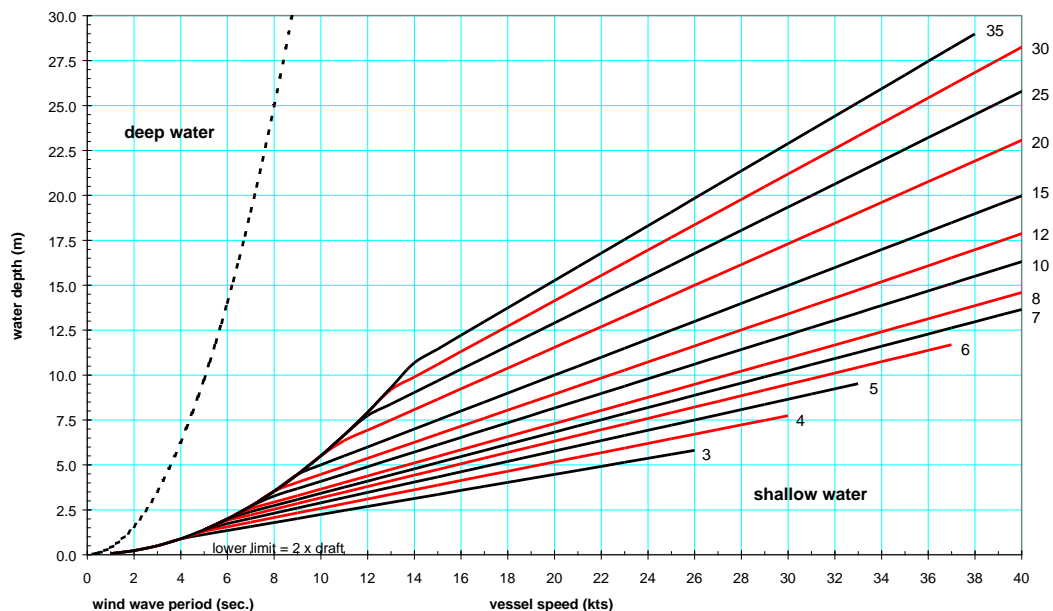
Spot the difference: both vessels are travelling at a length Froude number of 0.4. The wake on the left is caused by a twin hull vessel, the one on the right by a monohull of the same basic shape and length as one of the catamaran's demihulls, but with twice the displacement so that the total displacement of the two vessels is the same.

As the above plots have shown, the proportion and magnitude of wave energy directed towards river banks varies with vessel speed. Here's a more concise way of looking at it:



This diagram shows that at low speed much of the wave energy follows the boat however with increasing speed (towards the rear of the plot) more of the wave energy is directed away from the vessel track and towards the banks (to the right of the plot). Notice also that total wave energy increases with speed.

In shallow water the effect of wake waves may also extend to the bed beneath the vessel. This may resuspend bed sediment, making the water turbid or cloudy.

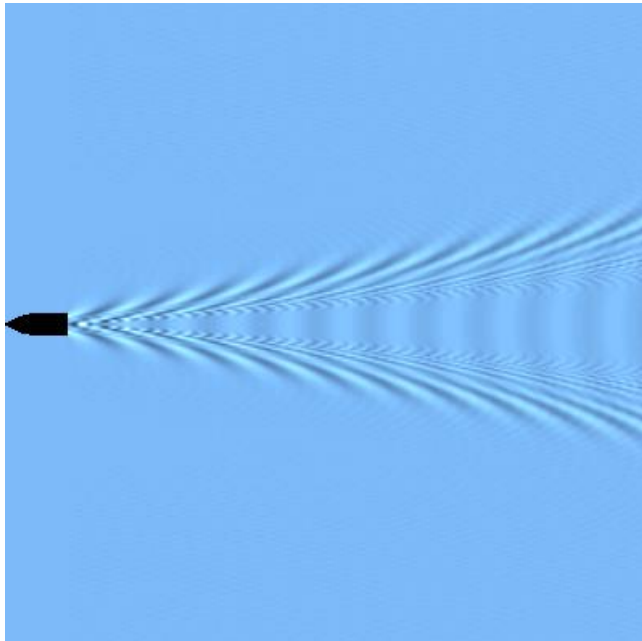


The main part of the graph above may be used to determine the maximum speed that a vessel of known length may operate in water of particular depth without having an effect on the seabed. Navigationally shallow water occurs in that region to the right of the solid curved line and below the appropriate numbered line representing vessel length. For example, a 5 metre dinghy may operate at up to 5 knots in 1.5 metres of water, 10 knots in 3 m, 20 knots in 5.75 m or 30 knots in 8.75m of water without causing significant water motion at the seabed.

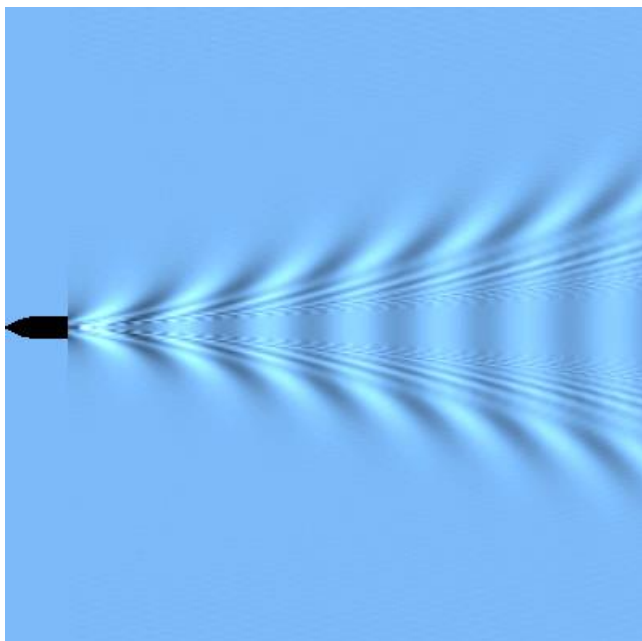


The dashed curved line to the left indicates the depth of wave activity according to the period (time in seconds between successive crests) of the natural, wind driven waves. If the depth of wave wake activity extends below that of the maximum expected storm waves repeated passes may have a geomorphological effect.

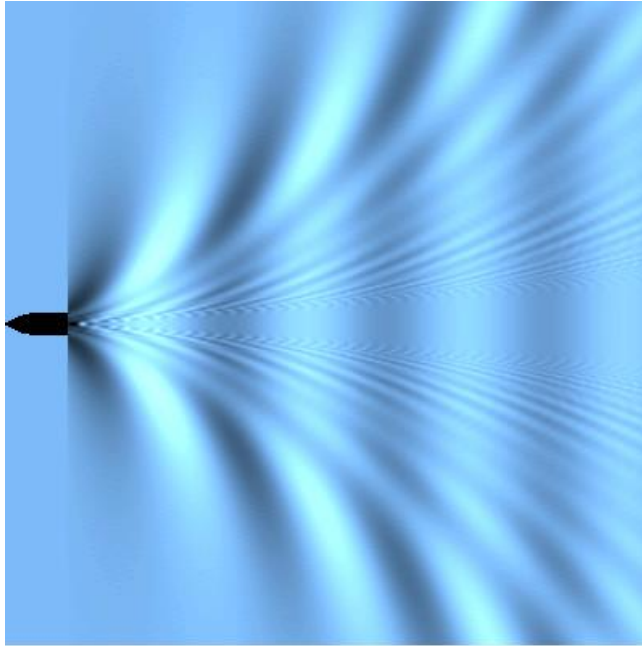
The following illustrations show how the wake pattern changes with changing depth. The example uses a 5 m dinghy travelling at a constant speed of 5 knots. Again plots are 50 m on a side and were generated using Michlet software.



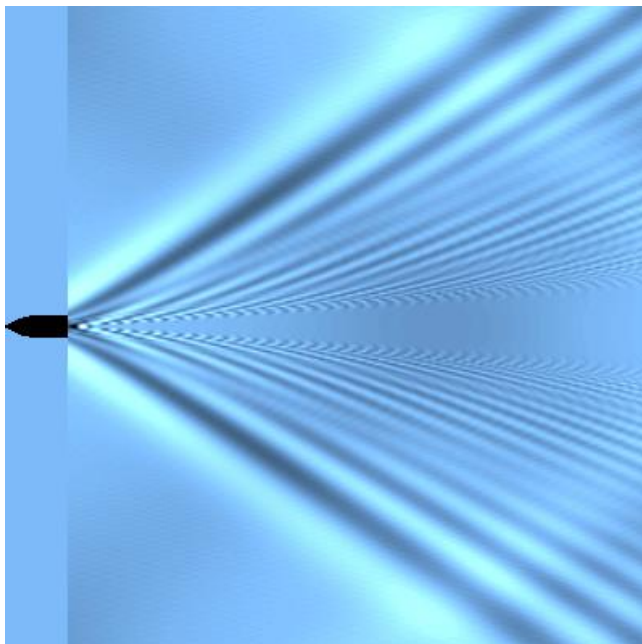
The deep water wave pattern is very similar to that for a length Froude number of 0.35 above. Wave motion does not extend as far down as the bed.



Upon entering shallow water the transverse waves are effectively squeezed by lack of depth and become larger. Here, in 1.4 m of water, bed sediments are likely to be set in motion by wave action. Even if you can't make out the bed, an increase in wake wave size, which may be accompanied by a change in trim, will indicate that you've entered shallow water.



With further decrease in water depth the transverse waves extend well beyond diverging ones and significant energy is being transferred to motion of bed sediments. This plot, at 0.7 m, is almost at the critical depth at which the transverse waves reach their maximum. Wake patterns like this are also seen when a 4WD vehicle fords a stream. Note that waves abeam of the vessel have not been calculated and are not shown in any of these plots.



Beyond the critical depth transverse waves are no longer generated. This plot shows our 5 m vessel travelling at 5 knots in less than half a metre of water. Not a terribly realistic scenario but included for completeness. This wave pattern can be more safely generated by dragging a stick through a puddle.