FLO-2D Limiting Froude Number Application Guidelines

Using the Froude number in flood routing models is an important to the both the understanding of the floodwave movement and the numerical stability of the model. It is even more important when considering mobile bed channels such as alluvial fans or high bedload rivers. The dimensionless Froude number F_r is given by:

$$F_r = \alpha^{0.5} V/(gd)^{0.5}$$

where V = depth averaged flow velocity, d = depth of flow above the thalweg, and α = kinetic energy correction factor (involving the fluid density and specific weight). Typically α is assumed to be 1. The Froude number helps to define the influence of gravity on the flow pattern. A low wave will propagate in free surface flow (open channel) depending only on the gravitational acceleration and the flow depth. The movement (speed) of the shallow wave, known as the wave celerity $c = \sqrt{gd}$, is related to average flow velocity through the Froude number. By accepting reasonable limitations of the overland (or channel) flow velocity and floodwave movement, the Froude number can be used to further define the relationship between the velocity and flow depth.

For essentially steady and uniform flow, the Manning's n value is defined would be defined by:

$$n = (0.262/F_r)\, d^{0.17}\, S_o{}^{0.5}$$

indicating that the flow roughness is inversely proportional the Froude number. By assuming a reasonable limiting Froude number, the n value can be estimated from the normal depth and slope for a given flow discharge.

In the FLO-2D model, the suggested n-value is based on either bankfull discharge for channel flow or 1 meter (3 ft) flow depth for overland flow (roughness is fully submerged). Suggested typical limiting Froude numbers are:

	Flat or Mild Slope (large rivers and floodplains)	Steep Slope (alluvial fans and watersheds)
Channels	0.4 – 0.6	0.7 - 1.05
Overland flow	0.5 – 0.8	0.7 – 0.95
Streets	0.9 – 1.2	1.1 – 1.5

Similar values are also reported in the CVFED FLO-2D Application Guide. If the limiting Froude number is exceeded, the grid element n-value increases by 0.001 for the next timestep. When limiting F_r is no longer exceeded, the n-value decreases by 0.0005 if it's greater than the original n-value. The changes in n-value reported in ROUGH.OUT, FPLAIN.RGH, CHAN.RGH and STREET.RGH files. The use of limiting Froude number in the FLO-2D model is documented in the FLO-2D Pocket Guide, the FLO-2D Reference Manual, and the CVFED FLO-2D Application Guide.

Additional considerations:

1. The maximum n-values for discretized models will be greater than typical n-values for HEC-RAS cross sections (both channel and overbank areas). This is because of the unsteady and non-uniform flow contribution between elements and the flow not being parallel to the cross section.
2. For flows over mobile bed conditions (supply unlimited), critical flows are approached asymptotically (Grant, 1997). A relatively steep slope is required for flow with sediment transport to achieve critical flow because the flow hydraulics oscillate. For $F_r > 1$, flow instability leads to rapid energy dissipation and bed erosion. Flow is forced to stay around critical by incipient motion thresholds. The equilibrium sand bed morphology tends to minimize the Froude number (Jia, 1990).
3. The limiting Froude number for mobile bed conditions can be approximated by (Grant, 1997):

$$F_r = 3.85\ S^{0.33} \quad \text{gravel bed } (\tau^*_{cr} = 0.03)$$
$$F_r = 5.18\ S^{0.11} \quad \text{sand bed } (\tau^*_{cr} = 0.06)$$

4. Roughness n-values include many factors: $n = n_1 + n_2 + n_3 + n_4 + \ldots$ such as friction drag, vegetation, expansion/contraction, bed forms, flow in bends, unsteady and non-uniform flow

References:

Grant, G.E., 1997. "Critical flow constrains flow hydraulics in mobile bed streams: A new hypothesis," Water Resources Research, V. 33, No. 2, pp. 349-358.

Jia, Y., 1990. "Minimum Froude number and the equilibrium of alluvial sand rivers," Earth Surface, Processes, and Landforms, 15, pp. 199-209.