

# Flow – Integrated hydraulic calculation software for water supply systems

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**Abstract**—The possibilities of applying technology in the context of engineering are numerous and must be explored since they increase efficiency by reducing operating time while delivering more accurate and therefore more reliable results. To follow these advances, it was noticed the need to develop a computational tool that helps and facilitates the resolution of hydraulic problems. This article aims to present the Flow software as an important educational and practical tool, addressing its conceptual and operational aspects. The software was developed using Visual Studio 2017 and CSharp as the programming language. The main topics covered by the program are closed conduits (friction head loss, local head loss, head loss with flow distribution, series and parallel connected pipes, and water hammer phenomenon), water distribution systems (dead-end and closed-loops system), water pumps (operating conditions, pump power and cavitation) and open channels (rigid boundary and erodible channels). The software has demonstrated great potential as a tool for hydraulic calculations as it has a user-friendly interface, and it provides accurate results.

**Keywords**—*Decision Support System, Computer Program, Open Channels, Pump Power, Water Distribution Systems.*

## I. INTRODUCTION

Hydraulics have always been present through all human history due to water's essentiality to human life. Industrial development, population growth and consequently the increase of consumption of this natural resource have made necessary the development of strategic solutions for water's proper use. Since then, concern about this resource has been brought up as its access has become limited. Reference [1] estimate that 2.2 billion people lack access to safely managed drinking water services and over 4.2 billion people do not have safely managed sanitation services. Considering this scenario, it is evident the need to study hydraulics to solve these and other issues.

The existing knowledge about hydraulics is being implemented in algorithms that are increasingly efficient due to the advancement of information technology. Reference [2] states that this has

conditioned a real revolution in the hydraulics field. Still according to them, a constant evolution of information technology combined with the introduction of progressively powerful numerical and computational methods, allow to emerge a perspective of intense development in Hydraulic Engineering. Despite this panorama, there is a lack of computer systems that can help and contribute to this sphere. To fill this gap, the Flow software was developed. It can be downloaded at the Department of Sanitary and Environmental Engineering's website of the Federal University of Juiz de Fora (UFJF), at the following link: <https://www.ufjf.br/esa/ensino/software/>>.

The objective of this article is to present the development of the Flow software as an important tool for calculating and solving hydraulic problems, aiming to assist the user through a user-friendly interface and delivering accurate results. The software was developed using C# language and Microsoft Visual Studio integrated development environment (IDE). Four main hydraulics topics were selected to compose the program: closed conduits (friction head loss, local head loss, head loss with flow distribution, series and parallel connected pipes, and water hammer phenomenon in pipelines); water distribution systems (dead-end water distribution system and closed-loop system - for single or multiple loops); water pumps (operating conditions, pump power and cavitation in water pumps); and open channels (rigid boundary and erodible channels).

### A. Computational hydraulic tools

Currently, there are few existing hydraulics software available for free use. Among them, those that are available are few and very limited in terms of applications. Taking that into account, Flow was created as a flexible tool as it covers a variety of hydraulic topics in one single computer program. The following are some of the hydraulics software that are available for use.

EPANET is an American software developed by the U. S. Environmental Protection Agency (USEPA) translated and adapted by the Efficiency Laboratory Energy and Hydraulics in Sanitation at the Federal University of Paraíba (UFPB). It performs static and dynamic simulations of hydraulic behavior and water quality in pressurized distribution networks. The user can also design networks with graphic resources in an intuitive and dynamic way, obtaining the flow values in each piping, the pressure at each node, the water

height at each variable level reservoir, and the concentration of chemical species through the network during the simulation period, subdivided into multiple calculation intervals [3].

HIDROS is a set of software that implement several models for dimensioning and managing of hydro-agricultural projects [4]. It was developed by the Water Resources Research Group (GPRH) of the Federal University of Viçosa (UFV). This tool was designed to meet the constant requests for users of these software, and it is composed of topics on parameters of rainfall equation parameters, channel design, surface drainage, terracing control, among others.

SmartPumping is a computer program for monitoring and controlling in real time flow networks, developed by [5]. This program uses a simulation-optimization approach as a strategy for forecasting and controlling the status of the network. This simulation module is based on steady state flow regime [5].

Bombasoft is a software for dimensioning discharge systems created by [6]. It performs calculations of friction and local head loss, calculates the gross pumping head, and is also capable of carrying out an economic analysis proposing optimized cost-effective pipe diameters and estimates monthly and annual costs with electric power, among other functions. This application can be used in discharge systems for irrigation, water supply, and other types of fluid transportations [6].

#### B. NBR 12218/2017

The Brazilian technical norm "Project of water distribution networks for public water supply – Procedures", NBR 12218/2017, provides guidelines that must be considerate when designing water distribution networks. Following those recommendations is essential to develop a correct and safe project. The Flow software requires the user to enter data from the network to dimension it. If these data are entered incorrectly or in disagreement with the standard, the results will not be valid.

Flow rates, for example, must be established to meet specific areas as well as flow rates that will attend expanding areas in the future, so that the required demand is correctly estimated [7]. Additionally, it also must include the study of fire hydrants placement, through a table presented in the standard that defines their adequate distribution in the network.

The item 5.3 "Operating pressure" of the NBR must also be carefully observed by the user. It establishes that the minimum dynamic pressure of the network must be 100 kPa and the maximum 400 kPa, reaching 500 kPa in regions of rugged topography.

Regarding velocity rates, the standard recommends a minimum of 0.40m/s. The maximum velocity must correspond to a head loss of up to 10m/km.

## II. THE FLOW SOFTWARE

### A. Software overview

Initially, the topics of interest that were going to be included in the software were selected. This decision was based on practical engineering problems and the motivation was to develop a decision support system for general hydraulics projects, as no other similar systems are available. Furthermore, Flow was developed to be a useful support educational, reinforcing the learning process, and encouraging students to develop studies and projects in Hydraulics.

Flow was divided into 4 main modules to group its forms in a more appropriate way. The modules are closed conduits, water distribution systems, water pumps, and open channels. The Flow structure diagram is shown in Fig. 1.

Then it was developed a project management plan, consisted of creating a schedule of activities, as well as defining them. A basic scope was planned for programming each form. Some procedures and structures have been decided to standardize the use of the software.

The user's interaction with the software begins with data entry, which may consist of choosing the method of calculation, as in the case of friction head loss in which Hazen-Williams or Darcy-Weisbach equations can be chosen, or, for example, in the case of local head loss, which offers the option of calculating using the equivalent length method or using the local head loss's general formula. In some cases, it is also necessary to choose the variable to be found, such as friction head loss, flow, pipe diameter, length, material coefficient, in addition to filling in the form fields with the data of the problem. Besides, when applicable, it is possible to access database in some forms, such as Hazen-Williams coefficients "C", equivalent lengths, local head loss coefficients "K", among others. Once this is done, the user clicks the Calculate button. The software checks the data entered: for example, in some cases zero values or empty form fields are not accepted. If the software finds any error of this type, a message box will appear on the screen informing the error occurred. Otherwise, the calculation is executed, and the result is displayed in the calculated variable's text box itself. Besides, it is also possible to export the results in some forms when they are shown as graphs or tables. Fig. 2 shows de software home screen.

### B. Closed Conduits

The first form of this section is about friction head loss (Fig. 3) and it performs calculations through the Hazen-Williams and the Darcy-Weisbach (or Universal) equations. It is possible to calculate the coefficient, flow rate, pipe diameter and length and friction head loss.

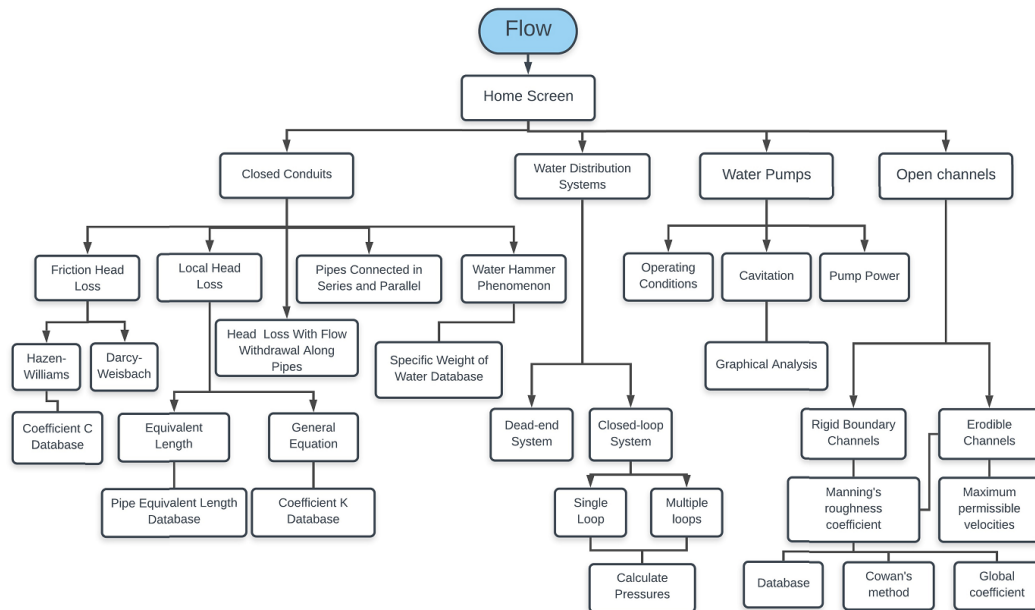


Fig. 1. Flow structure diagram

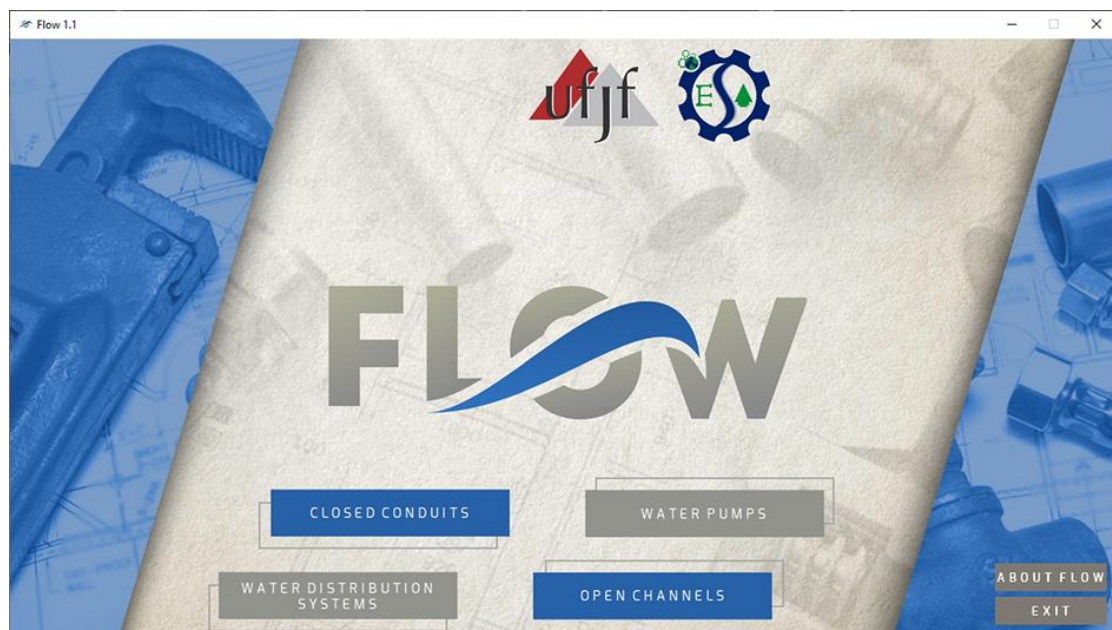


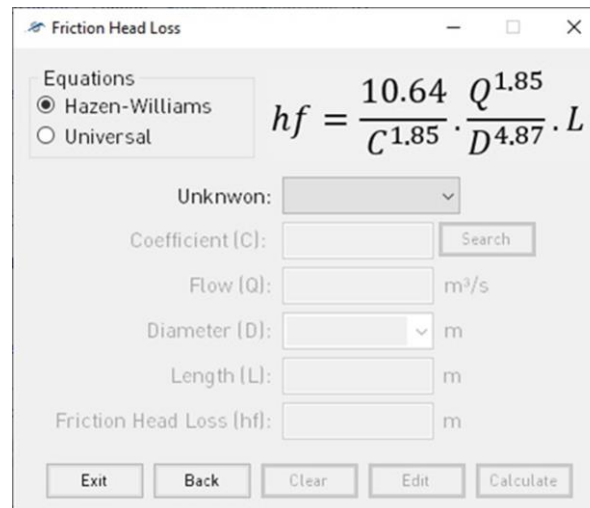
Fig. 2. Flow home screen

The second form is “Local head loss” (Fig. 4) and it is based on two methods. The first one is the local head loss's general formula. It calculates the total head loss, and it has the coefficient K's database. The second one is the equivalent length method, and it can calculate the flow rate, pipe length and the head loss. There is a pipe equivalent length database available according to the pipe diameter.

The head loss with flow withdrawal along the pipes form (Fig. 5) was created to head loss calculation when the pipes have derivations along their length. The unknowns in this case can be coefficient, diameter, length, and head loss.

The form for pipes connected in series and parallel (Fig. 6) performs calculations to find the equivalent beta, pipe diameter and length.

The water hammer phenomenon form (Fig. 7) calculates pressure variation in a pipe. The variables that must be informed (or that can be calculated) are celerity, characteristic time, closure time or stopping time (in the case of pumps). The software will compare the entered (or calculated) times and will classify the closure maneuver as fast or slow and will calculate the pressure variation. It is also possible to obtain the maximum and minimum pressure of the system if the user enters the value of the static pressure of the system.



Friction Head Loss

Equations

☒ Hazen-Williams

☐ Universal

$$h_f = \frac{10.64}{C^{1.85}} \cdot \frac{Q^{1.85}}{D^{4.87}} \cdot L$$

Unknown:

Coefficient (C):  Search

Flow (Q):  m<sup>3</sup>/s

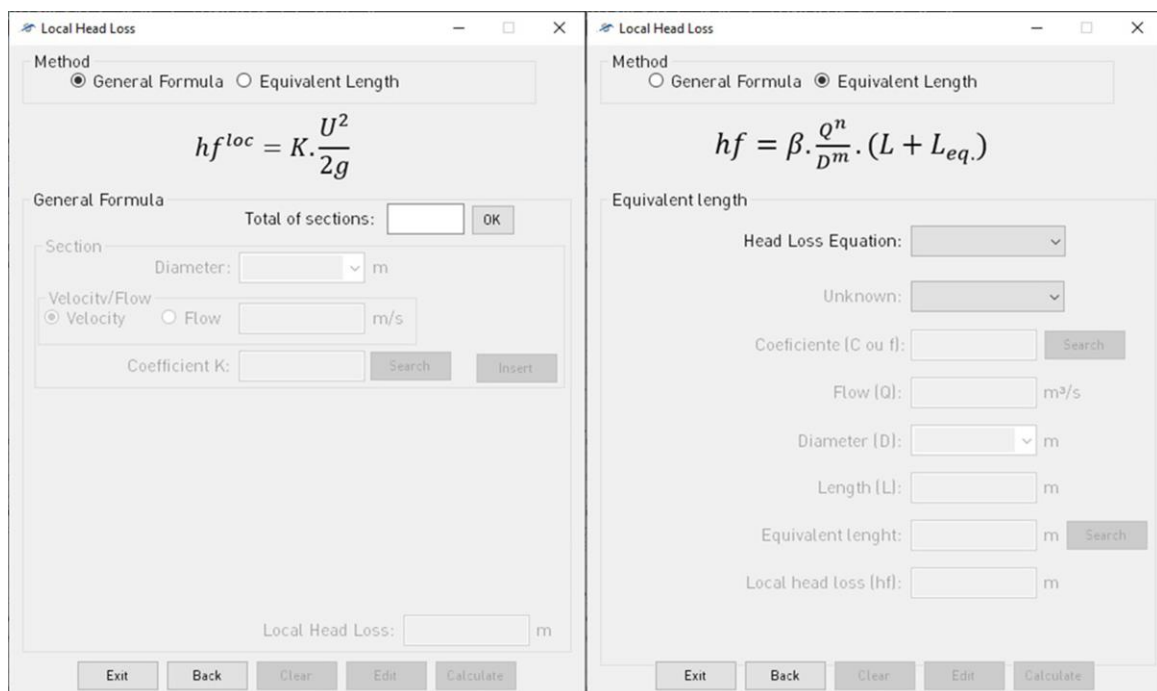
Diameter (D):  m

Length (L):  m

Friction Head Loss (hf):  m

Exit Back Clear Edit Calculate

Fig. 3. Friction head loss form.



Local Head Loss

Method

☒ General Formula

☐ Equivalent Length

$$h_{f^{loc}} = K \cdot \frac{U^2}{2g}$$

General Formula

Total of sections:  OK

Section

Diameter:  m

Velocity/Flow

☒ Velocity

☐ Flow

m/s

Coefficient K:  Search Insert

Local Head Loss:  m

Exit Back Clear Edit Calculate

Local Head Loss

Method

☐ General Formula

☒ Equivalent Length

$$h_f = \beta \cdot \frac{Q^n}{D^m} \cdot (L + L_{eq.})$$

Equivalent length

Head Loss Equation:

Unknown:

Coefficiente (C ou f):  Search

Flow (Q):  m<sup>3</sup>/s

Diameter (D):  m

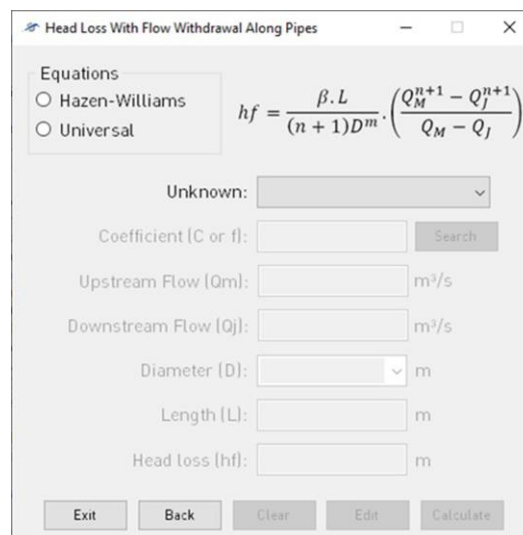
Length (L):  m

Equivalent length:  m Search

Local head loss (hf):  m

Exit Back Clear Edit Calculate

Fig. 4. Local head loss form.



Head Loss With Flow Withdrawal Along Pipes

Equations

☐ Hazen-Williams

☐ Universal

$$h_f = \frac{\beta \cdot L}{(n+1)D^m} \cdot \left( \frac{Q_M^{n+1} - Q_J^{n+1}}{Q_M - Q_J} \right)$$

Unknown:

Coefficient (C or f):  Search

Upstream Flow (Qm):  m<sup>3</sup>/s

Downstream Flow (Qj):  m<sup>3</sup>/s

Diameter (D):  m

Length (L):  m

Head loss (hf):  m

Exit Back Clear Edit Calculate

Fig. 5. Head loss with flow withdrawal along the pipes form.



**Pipes Connected in Series and Parallel**

Type of connection  
☒ Series ☐ Parallel

Equations  
☐ Hazen-Williams ☐ Universal

Unknown:

$\frac{\beta_{eq} \cdot L_{eq}}{D_{eq}^m} = \frac{\beta_1 \cdot L_1}{D_1^m} + \frac{\beta_2 \cdot L_2}{D_2^m} + \frac{\beta_3 \cdot L_3}{D_3^m}$

Equivalent B ☒ Coefficient (C or f):  Search

Equivalent length:  m

Equivalent Diameter:  m

Connected pipes

Sections:  OK

Section 1

Diameter (D):  m

Length (L):  m

Coefficiente (C):  Search

Insert

Exit Back Clear Edit Calculate

**Pipes Connected in Series and Parallel**

Type of connection  
☐ Series ☒ Parallel

Equations  
☐ Hazen-Williams ☐ Universal

Unknown:

$\left(\frac{D_{eq}^m}{\beta_{eq} \cdot L_{eq}}\right)^{1/n} = \left(\frac{D_1^m}{\beta_1 \cdot L_1}\right)^{1/n} + \left(\frac{D_2^m}{\beta_2 \cdot L_2}\right)^{1/n} + \left(\frac{D_3^m}{\beta_3 \cdot L_3}\right)^{1/n}$

Equivalent B ☒ Coefficient (C or f):  Search

Equivalent length:  m

Equivalent Diameter:  m

Condutores em Paralelo

Sections:  OK

Section 1

Diameter (D):  m

Length (L):  m

Coefficiente (C):  Search

Insert

Exit Back Clear Edit Calculate

Fig. 6. Forms for pipes connected in series and parallel.

**Water Hammer Phenomenon**

Celerity (a)  
☒ Calculate ☐ Insert  m/s  $a = \frac{9900}{\sqrt{48.3 + \frac{K \cdot D}{e}}}$

Diameter (D):  m

Wall thickness (e):  m

Material coefficient (K)  
☒ Calculate ☐ Insert   $K = \frac{10^{10}}{E}$

Modulus of elasticity (E):  Calculate K

Calculate celerity

Characteristic time (z)  
☒ Calculate ☐ Inform  s  $\zeta = \frac{2L}{a}$

Pipe Length (L):  m

Celerity (a):  m/s Calculate

Type of maneuver  
☒ Average flow speed (U) ☐ Flow (Q)  m/s

Calculate

Exit Back Clear Edit

Closure time (t)  
☒ Calculate ☐ Insert  s  $t = \frac{1}{2K}$

Water Pump constant (K)  
☒ Calculate ☐ Inform   $K = \frac{450 \cdot Q \cdot Hm}{\eta \cdot W_R^2 \cdot n^2}$

Flow (Q):  L/s

Pump head (Hm):  m

Overall efficiency (n):  %

Rotation (n):  rpm

Pump moment of inertia (Wr)  
☒ Calculate ☐ Insert  kg.m<sup>2</sup>  $W_R^2 = 150 \cdot \left(\frac{P}{n}\right)^{1.435}$

Pump power  
☒ Calculate ☐ Insert  CV  $P = \frac{\gamma \cdot Q \cdot Hm}{75 \cdot \eta}$

Specific weight of fluid  
☒ Inform the temperature:  °C

☐ Inform the specific weight (γ):  kgf/m<sup>3</sup>

1. Calculate Power

2. Calculate moment of inertia

3. Calculate pump constant

4. Calculate pump stopping time

Fig. 7. Water hammer phenomenon form.

### C. Water Distribution Systems

The first water distribution systems form developed was the dead-end system form (Fig. 8). It is necessary to inform the method of calculation of friction head loss, the coefficient of the material of the pipe, the distributed flow rate, and the number of branches of the system. The diameter is chosen by the software according to the selected pipe material or it can be made by the user himself. The next step is to enter information about each branch: nomenclature, length, flow downstream (when this information can be obtained directly, otherwise the software will calculate this value), if the section is "virgin" (that is, there is no flow distribution). The user can check if the distributed flow rate is correct by inserting data about the system's water consumption profile. For pressure sizing

purposes, the user is asked to inform the terrain elevations of the system nodes, and at the end of this process, a node where the pressure is known and its respective value. It is possible to add pressure reducing valves by informing its value and where they are going to be placed.

Besides the manual data entry method, it is possible to automatically entry data using the "Read File" button. Choosing this method, the user must upload a ".txt" file with pre-defined format and information.

The data calculated by the program are fictitious flow, diameter, average velocity, friction head loss, piezometric elevation and pressure (both upstream and downstream). These data are presented in a table that can be exported to an Excel spreadsheet.

Dead-end system

Head loss equation: Hazen-Williams

Coefficient (C): 100 Search

Distributed flow rate (q<sub>m</sub>): L/s/m

Number of branches: 5 OK

Branch: -

Length: m

Downstream flow: L/s

Virgin branch? Yes No

Special consumers: L/s

Terrain elevation upstream: m

Terrain elevation downstream: m

Undo Insert

Branch	L	Q <sub>j</sub>	Q <sub>d</sub>	Q <sub>m</sub>	Q <sub>f</sub>	D	V <sub>m</sub>	h <sub>f</sub> (m)	C <sub>Tm</sub>	C <sub>Tj</sub>
3-1	200	4	0.5	4.5	4.25	100	0.573	1.29	430	410
3-2	100	0	0.25	0.25	0.125	50	0.127	0.028	430	420
5-3	300	4.75	0.75	5.5	5.125	100	0.701	2.735	450	430
5-4	160	0	0.4	0.4	0.2	50	0.236	0.106	450	460
R-5	300	5.9	0	5.9	5.9	100	0.752	3.549	500	450

Exit Back Clear Read file Check qm Calculate Pressure Reducing Valve Export entry data Export table

Caption: Values tolerated by the standard (yellow), Values not recommended by the standard (red)

Fig. 8. Dead-end system form.

The second type of water distribution system developed was the closed-loop system (Fig. 9), which was divided into two forms: one for networks with a single loop and the other for networks with multiple loops. In the first case, the user must inform the method of calculating the head loss, coefficient, number of branches of the system, data of the outlet nodes and their respective flow rates and the material of the pipe.

The data for each branch must be entered sequentially: name of the upstream node and the downstream node (which together will form the section name), length and flow of this branch. If the node downstream of this section has an outflow, it will be presented in a text box. From the second branch, the software itself calculates the flow through the principle of mass conservation, that is, any flow that enters a

node must leave it. The calculated flow is then displayed, and the data insertion continues until all branches of the system are filled. As in the dead-end network, there is also the option of inserting data by reading a txt file.

Finally, the user must inform the closing error to verify energy conservation. If the verification returns a value greater than this error, the flow rates for each section are properly readjusted and a new dimensioning starts. The principle of energy conservation is checked again until the software encounters an appropriate error or until a total of ten iterations are reached. The resulting table can be exported to Excel and in addition to the data entered by the user, it will contain the following data: diameter, velocity, friction head loss, correction factor and flow rate correction for each iteration performed.

Closed-loop system

Head loss equation: Hazen-Williams

Coefficient (C): 100 Search

Number of branches: 3 OK

Closing error (Zh<sub>f</sub>): 0.005

Trecho: Branch: -

Length: m

Flow: L/s

Downstream node outflow: L/s

Undo Insert

Branch	L	Q-1	D-1	V-1	h <sub>f</sub> -1	nh <sub>f</sub> /Q <sub>f</sub> -1	Correct-1	Q-2	D-2	V-2	h <sub>f</sub> -2	nh <sub>f</sub> /Q <sub>f</sub> -2	Correct-2	Q-3	D-3	V-3	h <sub>f</sub> -3	nh <sub>f</sub> /Q <sub>f</sub> -3	Correct-3	Q-4	D-4	V-4	h <sub>f</sub> -4	nh <sub>f</sub> -1000
1-2	100	4	100	0.509	0.576	0.267	0.524	4.524	100	0.576	0.724	0.296	0.127	4.651	100	0.592	0.762	0.303	0.01	4.661	100	0.593	0.765	7.649
2-3	70	-1	50	0.509	-0.908	1.68	0.524	-0.476	50	0.242	-0.23	0.894	0.127	-0.349	50	0.178	-0.13	0.686	0.01	-0.339	50	0.173	-0.123	1.753
3-1	74	-3	75	0.679	-1.017	0.627	0.524	-2.476	75	0.56	-0.713	0.533	0.127	-2.349	75	0.532	-0.647	0.509	0.01	-2.339	75	0.529	-0.642	8.672

Read File Exit Back Clear Calculate Calculate Pressures Export table

Fig. 9. Single-closed loop form.

At the end of this step, it is possible to calculate the network pressures using a new form. The user must enter data for branches outside the loop (if any) and information about the terrain elevations of the system nodes. It is also necessary to inform a known pressure point to calculate the pressures. The software will present a table containing the data provided and the piezometric elevation and pressures (both upstream and downstream) calculated.

For multiple closed-loop systems (Fig. 10), the first step is to feed the program with information about the outflow nodes and their respective rates and the node in which the network is supplied, to check the hydraulic balance. The user must inform the number of loops, the method of calculating friction head loss and the coefficient of the material. Once this is done, the user must start entering data for each loop: its number of branches and information about them (similar to the single closed-loop form, however in this case there will be no automatic filling of flow rates). It is also possible to enter the data by reading a txt file.

By clicking the "Calculate" button, the program checks the hydraulic balance for each node. If the sum of the hydraulic balance module of the nodes belonging to each loop is not zero, a message will appear on the screen as an alert to the user. The standard NBR 12218/2017 tolerates a maximum residual flow of 0.1 L/s. The user will be informed of this fact and will decide whether to proceed with the sizing or interrupt the process to readjust the flow rates entered.

The verification of energy conservation in each loop is done in the same way as described for single closed-loop networks. The flow calibration will be done until an acceptable error is found or until the program reaches a total of 25 iterations. The resulting table can also be exported, and it will present the data entered

by the user, diameter, velocity, friction head loss, correction factor and flow correction rate of all loops for each iteration performed.

The pressure calculation form can also be accessed through the button "Calculate Pressures" and its filling must be done in the same way as described for single closed-loop system.

To make the most of the advantages of using computer systems to solve hydraulics problems a study was initiated to optimize the diameter determination of closed-loop networks.

The objective function was obtained by choosing the cost of the pipeline as the single criterion for classifying the most viable network configuration. The most viable solution of a network will be the one which, following the restrictions of hydraulic balance and energy conservation, has the lowest cost.

For this study, it was chosen a network with two loops (totaling 5 branches) and an input text file was created with the flow data filled in with arbitrary values. A routine in Python was programmed to replace these flow rates with randomly chosen ones.

The stochastic optimization algorithms chosen was the Differential Evolution (DE). A routine was programmed to generate 500 candidate solutions that, for this case, were formed of a vector of 5 positions (referring to the flow rates of the 5 branches). For each of these solutions, the DE was programmed to perform 500 iterations, to converge to a result and find a solution to the problem. It is important to note that due to the generation of random flow vectors, each execution of the developed routine can return different costs and solutions that are considered quasi-optimal solutions. There are still several alternatives in this context to be explored, so this study is still in progress.

Multiple closed-loop system

Enter the system nodes outflows:

Inform the node in which the network is supplied:

Number of closed-loops:

Head loss equation:

Coefficient (f):

Loop 2:  
Number of branches of this loop

Loop - Branch  
Branch:  -

Length:  m

Branch flow:  L/s

Closing error (Zhf):

Loop	Branch	L	Q-1	D-1	V-1	hf-1	n(hf/Ql-1)	Correct-1	Q-2	D-2	V-2	hf-2	n(hf/Ql-2)	Correct-2	Q-3	D-3	V-3	hf-3	n(hf/Ql-3)	Correct-3	Q-4	D-4	V-4	hf-4
1	1-2	100	4	100	0.509	0.331	0.165	0.046	4.046	100	0.515	0.338	0.167	0.023	4.069	100	0.518	0.342	0.168	0.005	4.074	100	0.519	0.343
1	2-3	90	1	50	0.509	0.595	1.19	0.046	1.046	50	0.533	0.651	1.245	0.023	1.069	50	0.545	0.68	1.272	0.005	1.074	50	0.547	0.686
1	3-1	130	-3	75	0.679	-1.019	0.679	-0.026	-3.026	75	0.685	-1.037	0.685	0.007	-3.019	75	0.683	-1.032	0.684	-0.003	-3.022	75	0.684	-1.034
2	1-3	130	3	75	0.679	1.019	0.679	0.026	3.026	75	0.685	1.037	0.685	-0.007	3.019	75	0.683	1.032	0.684	0.003	3.022	75	0.684	1.034
2	3-4	100	-1	50	0.509	-0.661	1.322	0.072	-0.928	50	0.473	-0.569	1.227	0.016	-0.912	50	0.465	-0.55	1.206	0.008	-0.904	50	0.461	-0.54
2	4-1	100	-5	100	0.637	-0.517	0.207	0.072	-4.928	100	0.627	-0.502	0.204	0.016	-4.912	100	0.625	-0.499	0.203	0.008	-4.904	100	0.624	-0.497

Fig. 10. Single-closed loop form.

### D. Water pumps

The first form of this session (Fig. 11) calculates the system's operating point, which is defined by the point of intersection of the pump characteristics curve with the system head curve. This form is divided into three steps. The first one consists of generating the pump characteristic curve (which can be more than one, connected in series or parallel) through the discharges and pump heads inserted by the user. The second one generates the system head curve, which can be informed directly by the user or that can be calculated by entering data from the system sections. The third step is the plot of the graph with the curves previously generated and the presentation of the operating point (if found).

The second form developed (Fig. 12) calculates the pump power, discharge, and suction diameters, and

suggests values referring to the positioning and disposition of the pump. The user must inform the specific weight of the water; the flow rate (which can be calculated through the average per capita water consumption and the number of inhabitants of the system) to calculate the economic diameters (depending on the time of operation of the pump using Bresse's equation and the type of material chosen); pump heads (which can also be calculated) and overall efficiency. All results and information entered are shown schematically on the form itself.

The third form (Fig. 13) analyzes the operating conditions of discharge systems for the occurrence of the cavitation phenomenon. The user can choose between three analysis methods: check the occurrence of cavitation, find the suction head, or graphical analysis to determine the flow rate limit.

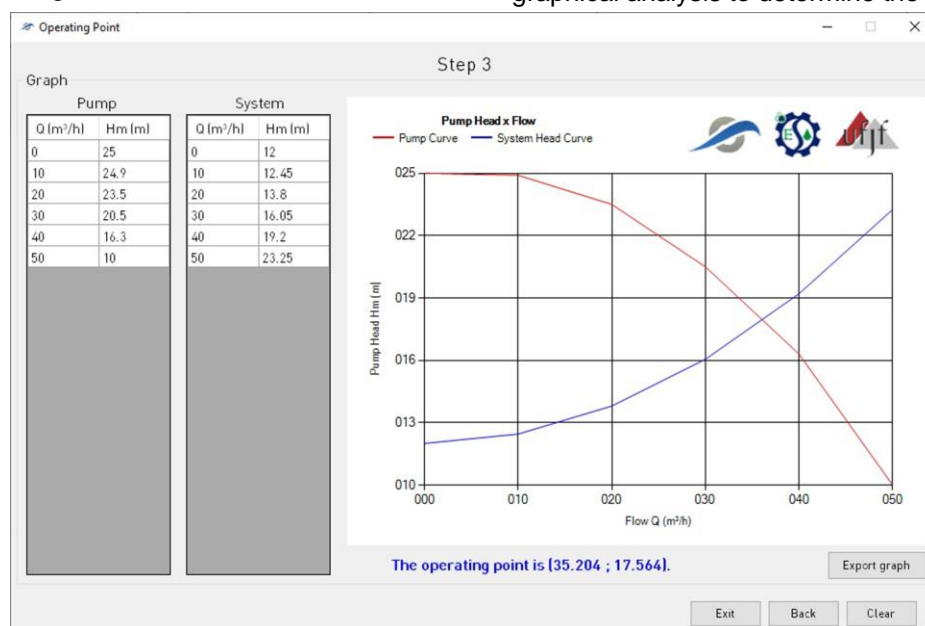


Fig. 11. Third step of the system's operating point form.

Specific weight of fluid  
☐ Insert the temperature:  °C  
☒ Insert specific weight [γ]:  1000 kgf/m³

Flow  
☐ Calculate ☒ Inform  0.03 m³/s  
 Average per capita water consumption:  200 L/hab.day  
 Insert the total of inhabitants:  hab.

Economic Diameter  
☒ Installation operating continuously (24h/day)  
☐ Installation operating continuously (<24 h/day)  
 Enter the number of operating hours per day:  h

Pump Head  
☒ Calculate ☐ Insert  21.295 m  
 Geometric Height (Hg):  21 m   
 Suction head loss (hs):  0.039 m   
 Discharge head loss (hr):  0.256 m

Overall Efficiency  
 Overall Efficiency (η):  72 %

Discharge  
 Diameter: 250 mm  
 Length: 100 m  
 Coefficient (C): 130  
 Head Loss: 0.256 m

Pump  
 Flow: 0.03 m³/s  
 Pump head: 21.295 m  
 Overall efficiency: 72 %  
 Pump power: 8.707 kW

Suction  
 Diameter: 300 mm  
 Minimum height h: 0.45 m  
 Length: 10 m  
 Coefficient (C): 130  
 Head loss: 0.039 m

Fig. 12. Pump power form.



Fig. 13. Cavitation form.

### E. Open Channels

The first topic of this subject is about rigid boundary channels (Fig. 14), and it checks the hydraulic operating conditions and dimensions channels of this type. The verification is done through the Manning's equation, and the form can calculate the flow rate, the Manning's roughness coefficient, area, hydraulic radius, and the slope. When necessary, the Manning's roughness coefficient can be estimated from calculations using the Cowan's method or the global coefficient, or it can be found through some database tables. It is also possible to determine the hydraulic radius and the channel area according to the channel geometry (which can be rectangular, trapezoidal, triangular, circular, or parabolic).

Channel sizing can be performed for the sessions mentioned above. The user must enter the flow rate, coefficient of roughness, and slope (the hydraulic parameters will be calculated by the program after the dimensioning) and must enter at least one data about

the channel geometry. In the case of the rectangular section, it is necessary to inform the width of the section. For trapezoids and triangles, the program requires the dimension of the base and the Z slope. For the parabolic section, it is necessary to inform the width of the parabola on the channel surface. The program will return the most appropriate dimension for the information entered.

The erodible channels form designs channels of this type following the same calculations performed in the previous form. The difference is that in this case the central issue is related to the stability of the channel (related to the type of the material into which the channel is excavated) and therefore, it is necessary to verify it. To verify that the dimensioning performed is a viable solution for the channel, the user is asked to select or insert the maximum permissible velocity.

Fig. 14. Rigid boundary channels form.

Fig. 15. Erodible channels form.

### III. CASE STUDY

The case study is about a water distribution system design proposed for a subdivision in the city of Juiz de Fora. It was chosen to calibrate the Flow software in its dead-end water distribution system form and to verify its behavior in real situations.

Flow developers and technicians from the water and sewage company in Juiz de Fora, responsible for analyzing water and sewage projects for installations of such nature, had work meetings to discuss the results, propose adjustments and improvements for both sides. The project to which Flow was applied was in the final stage of evaluation, which made the process more interesting for validation.

The subdivision is in the northern region of the city of Juiz de Fora, in an area of 164,026.20 m<sup>2</sup>, with 247 lots and an estimated population of 2,596 inhabitants.

According to the water company's guidance, due to the city's history of occupation, 20% of the lots must be estimated to be occupied by small multifamily units, these with 09 units each. Hence the explanation of the discrepancy, at first glance, between the number of lots and inhabitants, when it is assumed 04 inhabitants per lot.

Due to the local topography, the water supply project was designed with 02 pressure zones, upper and lower (Fig. 16), composed as follows: the lower elevation receives water from the existing system and discharges to the main reservoir, which serves the lower part of the subdivision. Simultaneously, it supplies water for the upper lift station to discharge to the upper reservoir, which serves the upper part of the subdivision.



Fig. 16. Rigid boundary channels form.

Alongside the reservoirs are the distribution systems, object of the calibration presented here, which are responsible for directly supplying the lots. To balance pressures and match them to compatible values, a pressure reducing valve was specified for the lower zone network. The material specified for the pipes was PVC and the selected diameters were 50, 75, 100, and 150 mm.

In addition to the extreme branches and those that form junctions, from where the nodes are originated, the subdivision networks describe several closed-loops systems. In this case, the dimensioning was made by the fictitious sectioning method and Flow was also used for verification purposes.

To compare the values calculated by Flow and those presented by the subdivision's entrepreneur to the water company, the first method chosen was the discrepancy ratio (DR) (1), defined by [8].

$$DR = \log \frac{E_i}{O_i} \quad (1)$$

In this method, if the discrepancy ratio (DR) is zero, the prediction of the longitudinal dispersion coefficient value is identical to the measured dispersion coefficient. If the discrepancy ratio is greater than zero, the prediction of the dispersion coefficient is overestimated, and if the discrepancy ratio is less than zero, it is underestimated. The higher the value of the discrepancy ratio (DR), the more distant the set of estimated data ( $E_i$ ) from the observed values ( $O_i$ ).

The second method used was the root mean square deviation (RMSE), as Equation 2 shows.

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N [E_i - O_i]^2} \quad (2)$$

The third comparative method used was the confidence index (c), proposed by [9]. In this method, when correlating the estimated values ( $E_i$ ) with those measured ( $O_i$ ), using linear regression, the following statistical indicators are considered: "precision" - correlation coefficient (r); "accuracy" - Willmott index (d); and confidence or performance (c).

Precision is given by the correlation coefficient, in which the absolute values of the coefficient indicate the degree of dispersion of the data obtained around the adjustment function [10]. It is worth mentioning that the correlation coefficient (r) varies between -1 and 1. A correlation close to zero indicates that the two variables are not related. A positive correlation indicates that the two variables move together, and the relationship is strong the closer the value approaches 1. A negative correlation indicates that the two variables move in opposite directions and that the relationship gets stronger the closer -1 the ratio remains. If the variables are perfectly positively correlated ( $r = 1$ ) they move essentially in perfect proportion in the same direction, while two sets that are perfectly negatively correlated move in perfect proportion in opposite directions [11].

Accuracy is related to the deviation from the estimated values in relation to those observed.

Mathematically, this approximation is given by a designated index of agreement, represented by the letter "d" (WILLMOTT et al., 1985). Their values range from zero, for no agreement, to 1, for perfect agreement. According to, values of "d" above 0.75 are considered satisfactory. The index is given by the following expression: Accuracy is related to the deviation from the estimated values in relation to those observed. Mathematically, this approximation is given by a designated index of agreement, represented by the letter "d" (WILLMOTT et al., 1985). Their values range from zero, for no agreement, to 1, for perfect agreement. According to, values of "d" above 0.75 are considered satisfactory. The index is given by Equation 3.

$$d = 1 - \left[ \frac{\sum_{i=1}^n (E_i - O_i)^2}{\sum_{i=1}^n (|E_i - \bar{O}| + |O_i - \bar{O}|)^2} \right] \quad (3)$$

Where d is the index of agreement,  $E_i$  and  $O_i$  are, respectively, the estimated and observed values and  $\bar{O}$  is the mean of observed values. Therefore, the index (c) proposed by CAMARGO and SENTELHAS (1997) is given by the product of the precision index, corresponding to the correlation coefficient (r), with the agreement index (d) proposed by WILLMOTT (1981) (Equation 4).

$$c = r \cdot d \quad (4)$$

CAMARGO and SENTELHAS (1997) present the values for interpreting the performance (c) of the models regarding their accuracy (Table 1).

Table 2 (upper zone) and Table 3 (lower zone) present the pressures calculated by Flow software and the pressures presented by the subdivision's entrepreneur to the water company and the statistical data.

The confidence index c calculated for both upper and lower zone was 0.999, which according to Table 1 means that the accuracy of the results is excellent. Thus, it was possible to verify that Flow had a very adequate behavior.

TABLE I. CLASSIFICATION OF CONFIDENCE INDEX (C).

C	Performance
>0.85	Excellent
0.76-0.85	Very good
0.66-0.75	Good
0.61-0.65	Median
0.51-0.60	Tolerable
0.41-0.50	Bad
$\leq 0.40$	Terrible

TABLE II. UPPER ZONE PRESSURE VALUES PROVIDED BY THE WATER AND SEWAGE COMPANY (W.S.C) AND CALCULATED BY FLOW, AND STATISTICS.

UPPER ZONE									
Node	Pressure (m.c.a)		Absolute error (cm)	Mean error (%)	Discrepancy ratio	Mean square deviation	Correlation	Index of Agreement	
	W.S.C	FLOW						Num.	Deno.
RES	0	0.000	0.00	0.00		0.000000	1.00	0.000000	2862.83
01	11.79	11.792	0.20	-0.02	0.000074	0.000004		0.000004	895.41
02	35.04	35.027	1.30	0.04	-0.000161	0.000169		0.000169	274.28
03	31.80	31.785	1.50	0.05	-0.000205	0.000225		0.000225	101.60
04	42.63	42.619	1.10	0.03	-0.000112	0.000121		0.000121	1007.65
05	23.45	23.424	2.60	0.11	-0.000482	0.000676		0.000676	43.98
05'	23.79	23.765	2.50	0.11	-0.000457	0.000625		0.000625	35.41
06	34.66	34.651	0.90	0.03	-0.000113	0.000081		0.000081	249.82
07	31.73	31.722	0.80	0.03	-0.000110	0.000064		0.000064	98.93
08	42.06	42.042	1.80	0.04	-0.000186	0.000324		0.000324	936.15
09	17.33	17.304	2.60	0.15	-0.000652	0.000676		0.000676	356.13

TABLE III. LOWER ZONE PRESSURE VALUES PROVIDED BY THE WATER AND SEWAGE COMPANY (W.S.C) AND CALCULATED BY FLOW, AND STATISTICS.

LOWER ZONE									
Node	Pressure (m.c.a)		Absolute error (cm)	Mean error (%)	Discrepancy ratio	Mean square deviation	Correlation	Index of Agreement	
	W.S.C	FLOW						Num.	Deno.
10	31.24	31.218	2.20	0.07	-0.000306	0.000484	1.00	0.000484	6.19
11	33.94	33.923	1.70	0.05	-0.000218	0.000289		0.000289	8.51
12	15.22	15.193	2.70	0.18	-0.000771	0.000729		0.000729	1192.57
12'	15.74	15.714	2.60	0.17	-0.000718	0.000676		0.000676	1121.76
13	37.24	37.220	2.00	0.05	-0.000233	0.000400		0.000400	90.50
14'	37.07	37.039	3.10	0.08	-0.000363	0.000961		0.000961	83.95
15	38.90	38.877	2.30	0.06	-0.000257	0.000529		0.000529	164.62
16	44.00	43.968	3.20	0.07	-0.000316	0.001024		0.001024	529.98
14	37.15	37.124	2.60	0.07	-0.000304	0.000676		0.000676	87.00
15	38.90	38.877	2.30	0.06	-0.000257	0.000529		0.000529	164.62
16	44.00	43.968	3.20	0.07	-0.000316	0.001024		0.001024	529.98
17	48.41	48.383	2.70	0.06	-0.000242	0.000729		0.000729	1014.19
18	36.84	36.809	3.10	0.08	-0.000366	0.000961		0.000961	75.73
19	38.70	38.674	2.60	0.07	-0.000292	0.000676		0.000676	154.44
20	29.41	29.379	3.10	0.11	-0.000458	0.000961		0.000961	37.92
21	36.14	36.108	3.20	0.09	-0.000385	0.001024		0.001024	53.31



LOWER ZONE									
<b>22</b>	44.26	44.232	2.80	0.06	-0.000275	0.000784		0.000784	554.38
<b>18'</b>	36.85	36.823	2.70	0.07	-0.000318	0.000729		0.000729	76.15
<b>21'</b>	36.09	36.061	2.90	0.08	-0.000349	0.000841		0.000841	51.90
<b>H1</b>	32.82	32.798	2.20	0.07	-0.000291	0.000484		0.000484	0.45
<b>RES</b>	0.00	0.000	0.00	0.00		0.000000		0.000000	4218.07
<b>PRV'</b>	24.74	24.723	1.70	0.07	-0.000299	0.000289		0.000289	239.74
<b>PRV</b>	30.65	30.633	1.70	0.06	-0.000241	0.000289		0.000289	13.42

#### IV. CONCLUSIONS

The Flow software is a tool with a user-friendly interface that facilitates and simplifies its use. With it, it is possible to perform hydraulic calculations with accurate and reliable results in a faster way, considerably reducing the time spent on resolutions and minimizing possible calculation errors. The topics covered are closed conduits (friction head loss, local head loss, head loss with flow distribution, series and parallel connected pipes, and water hammer phenomenon), water distribution systems (dead-end and closed-loops system), water pumps (operating conditions, pump power and cavitation) and open channels (rigid boundary and erodible channels). The optimization study for diameter determination of closed-loop networks is being developed to be included in the software in the future. Flow has demonstrated great potential as a tool for hydraulic calculations in a practical and educational way, as it is accessible, and it provides accurate results.

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