Introduction

Approximately 50% of all canoeing accidents happen on white water and almost all of these occur on weirs: weirs are the biggest cause of canoeing accidents and the accidents occur owing to the difficult flow conditions immediately downstream of the weirs.

The hydraulic jump (the canoeist's stopper) is probably the most dangerous flow feature and especially to the less able canoeist who may not recognize the extent of the potential danger. The most benign jumps have been the cause of drownings, some of which may have been due to the victim's becoming disoriented or unconscious owing to the coldness and not able to stand up or push off the bed of the channel. A case in Ireland happened where the water depth could not have been greater than 1.7m and possibly as shallow as 1.5m.

Understanding the reason why hydraulic jumps occur and what happens to the flow inside one of them should aid with the correct interpretation of the behaviour of the flow and what is likely to happen to a swimmer in one. More than this, it is possible to arrive at conclusions about weir design and modifications to reduce the dangers owing to the stoppers they cause.

This is the purpose of what follows and it is written for those without a technical background. It is expected that those with a scientific background will appreciate the fundamental importance of the subject matter and accept the simplified form of presentation.

Energy and flow

A stopper is a sudden change in the type of flow of the water in a channel: all changes have a cause so the first thing to understand is what causes the water to flow at all.

Energy is the ability to cause change.

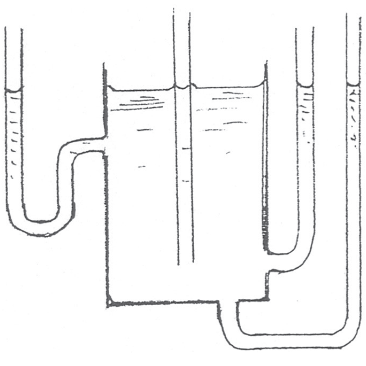

Figure 3.

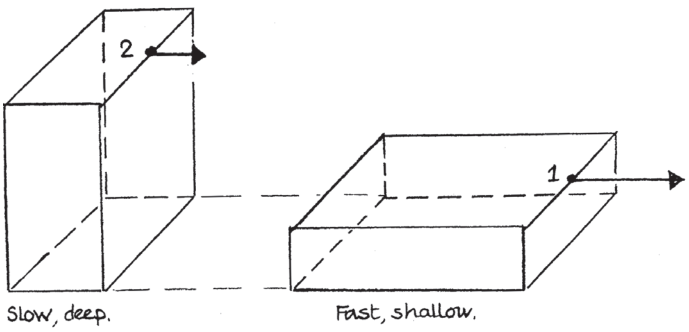

Figure 4

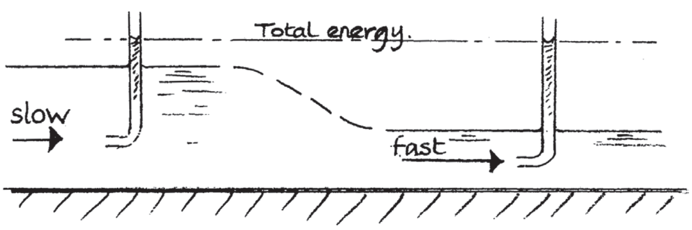

Figure 5

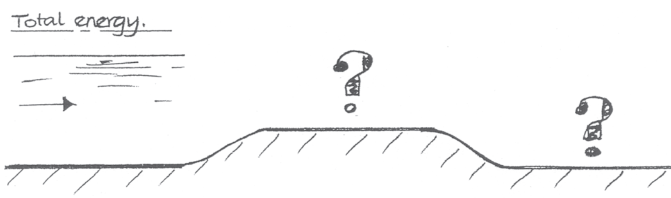

Figure 6.

In Fig 1 the mass at 1 has greater energy than the same mass at 2 because when it falls to a common level it can cause more change there; either it compresses the spring more or it is going faster itself.

In Fig 2 the same masses at 1 and 2 have moved to the same height when they come to a stop so they have the same energy; they finish with the same energy so they must have started with the same energy because nothing is giving them more total energy. The total energy is the same as the masses rise but it is converted from one type into another. Mechanical energy comes from the combination of height and speed: mass 1 has a low (zero) height and a large speed and mass 2 has a medium height and a medium speed and they can both rise to the same total height.

Water that is not moving (Fig 3) will always rise to the level of its surface if it is able to do so; the water surface level is the energy level of all of the water (because the water near to the surface is pushing on the water lower down).

Flowing water

A steady flow of water in a channel has the same volume per second passing any place. This same volume in each second could flow with a deep, slow flow or with a shallow, fast flow, as shown in Fig 4 which, for any small mass of water (1 or 2), looks like Fig 2. It is easy to show that the total energy of these two flows are the same, see Fig 5, which again is like Fig 2 except that we are now dealing with a water flow which does not happen only once and then stop but keeps on happening continuously.

It is now possible to explain the flow of water over a hump in a river bed (perhaps over a rock), see Fig 6. The two basic rules that must be obeyed are:

(1) The volume of water flowing per second is the same at all places.

(2) The total energy *above a constant level* is the same at all places.

There are three guesses we could make for the depth of flow over the hump:

(a) The *depth* remains the same. This means that the surface level rises and, because the speed must remain the same (for this constant depth), the energy would have to rise, impossible!

(b) The water surface stays at the same *level*. Then the depth reduces so the speed rises and the energy must increase, again, impossible!

(c) Obviously, the water surface must *go down* (and the water depth reduces by a large amount) over the hump. The speed of the flow increases just enough to keep the total energy (measured above the same level as before the hump) constant.

(It is left for the reader to draw this flow change on Fig 6 and what happens downstream of the hump is described in the next section, which enables the figure to be completed.)

Because the bottom of the channel has risen, the water is now flowing on a raised platform and the energy *in the flow* at this raised location is less: in this raised section of channel the flow is not able to cause as much change as it could before the hump.

Obviously, we cannot keep raising the bed level until the flow energy disappears altogether because, so long as the flow continues, it will always eventually run over the top of a hump of any height that we build. Hence there is a flow state with *least energy*.

This is the critical flow state.

The flow over a hump will reduce in energy as the height of the hump is progressively increased until critical flow occurs (with critical speed and critical depth) and then will remain at this critical flow if the hump is further raised. The critical state occurs when the flow depth gives a speed of flow equal to the speed of travel of a surface wave through this same depth in still water. This means that no wave can travel upstream against a critical flow (the speed of flow downstream is equal to the speed of the wave through the water in the upstream direction so the wave will stay still).

The hydraulic jump

As the water goes onto the hump it is accelerated and this acceleration continues downstream of the hump so that the flow becomes shallower and faster than critical. Here the water has a large energy owing to its very high speed and even though it is shallow its flow energy is greater than the critical flow minimum.

This supercritical flow state is not normal for the natural channel and the flow has to change back to the deep, slow (slower than critical) normal flow. Because the flow has energy greater than the minimum it