EXCEL SPREADSHEETS FOR HYDRAULIC TEACHING – INSTRUCTIONS

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This document describes a set of Microsoft Excel spreadsheets designed to be used in an undergraduate hydraulic engineering course, covering the basics of pressure flow and free surface flow. The spreadsheets are organized in 7 workbooks, as indicated in the table of contents below.

Within the spreadsheets, the cells are color-coded:

Yellow	Data to be entered by the user
Pink	Calculated variable
Orange	Constant
Grey	Auxiliary optimization variables
Green	Tables with intermediate or final results

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Workbook A – pipe flow

This workbook includes three worksheets, described below. The main objective is to evaluate continuous losses in a pipe segment using the Darcy-Weisbach equation and the Swamee-Jain expression for the friction factor.

Worksheet 1– Pipe without local loss

The problem to be solved is that of a simple pipe segment, applying the Darcy-Weisbach equation, whose friction factor is estimated with the Swamee-Jain equation. The equations are shown in the spreadsheet.

Option 1: Head loss calculation (calculation of energy dissipation)

The calculation of the energy dissipation given the rest of the variables (length, diameter, roughness and discharge) is explicit (the equation is shown).

Option 2: Discharge calculation (calculation of circulating flow)

The calculation of the discharge given the rest of the variables (length, diameter, roughness and energy dissipation) is implicit, as can be seen in the equation. The Excel optimization function *Goal Seek* is used. A seed value is entered for the discharge, and the calculated energy dissipation is imposed to be equal to that desired by modifying the flow rate (cell "Zero" is the difference).

Goal Seek	
Set cell:	H20
To value:	0
By changing cell:	G8

Option 3: Diameter calculation (calculation of the appropriate diameter)

The calculation of the diameter given the rest of the variables (length, discharge, roughness and enery dissipation) is implicit, as can be seen in the equation. The Excel optimization function *Goal Seek* is used. A seed value for the diameter is entered, and the calculated energy dissipation is imposed to be equal to that desired by modifying the diameter (cell "Zero" is the difference).

Goal Seek	
Set cell:	L20
To value:	0
By changing cell:	K5

The equation can be simplified for fully turbulent flow in rough conduits, since the Reynolds number is not relevant. The simplified equation is shown. In this case, the calculation of the discharge is also explicit. The calculation procedure for the diameter is similar to the general case.

Worksheet 2 – Pipe with local loss

This worksheet included an additional element: the sum of localized loss coefficients, which must be entered by the user. The equation (shown) is modified slightly. The calculation procedure is similar to that in worksheet 1.

Worksheet 3 – Pressure calculations

In this example, flow and pressures are calculated in a pipeline with different segments and elevations. The calculation block of worksheet 2 is included to determine the discharge. Local loss coefficients are extracted from the figure.

Once the discharge is calculated, the energy at each relevant point (A, B, C and D in the figure) can be calculated from the energy at point 0, subtracting continuous and local losses from this initial energy. The pressure at each point is then calculated by subtracting the kinetic term and the elevation from the total energy.

Workbook B - pumps

This workbook includes three worksheets, described below. The main objective is to incorporate pumping units in the calculation of pressure pipelines.

Worksheet 1– Operating point

In this worksheet the operating point of a pumping unit is determined.

Building on the calculation of a simple pipe segment in workbook A, a pumping unit is introduced. The energy difference between the start and end of the pipe system is negative if water is pumped from a lower to a higher elevation. The operating point is calculated as the intersection of the system resistance curve and the pump characteristic curve.

The points that define the system resistance curve are calculated as follows. Given a value of pumping height Hb (entered as data in the calculator), the *Goal Seek* function is used to calculate the pumped discharge, according to the resistance curve. The calculated pairs Q/Hb are written down in the corresponding cells (block marked in green), plotted in the graph "Resistance curve", and an equation is fit to the data.

Goal Seek	
Set cell:	C21
To value:	0
By changing cell:	B6

The points that define the pump characteristic curve, which is supplied by the manufacturer, are entered by the user in the corresponding cells (block marked in yellow). The curve is plotted and an equation is fit to the data.

The two curves are plotted together on the same graph, showing the operating point (the intersection between curves). To calculate numerically the corresponding Q-Hb value, the parameters of both curves are entered in the green block (curve equations are shown in the corresponding graphs). For each discharge value, a pumping height value is obtained according to each of the two curves. The value marked in grey is the difference between them, which must be zero. The *Goal Seek* function is used to find the value of discharge that matches this condition.

Goal Seek	
Set cell:	R3
To value:	0
By changing cell:	O3

Worksheet 2 – Choice of pump

This worksheet is similar to the previous one, but a characteristic curve that corresponds to a real pump is used. In the example, the aim is to select a pump that will give a discharge of 50 L/s.

The system resistance curve is obtained as in the previous worksheet. The pump must be chosen from those available in a commercial catalogue (Bombas Ideal Pump). The desired operating point (more or less) is obtained from the resistance curve, and plotted as a point on the pump catalog, which allows the choice of a specific typology. The set of commercial curves for that typology is shown on the right figure. The desired operating point is plotted on these commercial curves, and a specific pump is chosen. Please note that if the target discharge is changed, the points must be relocated, and this could eventually require the use of another set of commercial curves (not available in the worksheet).

Three points of the chosen curve are obtained and written down in the table of the characteristic curve (in yellow). The operating point is obtained as in the previous worksheet, as the intersection of the resistance curve and the characteristic curve (graphical and numerical calculation).

Worksheet 3 – Coupling of pumps

This worksheet is similar to the first one, but includes the possibility of coupling pumps in series or in parallel. The number of pumping units in series and in parallel must be indicated (cells J2 and J3). If values greater than 1 are entered in both cells, the total number of pumps will be the product of both numbers (n parallel lines with m pumps in each line).

The characteristic curve of one of the pumps (they are all the same) must be entered (yellow table). The resulting pump performance curve is calculated and plotted. The operating point for the set of pumps is calculated.

Workbook C – branched systems

This workbook contains two worksheets, described below. They are focused on the analysis of networks, illustrated with the problem of three tanks: a system with three branching pipes connected to a common node, with a tank at the upstream end of each pipe. The mass conservation equation at the node and the energy conservation along the branches are applied.

Worksheet 1 – Flow distribution

The aim is to calculate a consistent distribution of flows between the three tanks.

A calculation block equal to that of workbook A – worksheet 1 is used, assuming fully turbulent flow in rough conduits for simplicity. The water height in each tank is the data that needs to be entered (instead of the energy dissipation that was the input data in worksheet A-1).

The flows in each branch (AD, BD, CD) are calculated from the seed value of the energy at the node, which must be assumed and must have a reasonable value (intermediate considering the water height in the tanks, without being equal to any one of them). From this energy value, the flows and their directions are calculated (1=flow enters the node, -1=flow leaves the node). The energy conservation equation is imposed as the sum of all the flows that reach the node, which must be zero. The *Goal Seek* function is used to set the sum of flows to zero by changing the energy at the node.

Goal Seek	
Set cell:	D21
To value:	0
By changing cell:	D20

Worksheet 2 – Time

This worksheet is similar to the previous one, but in this case the effect of time is considered (i.e., we seek to observe the evolution of the water height in the tanks over time). The calculation is done in steps, so that each time interval is calculated and its results used to calculate the next time step. Since the levels in the tanks will vary, it is necessary to know their surface to be able to calculate the volume that enters or leaves the tanks in each time interval.

The worksheet includes an example already developed for some time increments and for certain tank surfaces. If these values are to be changed, the table marked in green needs to be redone. This table is to be filled in row by row, as explained below using the example. A rapid or "agile" calculation method is not sought in this worksheet. The purpose is rather to help the student to understand the procedure used by professional software such as Epanet to simulate a flow that varies over time by means of a succession of permanent flows, changing the levels of the tanks.

Time 0 corresponds to the initial condition, and the initial water levels in the tanks and the flows entering and leaving each tank are calculated in the first row of the green table. Given a time step (cell C23), the changes in volume in each tank are calculated in the auxiliary table (cells M15 to R18), which are converted into water height variations based on the tanks surface. The new energy values (after the increase in time) are obtained from the initial ones (in green), subtracting the variations.

The values of the second row of the green table are taken from the flow rates (with its sign) of each branch and from the new energy values. They must be transcribed by hand. The water height in the tanks must be set to the new values (by hand), and a new calculation interval needs to be defined (it may be different from the previous one). The procedure is then repeated.

Workbook D – water hammer

This workbook contains three worksheets, described below. The main objective is the analysis of hydraulic transients, illustrated with some examples of valve closures in a pipe system. The variation over time of the dynamic pressure is shown, assuming no attenuation.

Worksheet 1– Point A, stepwise closure

This spreadsheet allows to calculate the celerity of the pressure wave and the value of the dynamic pressure surge in a simple reservoir-pipe-valve system. Given the length of the pipe, the flow velocity before the valve closure, the diameter of the pipe, its thickness and the modulus of elasticity of the pipe material, these variables are calculated according to the simple expressions shown in the spreadsheet.

The pressure evolution as function of time is calculated in two cases: an instantaneous total closure and a total closure in 6 steps (of 1/6 each) ending before instant $t=L/2c$ (therefore a rapid closure). The increase (or decrease) in pressure that occurs in the first case is shown in blue in the graph. The second case is intended to show the cumulative effect of partial closures, which results in a nearly linear growth (or decrease) trend. The effect of each partial closure is shown in a different colour in the graph, and the sum of the 6 partial closures is depicted in brown. The graph is constructed from the numerical results shown in the table, which include partial and total pressures.

Worksheet 2– Point A, linear closure

A linear valve closure is analysed in this worksheet. The pressure next to the valve (point A of the diagram) is evaluated, considering a closure time that can be modified by the user (cell B21 of input data in yellow). The rest of the input data and intermediate variables are similar to those already mentioned in worksheet 1. As shown in that spreadsheet, a linear closure can be understood as the sum of partial instantaneous closures.

The graph shows the evolution of the compression and decompression waves that start from the valve at times multiple of 2L/c, and their sum, which is the resulting pressure distribution (in green). A total of 5 waves (3 of compression and 2 of decompression) are considered. By introducing different closure times, its role with respect to reaching (or not) the maximum dynamic pressure can be observed. The calculations are shown in the table.

Worksheet 3– Point B, linear closure

A linear valve closure is analysed in this worksheet. The pressure at the midpoint of the pipe (point B of the diagram) is evaluated, considering a closure time that can be modified by the user (cell B21 of input data in yellow). The rest of the input data and intermediate variables are similar to those already mentioned in worksheet 1. As shown in that spreadsheet, a linear closure can be understood as the sum of partial instantaneous closures.

The graph shows the evolution of the compression and decompression waves that start from the valve at times multiple of 2L/c, and that reach point B in multiples of L/2c, and their sum, which is the resulting pressure distribution (in black). A total of 10 waves (5 of compression and 5 of decompression) are considered. By introducing different closure times, its role with respect to reaching (or not) the maximum dynamic pressure can be observed. The calculations are shown in the table.

Workbook E – channel flow

This workbook allows to calculate the basic characteristics of a channel with different geometries, such as its normal depth, its critical depth, and variables derived from these, such as its velocity or the conjugate depth of the normal depth.

The workbook contains 4 worksheets, each of which corresponds to a different geometry.

Worksheet 1– Rectangle

First, the input data (in yellow) need to be entered, including the depth (y) and discharge (Q) values. The velocity (v), wetted perimeter (Pm), hydraulic radius (Rh) and Froude number (Fr) corresponding to that depth are obtained.

Given the shape of the cross section and the discharge, the calculation of the critical depth is explicit. To calculate the normal depth, we impose the equality between the channel slope and the energy slope (i-I=0 in cell C21), using the *Goal Seek* function with the depth (y) as changing variable. Finally, the conjugate depth of “y” is calculated using the Bélanger equation.

Worksheet 2– Triangle

The geometry is defined by the angle β. The discharge, slope and Manning's roughness coefficient are entered to calculate the geometric variables.

For the calculation of the critical depth, a Froude number of 1 is imposed, using the *Goal Seek* function with the depth (y) as changing variable, as shown below. The normal depth is calculated as in the previous worksheet.

Goal Seek	
Set cell:	C19
To value:	1
By changing cell:	C6

Worksheet 3– Trapezoid

The geometry is defined by the angle α and the length L. The procedure is the same as in the previous worksheet.

Worksheet 4– Semicircle

The geometry is defined by the radius and the angle Θ. The procedure is the same as in the previous worksheet.

Workbook F – hydraulic sections

The main objective of this workbook is to calculate the best hydraulic sections for four cross-sections shapes: rectangle, triangle, trapezoid and semicircle. The best hydraulic section is the one that has the maximum conveyance for a given surface area, which implies that the wetted perimeter is minimum. The workbook contains only one worksheet.

For each of the four shapes included in the worksheet, the wetter perimeter has been expressed as a function of the basic geometric parameters. The area A (in yellow) and seed values for the basic parameters (in pink) are entered. For example, in the case of the rectangular section, the depth (y) is entered and the width (B) is calculated as y/A, so that the area remains constant.

To minimize the value of the wetted perimeter (Pm), the *Solver* function in Excel is used, with Pm as the target cell (in brown). In the case of the rectangular and the triangular sections, the "changing cell" is the depth. In the circular section, the angle is used (larger angles imply smaller radius for a given area). In the case of the trapezoid section, two parameters are required: the base (L) and the half-difference between the bases (D), as shown below.

Solver Parameters	
Set Objective:	C24
To:	Min
By Changing Variable Cells:	C19: C20
Select a Solving Method:	GRG Nonlinear

Once the optimization is finished, the cross section shapes obtained are the half of a square, in the rectangular and triangular cases, the half of a hexagon, in the trapezoidal case, and the semi-circular one in the circular case.

Workbook G – backwater curves

The workbook allows the calculation of backwater curves in a hydraulic channel. It contains only one worksheet.

The water surface profile in a channel of constant slope and rectangular cross-section is drawn. The input data are the initial abscissa (x_0), the length increment (Ax), which is positive (negative) if we look for downstream (upstream) values, the elevation of the initial point (z_0), the slope (i), the Manning's roughness coefficient (n), the discharge (Q) and the width (B). Additionally, the depth at the initial point (y_0) is required, which will be used as boundary condition for the integration. The integration is performed by means of a fourth-order Runge-Kutta algorithm (the equations are included in the spreadsheet)

The critical and normal depths are calculated as auxiliary variables, using the methodology already described in workbook E – worksheet 1.

The calculations are shown in the table: the auxiliary variables of the method (hidden columns F to N) and the main variables for each of the spatial increments (100 increments are calculated). The graph, constructed from the numerical results in the table, shows the water surface profile (z+y), as well as the lines that delimit the normal and critical depth ($z+y_n$, $z+y_c$), and the conjugated depth that corresponds to each depth ($z+y_{conj}$).