SOME OF WHAT YOU SHOULD KNOW ABOUT WATER or, K.I.S.S.* for HYDRODYNAMICS (*Keeping It Stupidly Simple)

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For those of you who attended the special session "Hydrodynamics of Benthic Organisms" on Thursday, 4 th June, at the 35th Annual Meeting of NABS, Orono, Maine, but did not manage to get the hand-out, here is an expanded version and some further thoughts.

When you walk up to your favourite stream and want to describe it in a manner useful to yourself, or your fellow benthologists, think of the "power" of that flow. Better still, think in terms of the **Specific Energy** (SE) of the flow where SE=D + (U^2/2g). N.B. See the symbol definitions at the end.

At any given situation SE remains essentially constant. Therefore, if flowing water is stopped (i.e. U_2=0) the SE in the flowing situation must equal that with the water stopped, or SE_1 = SE_2, or D_1+ (U_1^2/2g) = D_2+ (U_2^2/2g), or since U_2 =0, D_1+ (U_1^2/2g) = D_2, or U_1^2/2g = D_2-D_1, or U_1 = (SQRT(2g))(D_2-D_1).

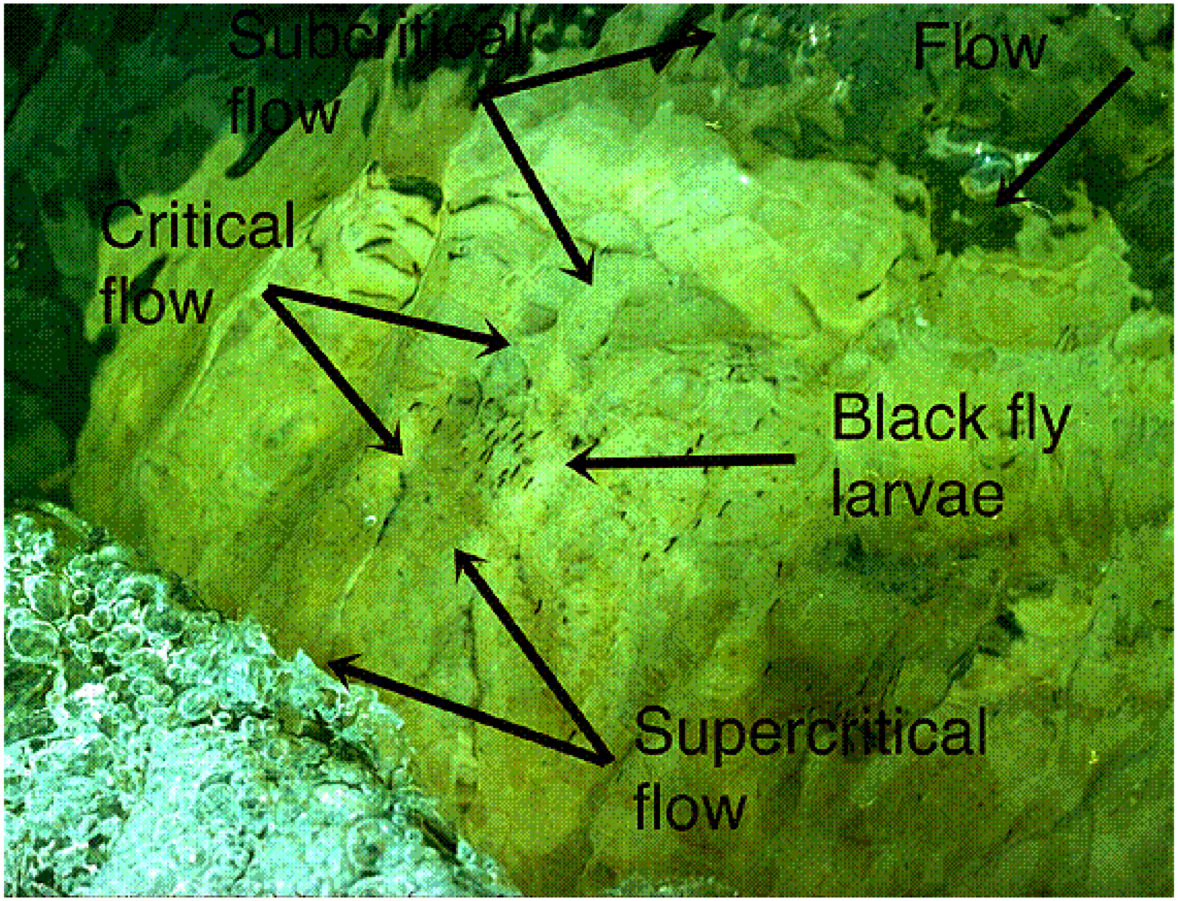
Try this with a steel ruler touching the substrate of the stream. Take D_1 with the ruler parallel to the flow, then turn the ruler at right angles to the flow and measure D_2. Not only will this demonstrate the principle involved, but will give you a reasonable estimate of the mainstream velocity (U)! In a more natural situation, when you observe dimples and bumps on the surface of flowing water, or changes in depth as water flows over a rock, just remember that since SE is essentially constant at any given situation, if U changes, then D must also and vice versa.

If the water has to flow over or around a more substantial object, then U and D may change sufficiently to produce what is called **Critical** (U_c) flow, where D=2(U^2/2g) and U_c=SQRT(gD). This last formula is also that for a simple Pitot tube. Critical flow is somewhat difficult to understand, but occurs when the total of velocity energy and depth are at a minimum. This is a very important flow condition and is paid a lot of attention to by hydro-engineers and those dealing with open channel flow.

However, since most benthologists do not think of their favourite medium in terms of specific energy, a ratio, much used for describing flow and as a correlate for density and distribution of benthic organisms, is perhaps better. This is the Froude number (F) = U/ SQRT(gD), You will note that this ratio embodies the same factors as specific energy. When F =1, U=SQRT(gD) and such flow is termed **Critical**; exactly the same type of flow as when we considered specific energy. However, use of Froude number gives us a set of very useful terms for describing flow - terms which carry some weight because you had to get out there into the water and do some measurements!

- When F <1, flow is termed "subcritical" (or "tranquil", or "smooth").
- When F =1, flow is termed "critical".
- When F >1, flow is termed "supercritical" (or "rough", or "shooting").

The position of critical flow can be relatively easily determined without measuring either depth or velocity, by making small waves on the water's surface. These try to move upstream, but obviously are carried downstream by the flow. At "subcritical" flows, the waves will travel a way upstream, but at "critical" flow they are swept back against the object used to disturb the surface, because the speed of propagation of a wave (U_w) =SQRT(gD). Seem familiar? An example of these flow types over a rock can been seen here:



Another useful ratio that describes the inertial and viscous relationships of flow is Reynolds number (*Re*) = velocity x length/ kinematic viscosity (v) . For mainstream flow when :

> *Re* < 1000, flow is "laminar" (i.e. smooth, oily flow, where the stream lines are parallel);
>
> 1000 < *Re* < 2000, flow is "transitional";
>
> *Re* > 2000, flow is "turbulent".

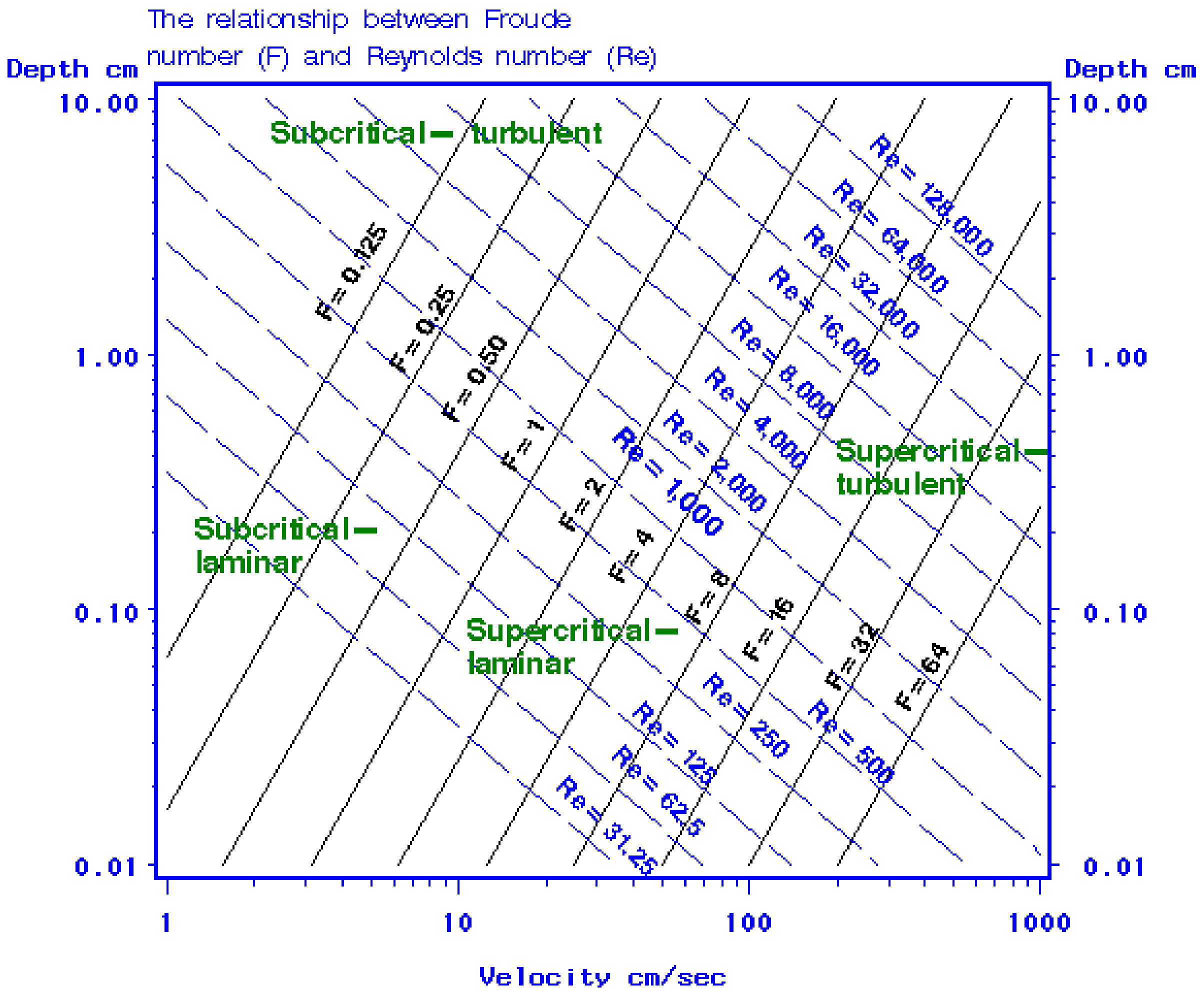
If you do the calculations in millimeters, a rough *Re* is the velocity times length over which the water flows. Obviously most water that we deal with is fully turbulent. Reynolds number also determines the vorticity of flow around an object and when:

> *Re* < 10, no vortices form because flow is laminar;
>
> 10 < *Re* < 40, the vortices remain attached to the object;

Re > 40, the vortices detach (i.e. form a von Karman trail - next time you are paddling a canoe, you'll see these off the end of your paddle).

(N.B. The values for *Re*'s of flow and vorticity are not written in stone).

The relationship between Froude number and Reynolds number can be seen in the figure below. You will note that use of these two ratios provides us with useful descriptive terms for the four main types of flow. Again, obviously, most of the flows we encounter are in the top portion of the nomogram, i.e. "subcritical-turbulent" and "supercritical -turbulent", with "critical-turbulent" being a rather restricted type of flow, but important never-the-less. Flow such as "supercritical-laminar" is rare, but can be found when a sheet of water flows down a smooth rock face (madicolous flow).

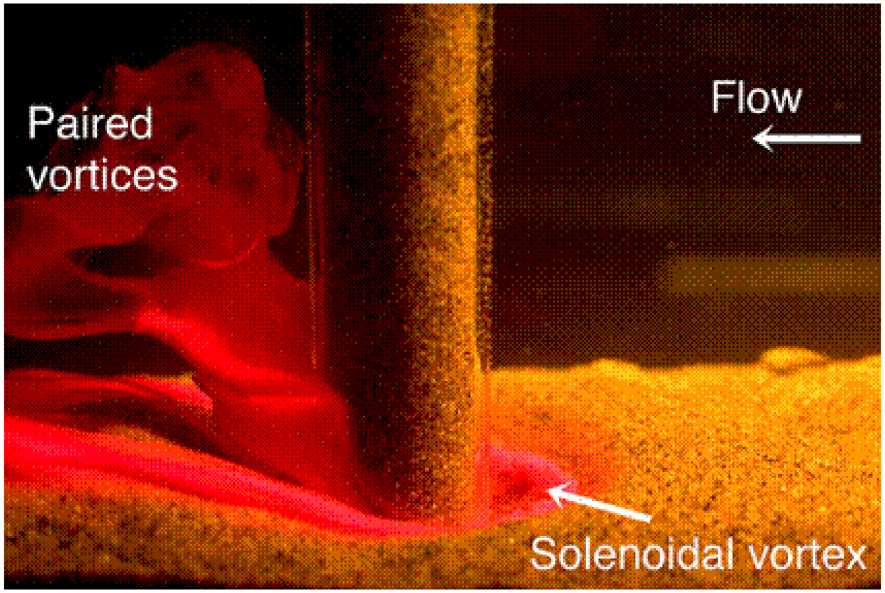


In the figure above, depth was used as the linear measurement for computing Re.

([Click for a program](#) to generate this graph using the SAS System.)

Remember that, because of the viscosity of water, velocity of flow on the substrate will be slower than in the main stream flow. This velocity gradient is called the "boundary layer" when its velocity is lower than 99% of the mainstream velocity. Note, that that figure is set arbitarily. In normal turbulent flow, the velocity of flow right at the substrate is low enough that laminar flow can occur. This is called the "**laminar sublayer**" or "**viscous layer**" of the boundary layer.

The boundary layer flowing around an object on the substrate can cause some moderately complex effects, such as the horseshoe - shaped "**solenoidal vortex**" upstream and lateral to the object. This highly energetic vortex keeps the substrate clear of material and may be more important for benthic organisms than previously recognized. An example of these flow types around a cylinder can been seen here:



For flow on the substrate, since it is essentially in a closed system, the **Principle of continuity** can be invoked. This states that discharge [i.e. cross sectional area(S) x velocity (U)] out of a system, equals that entering, or $S_1U_1=S_2U_2$. Of importance here is that streamlines of flow do not cross and therefore diverging streamlines indicate a decrease in velocity and vice versa.

For those of you dealing with flows that do not lend themselves easily to depth and velocity measurement, consider doing some "flow visualization" with methylene blue dye. There may be a regular, or recognizable type of flow at that particular habitat preferred by your favourite animal. Try it, you might be surprised and anyway it's fun**!**

Things To Do

- Read Vogel (1981) - he is an expert on K.I.S.S.
- Carry methylene blue and a syringe around with you for flow visualization - watch for the solenoidal vortex.
- When you look at flowing water, think of depth and velocity and how these interrelate at the specific energy level. Then get out there and with the thin, steel ruler (or other measuring device) that you **ALWAYS** carry with you, make some measurements so that you can use the powerful descriptive terms available to you!

Symbol Table

- D=depth of water.
- g=force due to gravity, or 981 cm/sec^2.
- S=cross sectional area of discharge.

- U=velocity.
- v=kinematic viscosity of water=1.1 mm/s^2 at 15 degrees C.
- SQRT means square root.

Some Useful Reading

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(Modified 1993 by D.A. Craig)

(Prepared for WWW publication in 1996 by T.C. Folsom, including production of the graph.)