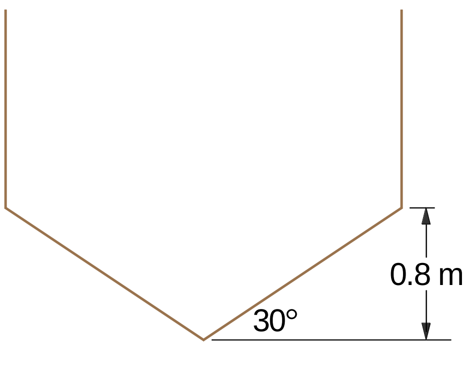
Normal and Critical Depths

Q1.
If the discharge in a channel of width 5 m is 20 $m^3 s^{-1}$ and Manning's n is 0.02 $m^{-1/3}$ s, calculate:
(a) the normal depth and Froude number for a streamwise slope of 0.001;
(b) the normal depth and Froude number for a streamwise slope of 0.01;
(c) the critical depth;
(d) the critical slope.

Q2.
A prismatic channel of symmetric trapezoidal section, 1600 mm deep and with top and bottom widths 3 m and 0.6 m respectively carries water at a rate of 2.6 $m^3 s^{-1}$. Manning's n may be taken as 0.012 $m^{-1/3}$ s. Find:
(a) the normal depth at a slope of 1 in 2500;
(b) the Froude number at the normal depth;
(c) the critical depth;
(d) the critical slope.

Q3.
A channel of semi-circular cross-section, radius 0.7 m, carries water at a rate of 0.8 $m^3 s^{-1}$. Manning's n is 0.013 $m^{-1/3}$ s. Find:
(a) the normal depth (relative to the bottom of the channel) at a slope of 2%;
(b) the Froude number at the normal depth;
(c) the critical depth.

Q4.
A prismatic channel with the symmetric cross-section shown carries water at a rate of 1.5 $m^3 s^{-1}$. Manning's n may be taken as 0.02 $m^{-1/3}$ s and the streamwise slope is 0.1%. Find:
(a) the normal depth (relative to the lowest point);
(b) the Froude number at the normal depth;
(c) the critical depth at this flow rate.



Rapidly-Varied Flow

Q5.
A broad-crested weir is placed in a wide channel with a slope of 2×10^{-4} with a discharge of 1.5 m^3 s^{-1} per metre width. Manning's *n* is 0.015 $m^{-1/3}$ s. Assuming that the flow far upstream is normal, hydraulic jumps do not occur and energy losses over the weir may be neglected:

(a) find depths upstream, over, and downstream of the weir if the weir height is 0.2 m;
(b) find depths upstream, over, and downstream of the weir if the weir height is 0.5 m;
(c) the weir height that will just make the flow critical.

Q6. (Examination, January 2013)
A discharge of 9 m^3 s^{-1} flows down a long channel with streamwise slope 1 in 1000 and Manning's roughness coefficient $n = 0.024$ $m^{-1/3}$ s. The channel cross-section is rectangular with bottom width 4 m and side height 2.5 m.

(a) Find the normal depth and critical depth in the channel.

A broad-crested weir is constructed at one point in the channel. Find the heights of weir that will:

(b) just make the flow go critical;
(c) cause the flow to overtop the banks.

Q7.
A long wide rectangular channel has a slope of 2×10^{-5}, a Manning's *n* of 0.01 $m^{-1/3}$ s and a flow rate of 0.5 m^3 s^{-1} per metre width. A broad-crested weir with a height of 0.7 m is placed in the channel. Determine:

(a) the normal depth in the channel;
(b) the depth over the weir;
(c) the depth downstream of the weir assuming that the hydraulic jump occurs well downstream;
(d) the depth upstream of the hydraulic jump, and thus …
(e) the actual position of the hydraulic jump.

Q8.

(a) A venturi flume in a channel of width 1 m has a throat width of 0.7 m. If the depth of 0.5 m upstream of the flume just causes critical conditions, calculate the discharge.
(b) Assuming that the bed is level and that a hydraulic jump occurs downstream of the constriction where the channel has resumed its original width, find the depths upstream and downstream of the jump.

Q9.

Water is conveyed at 12 $m^3 s^{-1}$ through a rectangular channel of width 5 m, streamwise slope 0.01% and Manning's $n = 0.016$. At one point the channel narrows to a width of 2 m. Assuming that normal-flow conditions prevail upstream, calculate:

(a) the normal depth in the main channel;

(b) the critical depth at the narrow point and show that the flow does *not* become critical here;

(c) the actual water depth at the narrow point;

(d) the minimum height by which the bed of the constricted section must be raised locally in order to force critical conditions there;

(e) the depths at the narrow point and in the main channel just up- and downstream of the constricted section if the bed is raised as in part (d). (Assume that no hydraulic jumps occur here.)

Q10.

Water is conveyed at 11 $m^3 s^{-1}$ through a long rectangular channel of width 4 m, streamwise slope 2×10^{-3} and Manning's $n = 0.02$ $m^{-1/3}$ s. At one point the channel narrows to a width of 2.5 m. Calculate:

(a) the normal depth and critical depth in the main channel;

(b) the critical depth at the narrow point and show that the flow *does* become critical here;

(c) the water depths at stations just up and downstream of the contraction;

(d) the depth by which the bed of the constricted section must be *sunk* locally in order to just prevent the occurrence of critical conditions there.

Q11.

A sluice gate controls the flow in a channel of width 2.5 m. If the depths of water upstream and downstream of the gate are 1.4 m and 0.25 m, respectively, then calculate:

(a) the discharge;

(b) the Froude numbers upstream and downstream of the sluice gate.

Q12.

Water passes under a sluice gate in a horizontal channel of width 2 m. The depths of flow on either side of the sluice gate are 1.8 m and 0.3 m. A hydraulic jump occurs a short distance downstream. Assuming no energy loss at the gate, calculate:

(a) the force on the gate;

(b) the depth of flow downstream of the hydraulic jump;

(c) the fraction of the fluid energy that is dissipated in the jump.

Q13.

An undershot sluice controls the flow in a channel of width 1.5 m. If the flow rate is 3 $m^3 s^{-1}$ and the upstream depth is 1.8 m calculate the minimum depth and Froude number just downstream of the sluice if:

(a) there is no energy loss;

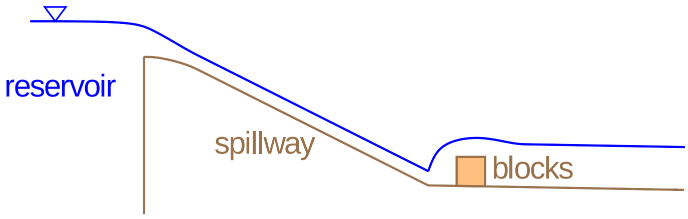
(b) there is a 10% loss in specific energy through the sluice.

Forces on Obstacles

Q14.
Two rows of baffle blocks are installed in a stilling basin in order to force a hydraulic jump within the basin. Each row of blocks has a drag coefficient $c_D = 0.3$, defined as $force / \frac{1}{2}\rho V^2 A$, where A is the frontal area (blocks + gaps) facing the flow and V is the upstream velocity. The effective height of the blocks is 0.3 m and the width of the basin is 6 m. If the discharge is 28 $m^3 s^{-1}$ and the upstream depth is 0.6 m, determine the downstream depth if:

(a) a hydraulic jump *does not* occur;
(b) a hydraulic jump *does* occur.

Q15. (Examination, January 2012).



The spillway of a reservoir is a rectangular channel of width 4 m and slope 1 in 20. Manning's n may be taken as 0.012 $m^{-1/3}$ s. Shortly after a storm the water depth in the reservoir is 0.5 m above the top of the spillway.

(a) Assuming critical flow at the entrance to the spillway calculate the discharge.
(b) Calculate the normal depth on the spillway and confirm that the slope is hydraulically "steep" at this discharge.

The spillway leads to a channel of the same cross-section and roughness but slope 1 in 1000. A set of blocks is placed at the start of this channel, causing a hydraulic jump to occur there.

(c) Calculate the normal depth in the downstream channel.
(d) Assuming that the blocks cause a hydraulic jump to the downstream normal depth, calculate the total force on the blocks.

Q16. (Examination, January 2010).

(a) A sluice gate controls the flow in a rectangular channel of width 3 m. If the depth of parallel flow just upstream of the sluice is 2 m and that just downstream of the sluice is 0.3 m calculate the discharge in the channel.
(b) If the channel has slope 1 in 1000 and a Manning's roughness coefficient $n = 0.014$ $m^{-1/3}$ s calculate the normal depth at this discharge.
(c) A short distance downstream of the sluice a set of blocks provokes a hydraulic jump. If the flow depth immediately downstream of the blocks is the normal depth, calculate the total force on the blocks.

Hydraulic Jumps Triggered by Abrupt Expansions

Q17.
A rectangular channel carrying 10 $m^3 s^{-1}$ undergoes an abrupt expansion from width 4 m to width 8 m, triggering a hydraulic jump. The upstream depth is 0.5 m. Stating assumptions clearly, find the downstream depth.

Gradually-Varied Flow

Q18.
A wide rectangular channel has a slope of 2×10^{-5}, a Manning's n of 0.01 $m^{-1/3}$ s and a flow rate of 0.5 $m^3 s^{-1}$ per metre width. At the end of the channel there is a free overfall. Determine the distance from the free overfall to where the depth is 1 m. Use 2 steps in the gradually-varied-flow equation for hand calculations. Then code your calculations in a spreadsheet and repeat with 2, 5, 10, 50 and 100 steps.

Q19.
A sluice gate discharges water at 9 $m^3 s^{-1}$ into a 6 m wide rectangular channel laid on a slope of 0.0004 with $n = 0.015$ $m^{-1/3}$ s. The depth at the vena contracta is 0.15 m.

(a) Find the normal and critical depths.

(b) Compute the position of the hydraulic jump, assuming normal depth downstream. Use one step in the GVF equation.

Q20.

(a) A long rectangular channel is 3 m wide with Manning's $n = 0.018$ $m^{-1/3}$ s and runs downstream from a reservoir at a slope of 1:50 into a free overfall at its end. In the reservoir the surface water level is 1.35 m above the bed of the channel at its entrance and the velocity is negligible. Calculate the critical depth, the discharge and the normal depth, and hence sketch the shape of the water surface, giving the profile type.

(b) A sluice gate is installed a short distance upstream from the end of the channel and is lowered to produce a depth just downstream of 0.5 m. Determine relevant depths and positions of any hydraulic jumps (using two steps in the GVF equation). Sketch the surface profiles along the channel, naming the types of profile.

Q21.
A rectangular prismatic channel with width 2 m and Manning's $n = 0.012$ has slope of 1 in 2000 and ends in a free overfall. If the discharge is 1.6 $m^3 s^{-1}$ find the distance upstream of the overfall at which the depth is 650 mm. (Use 3 equal steps in the GVF equation.)

Q22.
Water runs down a wide spillway at 6 $m^3 s^{-1}$ per metre width onto a long concrete apron ($n = 0.015$) having a uniform downward slope of 1 in 2500. At the foot of the spillway the depth of flow is 600 mm. How far from the spillway will a hydraulic jump occur? (Use one step in the GVF equation).

Q23. (Examination, January 2013).

A long rectangular channel of width 5 m has a slope 5×10^{-3}, a Manning's n of 0.03 $m^{-1/3}$ s and carries a discharge 15 m^3 s^{-1}. Temporary works are constructed which restrict the width of the channel to 2 m for a short length.

(a) Find the normal depth in the main channel.

(b) Show that the flow goes critical in the restricted section and find the depth just downstream of the temporary works.

(c) Find the distance to the downstream hydraulic jump, using two steps in the gradually-varied-flow equation.

Q24. (Examination, January 2010 – modified and extended)

(a) A broad-crested weir with a crest height of 1.5 m controls the flow in a wide channel. If the discharge is 0.9 m^3 s^{-1} per metre width find the depths of flow over, just upstream and just downstream of the weir.

(b) If the channel has slope 3×10^{-4} and Manning's roughness coefficient 0.012 $m^{-1/3}$ s find the normal depth at this discharge.

(c) Using *two* steps in the gradually-varied-flow equation, find the distance upstream of the weir at which the depth is 0.1 m greater than the normal depth.

(d) Downstream of the weir the flow undergoes a hydraulic jump back to normal flow. Use *one* step in the gradually-varied-flow equation to estimate the distance from weir to hydraulic jump.

(e) Sketch the surface profile, indicating the main flow features and, in particular, showing the 2-character designation for each of the GVF curves (S1, M2 etc.).

Q25.

A long rectangular channel of width 5 m, slope 5×10^{-4} and Chézy coefficient 100 $m^{1/2}$ s^{-1} carries a discharge of 15 m^3 s^{-1}. A broad-crested weir is installed with a height of 1.0 m, which causes a critical-flow transition at the weir, with a hydraulic jump further downstream. Calculate:

(a) the normal and critical depths;

(b) the depth of flow at the downstream end of the weir;

(c) the depth of flow just upstream of the hydraulic jump;

(d) the distance of the hydraulic jump from the downstream end of the weir.

You may assume that the flow downstream of the hydraulic jump is normal flow. Use TWO steps in the GVF equation to locate the hydraulic jump.

Q26. (Examination, January 2011)

A long rectangular channel has width 4 m and streamwise slope 0.001. At one point in the channel a venturi flume is constructed with minimum width 2 m. The channel carries a flow of 5 $m^3 s^{-1}$ and the water depth far upstream of the venturi flume is 0.8 m.

(a) Estimate Manning's *n* for the channel.

(b) Show that the flow *does* go critical in the venturi section and find the water depth in the main channel just downstream of the flume.

(c) A short distance downstream of the venturi flume the flow undergoes a hydraulic jump. Assuming that normal-flow conditions prevail downstream of the jump use TWO steps in the gradually-varied-flow equation to estimate the distance from the end of the flume to the hydraulic jump.

Q27. (Examination, January 2012)

A wide rectangular channel, with Manning's roughness coefficient 0.012 $m^{-1/3}$ s, carries water down a slope of 0.001. At one point in the channel an undershot sluice is lowered to control the flow. When the gate opening is 0.35 m the depth of water upstream of the sluice is 1.2 m.

(a) Assuming that the depth at the vena contracta is 0.6 times the gate opening and that no energy is lost at the sluice, find the discharge per metre width in the channel.

(b) Find the normal depth and critical depth at this discharge.

(c) Using two steps in the gradually-varied-flow equation, find the distance upstream of the sluice at which the water depth is 0.1 m greater than the normal depth.

(d) If there are long undisturbed fetches upstream and downstream of the sluice sketch the water surface profile and classify the profile using its 2-character designation in each region of gradually-varied flow.