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Python Routine for an Easy Visualization of the Influence of Supply Network Characteristics on the Hydraulic Behavior of a Small Closed Loop

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Abstract

A routine coded in Python aiming at a quick detection of the hydraulic behavior of a closed supply network as a function of the variation of the input data is presented. Such variables are lengths and diameters of the sections, roughness coefficients of the pipes, terrain elevations, flow distributed in the section and residual flow, and pressure at the upstream node. After a review of the literature on the subject of hydraulic supply models, the process of the fictitious sectioning point is used, so that the closed circuit network can have its behavior assimilated as that of branched network sections, and its calculation be performed as such. This arrangement is achieved by matching head losses between sections. In order to demonstrate the functionality of the routine, 12 simulations are exposed, 06 in each particular sectioning condition, with different input data and respective influences on the network operating conditions, notably, the positioning of the fictitious sectioning point and the contribution of each stretch to the residual flow node.

Keywords: *network characteristics, fictitious sectioning method, python programming, water supply*
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I. INTRODUCTION

For further than a generation, water and wastewater services have been delivered through centralized systems. Water system operating and management practices are being challenged by population expansion, urbanization, and aging population. Smart water networks are one of the most recent advances in water system engineering. Such intelligent networks solve the planning and organizational issues associated with flows and pressures changes in the water network, as well as shortening the time it takes to detect pipe breaks and leaks [1].

Designers utilized simulations to address design difficulties and develop fully working water distribution systems in the earliest days of supply computer modeling. Initially, the usage of automated systems became common practice because computerized analyses allow designers to focus on design changes rather than monotonous, iterative simulations. Second, as models can compensate for a far larger proportion of the sophistication of practical systems than hand calculations, they increase the technician's assurance that the concept will work once it is realized. Finally, the speed and ease with which simulations may be applied allows engineers to study a greater number of options under a range of circumstances, leading to further cost-effective and robust alternatives [2].

A great deal of work has gone into developing simulators to be used in water resource management and planning over the past ages. Robust generic computer programs are becoming progressively important in many aspects of water supply. Because of recent advancements in computer technology, almost everyone engaged in the water issues and environmental industries now has access to computers with all of the functionality necessary to run the massive number of accessible models. Each day, fresh and varied technologies are presented in an intense format. Connectivity to worldwide data over the

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network, email, the creation of ever-faster processors, increased data storage efficiency, and the advancement of ever-sturdier software systems are just some instances of this remarkable progress [3-4].

II. Overview on Models of Water Supply Networks

A. Recent Background

Nowadays systems employ improvement approaches to resolve water supply challenges such as the minimum costs and most efficient process, bounded by network size, amount of restrictions, and variety of loading situations [5]. The researchers used EPANET 2.0 to design the pipes for an optimized water distribution system.

It is introduced a novel method for designing multi-objective multimodal and discontinuous water supply networks in uncertainties. To manage the finite multifunctional search area, the suggested methodology employs a combination of known resilient parallel strategies and a meta-heuristic known as the combinatorial optimization cuckoo search algorithm. The nodal demands are the unknown variable in this case. The problem's aims are to minimize building costs while increasing the robustness index [6].

A hydraulically guided chart method for evaluating the resistance of water distribution networks in the event of pipe failures is presented. The goal is to rank essential pipes using just topological characteristics and simulating hydraulic performance, without running any hydraulic computations. The technique proposed focuses on pipe resistance, capacity, and connection. The findings of employing the approach to two networks demonstrate that more than 95% of crucial pipes indicated by it rank first in a hydraulic-based method. The proposed approach may be improved to integrate numerous and parallel failures that hydraulic models cannot analyze in an appropriate runtime [7].

Reference [8] explores three methods to resolve water distribution networks. They are the Newton-Raphson method based in heads, the finite element method, and the gradient technique. These were created using MATLAB and spreadsheets. Because the instructional features of the system were the primary focus of the study, the principles of this software application were presented step by step utilizing codes. The scripts and computer application are provided in the expectation that many professors and applicants would assess them for instructional and practical applications in this engineering area.

The same researchers of [8] explain in [9] a stage process implementation of Hardy-Cross, Linear Theory, and Newton-Raphson based in flow methodologies for solving water supply networks using MATLAB and Excel spreadsheets. These methodologies are used to examine a simple piping system in order to concentrate on the instructional aspects of software packages.

The model SPERTS [10] presents implementations of the time-marching approach technique [11] to permanent modelling as well as for long-term analysis. The advantage of this strategy over other system determination strategies is noted to be its genuine convergence when pursuing the transitory progression, achieving the ultimate permanent regime, to the disadvantage of the mathematical ongoing process of the other schemes, not to point out that these are matrices, culminating in a series of solutions of systems of equations, which have uniqueness for interpretation that should always be investigated. Because the component formulations are hydraulic transient formulas, the technique can also be applied to non-permanent regime situations.

To reduce energy consumption, an adjustable speed driver was used to regulate the rate of the water boost pump to the speed required by the water distribution system, and a repetitive neurologic concept articulation control scheme was proposed to maintain the water pressure at the desired reference even in the face of anomalies. In addition, to accommodate the environment, the framework is built on a programmable controller, and industrial connections were developed to connect and transmit data between monitoring stations and observation equipment. The water system experiment results demonstrated the usefulness of the suggested control system. Moreover, the presence of inconsistencies, nonlinearities, perturbations, and noises in real industry applications is undeniably present. As a result, the suggested control system is applicable to a variety of practical situations [12].

The SCALER is a lightweight and practical free desktop system that allows the sizing of dead end water distribution networks, determining the diameters and pressure loss in each distance, displaying the heads available at every node and reservoir level of water to fulfill the previously predetermined criteria of minimum pressures at the nodes. In [13] the SCALER program presents and compares the final results of a hydraulic network containing 52 sections and 53 nodes, with the values determined by the well-known EPANET software. The results of the comparisons were quite satisfactory, generating acceptable deviations of 0.233% as average value.

A conceptual framework for the water distribution scheme is proposed [14], which builds looped networks and is suitable for systems with numerous water sources. The proposed methodology is used to four actual networks to demonstrate that it generates networks with comparable architecture to the actual ones. In terms of network design, the comparison of actual and simulated networks reveals that the actual may achieve an acceptable mix of budget, performance, and resilience. It is also being investigated how to create pipe sizes using a bio feedforward process. A Physarum polycephalum-inspired model is used to show modest significant correlation between actual and simulated pipe sizes. The findings show that the concept could be employed to guide the design and expansion procedures of network systems.

B. Optimization and Convergence Aspects

For development, a cost optimization technique for the suggested water supply network is offered [15]. Several current water distribution analysis apps lack optimal solution features, but they do assure that other critical parameters are met. Pipeline sizes were changed, and the overall cost of pipes was reduced significantly. The hydraulic qualities of the whole distribution network are enhanced, resulting in a total cost savings of 7.15%. By implementing a reliability restriction, the network's effectiveness and cost are both evaluated. The optimum planned water distribution system answers the researched area's water scarcity issue.

The introduction of a novel design method that reduces capital and operating expenditures, together with energy and water losses expenses. Design choices specify a mix of infrastructure upgrades, such as pipeline retrofits and control installation, as well as storage and engine control guidelines. Mechanisms for solving one and more than one problem formats are provided. Within an elevated server computer, an optimization algorithm and a subset grouping genetic algorithm are used to choose container dimensions, pumping location and functions, pressure-reducing device location, and conduit dimensions for changing pipelines. The metaheuristic optimization techniques provide options that reduce water loss owing to loss, operating expenses, and expenses while preserving heads at vertices and container and pumping viability. Alternatives are evaluated in order to determine the best layout. In an exemplary research project, the approach is used to rebuild a piping system [16].

A cross optimization technique for pipe network design is suggested, in which the state of the tubes and the flow speed profile of the machines for a specific system architecture are calculated. The goal of the cross design issue is to determine the operational sequence for the pumps while evaluating aims in a unified model, so that the hydraulic rules are preserved and quantity and heads limits at the consumers are met for a specific number of loading. The cross performance presents a variety of different optimum water supply operating techniques, allowing designers to choose the option that best matches their goals and requirements. Additionally, this technique gives a collection of options which can be used to take parameters relating to expenses, water aging, and leaking pipes [17].

As per [18], many purpose optimization of the water distribution network planning would be a crucial stage to good infrastructure administration. This, in effect, is determined by the judgment operator's ability to identify the exchange between the goals. To overcome this difficulty, a three-step strategy is provided. NSGA-II has optimized a portion of the network in Iran based on expense and durability index targets. The discovered non-dominated alternatives on the Pareto side were quantified using the entropy approach while taking the judgment operator's choices into account. Ultimately, the TOPSIS approach was applied to choose the best solution. As contrasted to the initial designers' and economic evaluation, the findings demonstrate that the present scheme may be utilized as a more trustworthy resource to validate networks budgeting while achieving a fine integration between the goals. One of the advantages of the suggested scheme include the fact that there is no limit to the amount of relevant parties and their targets, the decreasing the area of contending different goals to a double space, and the ability to determine the significance of the aims. It may also be claimed that the ongoing employment has offered a suitable platform for the examination of additional terms in order to find the necessary practical answers.

The offering of strong and trustable simulators capable of running big water distribution systems in a brief period of time, last several research has turned to utilizing these systems to answer more critical issues such as one- or multi-purpose optimizations or improving frameworks. To complete a new problem it is frequently necessary to perform hundreds upon a great number of trials. In this case, using fully skilled artificial neurons as a replacement for the hydraulic model can significantly minimize the time consumption needed for the new methods. Several neuronal net topologies used to simulate the behavior of a complicated system of water distribution are demonstrated [19].

To cope with the difficult and computationally expensive finite, multimodal, cross planning of water supply networks, an innovative mixed optimizer is proposed [20]. Its benefit is its capacity to drastically decrease normalization difficulties and unnecessary computing expenses. It follows the creative pattern of cross evolutionary codes and includes six query processors along with other critical techniques. These drivers are selected because of their ability to jump in the domain using local and general search perspective. The techniques guide efficiency while combining survey and manipulation aspects. Its distinguishing feature is that it eliminates the majority of variables, allowing it to be quite powerful and customer friendly.

According to [21], the first output of computations in the iterative technique in the classic and enhanced Hardy Cross methods is not flow rate, but instead flow adjustment. However, according to sophisticated mathematical laws, these changes must be appended to or removed from the flow estimated in the preceding iteration. The novel node-loop technique, apart from the Hardy Cross technique, does not need sophisticated formulae for flow adjustments because flow is evaluated immediately. The node approach has the same number of rounds as the altered Hardy Cross method, which is its key benefit. As a consequence, a difficult mathematical technique for circulation indication rectification is bypassed, yet the final findings persist precisely.

Twenty-two novel math techniques with third-order resolution are obtained from available references and used to pipe analysis methods. Based on the amount of theoretical releases used in resolving pipeline systems, the given approaches were divided as one, two, and three stage plans. By addressing an example piping system under four distinct conditions, the capabilities of such novel approaches and the Hardy Cross methodology were evaluated (92 cases). The findings demonstrate that the one-stage approaches enhance the level of convergence of the Hardy Cross technique in 10 out from 24 instances (41%), but the two and three stage methods increase it in 39 from out 56 situations (69.64%) and 5 of 8 situations (62.5%), accordingly [22].

For water supply systems, a novel adapted fifth-order Hardy-Cross approach is provided. The basic equations of piping systems in stable are the continuity formula for each junction and the energy law to every circuit [23]. As a result, the essential purpose of a piping system is to calculate a nonlinear set of equations in terms of conduit discharges. Alternatively, one of the ways to solve piping systems, the Hardy-Cross method, guarantees solutions without building the mentioned set of equations, which is considered more efficient than the matrix-based one. The Hardy-Cross approach employs a unique type of initial estimate that solves the continuity equations before going on to the energy equations, computed independently for every circuit. As a result, one of the key drawbacks of this strategy is its weak speed of convergence. The suggested improved Hardy-Cross techniques achieve a greater level of convergence than classic approach. Lastly, a contrast of the suggested fifth-order Hardy-Cross techniques with the classic one reveals that the suggested adjustment enhances the velocity of convergence of the classic Hardy-Cross approach.

C. Educational Applications

Reference [24] introduced a Microsoft Excel program for instructing hydraulic studies of pipe networks. The software can do either stable and stretched term computations, does not require need installation, and provides a mobile approach to the pipe net project challenge in college environmental degree programs.

It is demonstrated a freeware and useful tool for water networks [25]. The application is freely available, and it employs worksheet operations and choices and also VBA coding. Networks project constitutes challenging tasks, especially for undergrads, because to the significant math procedures involved. For academics, who typically demand free apps, some proprietary frameworks for the nets design are unrealistic. While certain open source software, like EPANET, are available, the author claims that learners are usually forced to write routines in terms of running simulations with them. Additionally, EPANET employs a distinct strategy (global gradient engine) that usually clashes with the Hardy-Cross method’s educational aims. As a consequence, only a few basic, open source applications are suitable for teaching. The app developed for the project is intended to meet this demand and serve as a dependable solution for professionals who can’t afford a business solution.

Reference [26] highlights the Flow software as an effective training and strategy that addresses either academic as professional difficulties. The item was built using Visual Studio 2017 and the coding environment is C Sharp. The main subjects enclosed by the computer system are water supply networks, pumping systems, closed conduits, hydraulic surges, and channels. The application has shown substantial potential as a solution for hydraulic calculations due to its easy interface and exact outputs. The technique was used to a unit distribution system and pressures contrasted toward those used by the municipal sanitary business. The actual and relative major errors were 0.032mH2O and 0.18 percent, demonstrating that the Flow program works properly. Another fidelity and deviance indexes are shown in the study.

A comprehensive assortment of computer resources for implementing dynamic instructional strategies on an academic hydraulic engineering degree in the topic areas of pipes and channels are proposed [27]. The resources include a number of simple Excel-based applications to assist learners realize fundamental ideas, in addition to a sequence of tasks that utilize the open simulators EPANET and IBER to orient learners with practical technologies. The new method increased team pleasure and involvement, in addition to communication with professors and peers. The software and practical training are simply portable and openly provided to the population to enable adaption to other programs and degrees.

Reference [28] present a comparison of hydraulic characteristics, namely discharges and heads, measured on a real model and approximated employing automated program for constant stream, RIMIS. To investigate velocity in a pipe network loop, the team conducted a real scheme. The goal of the comparison analysis is to confirm the RIMIS platform.

A routine for educational purposes was developed for simulating a branched hydraulic network. The language used was Python. Because of the basic instructional character of the study, a quite easy setup network was chosen intentionally. The goal of this shortcut was to keep the learners’ mind focused solely on the differences in the outputs (pressure losses and junction heads) produced by the varied control parameters in the scheme [29].

A didactic computing system for instructing public undergrads real-time flow modeling of water supply lines is provided [30]. Applying actual information, the variables were estimated employing weighted-least-square approach and the Davidon-Fletcher-Powell technique. The app included net load, condition modeling, and data processing. Delphi 7.0 was employed to create the application and visual user experience. To illustrate the application device’s usefulness in classroom use, two assessment approaches were applied. Additionally, the positive results encouraged programmers and instructors to invent or use digital teaching methods.

The major goal of [31] is to look at the role of coding in studying and comprehending distribution systems for water. They demonstrate the construction of a scripting language C# for purposes for educating in water distribution network computations to students at the university and doctoral levels using an application named BayUni Pipe Flow. A person’s handbook for the program, which contains hydro theories and enhancement estimates, is also being produced. Pipe networks may be built in a variety of manners. The Hardy Cross technique is frequently used in network optimization. As a result, in this investigation, the Hardy Cross efficient algorithm was used. According to them, it is an ideal experiment to use as an instructional technique at the college and university levels.

Implementation of Mathematical, Experimental, and Computer-based Education is an innovative pedagogical technique presented to explore the stimulatory effect of conventional math solver methodology, picture application, and MATLAB-based designing on engineering participants’ notions and study based [32]. The water flow was chosen as an example of usage inside the purpose of the research (a particular implementation of Bernoulli equation and Toricelli’s theorem). The study detailed the practical findings from three different container designs and the MATLAB analysis techniques, as well as innovative formulas produced per lab magnitude apparatus empirical results. The effectiveness of the proposed technique was quantitatively assessed with the participation of 84 trainees. According to the average values obtained from all users, the quality of the technique was rated as 97.73 percent, 67.36 percent, and 82.55 percent.

III. Methodology

A. Fundamentals

The proposal of the work is the presentation of a routine, developed in Python language, for the simulation of water supply networks simultaneously in a situation of linear distribution along the pipes, given by the consumption of the dwellings, made directly from the closed loop, and the transfer of flow to a specific point (residual flow) for example, to other neighborhoods. The presented routine lends itself to essential information on the hydraulic behavior of the system, based on the characteristics of the network, mainly regarding the flow direction and contribution balances of each section for the node with residual flow. The knowledge of this general behavior, as a function of the input parameters in the simulation model, is a very important factor in the decision making of the operational issues of the sanitation companies, aiming at optimized decisions, leading to an adequate performance of the water supply system. Such input parameters are lengths and diameters of sections, pipe roughness, terrain elevations, flows with linear distribution, residual flow, and head at the upstream node of the network. The output data are the delimitation and positioning of the point identifying the direction of flow through the branches (to be defined as a fictitious sectioning point), the contributions of each branch to the residual flow, and the heads at the network nodes.

B. Fictitious Sectioning Point

The fictitious sectioning concept applies to the point in a closed loop where, up to that point, the head losses (hf) from the upstream common point are the same (or nearly so, within a tolerance limit) in both directions of flow, causing equal heads, both in one section of the network and in the other. In this way, there is no interference from one stretch to the other, thus making it physically possible to assimilate such a network as divisible at that point, generating, fictitiously, two branched network stretches, and can, as such, be simulated. The fact that the heads become equal is what justifies the calculation hypothesis, since it configures the real situation. Networks in closed loops (or rings) can be simulated through different techniques, available in the specific literature. In the present work, the fictitious sectioning method was chosen, even because one of the intended variables of interest was knowledge of the situation of such a point as a function of the characteristics of the network in each section, and correlation between these. An interesting issue is the fact that the fictitious sectioning point, henceforth treated by FSP, may be positioned along a given stretch or at the residual flow node, and what determines this situation are precisely the network variables. Fig. 1 illustrates the FSP issue.

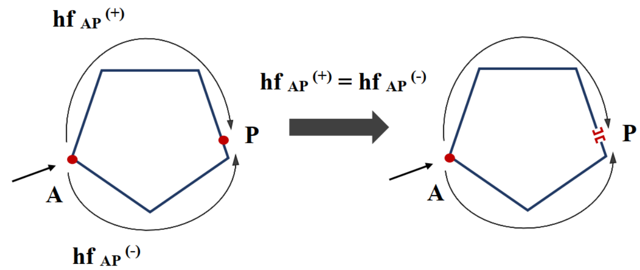


Fig. 1. Graphic visualization of the fictitious sectioning point.

C. Structuring Aspects

Considering the use of the fictitious sectioning (FS) method, a routine was initially developed [29], for dead end networks. The Hazen-Williams equation (1) was used to determine the head loss in the stretches.

$$h_f = 10{,}65\, Q^{1,85} C^{-1,85} D^{-4,87} L \tag{1}$$

Where h_f is the head loss (m), L is the pipeline length (m), D is the pipe diameter (m), Q is the flow rate (m3/s), and C is the roughness coefficient (empirical).

The total energy in a generic node i is given by Bernoulli theorem (2) and, since the kinetic energy can be neglected in water distribution networks, because of limitations of flow velocity, appears the piezometric head (3).

$$E_i = \frac{V_i^2}{2g} + \frac{p_i}{\gamma} + Z_i \tag{2}$$

$$PH_i = \frac{p_i}{\gamma} + Z_i \tag{3}$$

Where E_i is the total energy, (V_i^2 / 2g) is the kinetic energy, (p_i / γ) is the pressure energy (or nodal head), Z_i is the gravitational potential energy (or terrain level), PH_i is the piezometric head, all of them in (m), V is the average flow velocity (m/s), p_i is the nodal pressure (N/m2), and γ is the specific weight (N/m3).

The piezometric head in a downstream node is equal to the piezometric head in an upstream node minus the head loss in the connecting section, as written in (4).

$$PH_{downstream} = PH_{upstream} - h_{f\,section} \tag{4}$$

Coupling (3) e (4) it is possible to determine all the nodal pressures of the network. The routine considered only positive nodal pressures.

The next phase dealt with the development of codes for the network object of this work, that is, the closed loop with linear flow distribution along the line, and simultaneous transfer of a full portion of water to the residual flow point. To reach this stage, the problem was subdivided into parts, later coupled. In the first step, the situation was coded for a closed loop with residual flow in a node and without flow distributed in the section, as shown in Fig. 2. In this case, the resolution method was the Hardy-Cross method, widely disseminated in the literature. In the next step, a routine was created for a closed loop without residual flow and with flow distributed in the stretch, as shown in Fig. 3. For this situation, the solution was obtained by trying to position the FSP from meter to meter of the network, and at each iteration, the differences between head losses in one direction and the other were tested, and the FSP found was the one whose position provided smaller modular differences between them. Next, the situations were coupled, as shown in Fig. 4, generating the intended final situation for the work, with the solution following the same sequence as in the previous step, which makes it possible to locate the FSP.

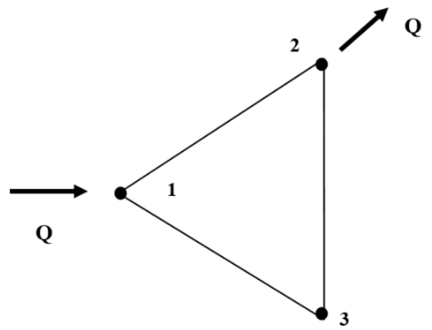


Fig. 2. Closed loop with only nodal residual flow.

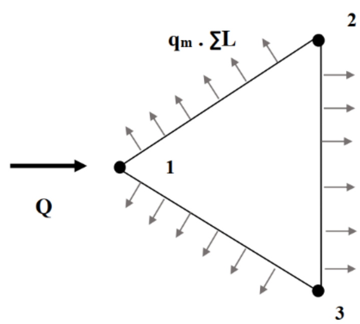


Fig. 3. Closed loop with only flow distributed along the section.

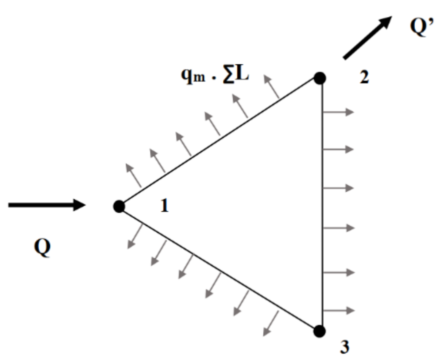


Fig. 4. Closed loop with nodal residual and distributed flow.

A single generic ring network was purposely adopted, with only three sections, so that the observations on the influence of the variables adopted for such networks on the positioning of the FSP and on the balance of the contribution to the residual flow were very clear and simple to be visualized and analyzed, without dispersion and misinterpretation due to other interferences and/or hydraulic effects. Thus, the initial routine [29] for a dead end network was adapted to the present context, making it possible to obtain the nodal heads and the balance between partial contributions per section for the residual flow. Once it was identified that, in fact, the FSP was in the residual flow node, a series of iterations were performed, with variable contribution weights between one section and another, for the total contribution flow. The routine returned the combination of flows that produced the smallest modular difference between head losses obtained by one stretch and the other. The routine flowchart and two partial extracts of the listing are shown in Figs. 5, 6, and 7, respectively.

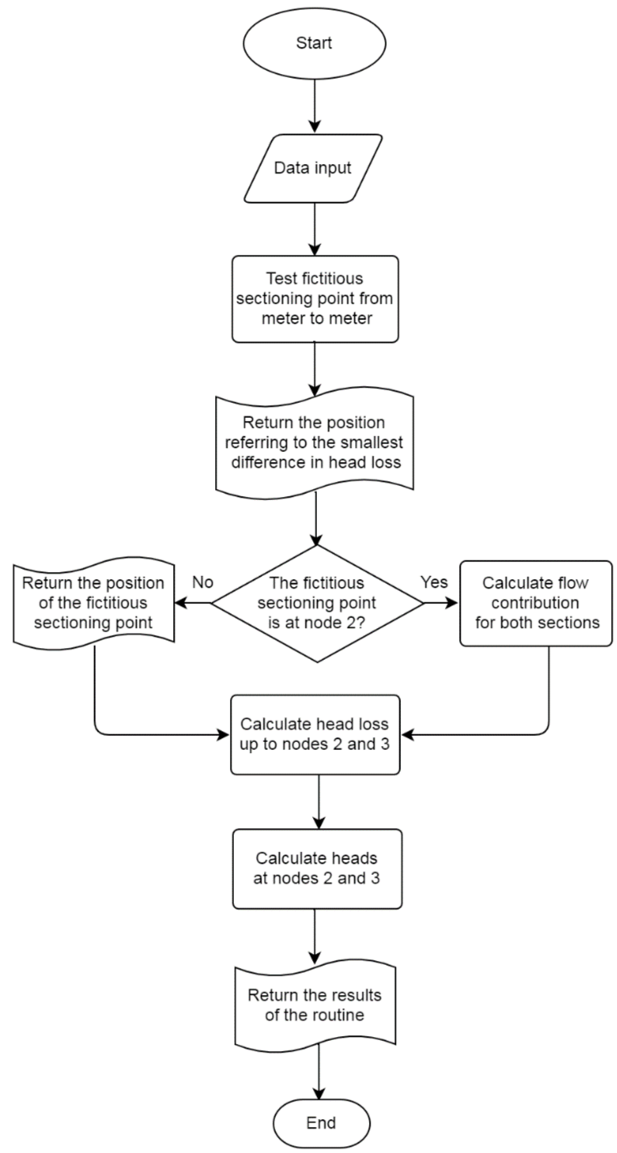


Fig. 5. Routine flowchart.

```
y = 1
hd =  []
hdi = []
while y < L:
  way1 = y
  way2 = L-y


 # Para o way 1
  W1=pd.DataFrame(data=LpDF[0:way1])
  if y > L1:
    u = L1

    while u < y :
      W1['Qout'][u] = Qout
      u = u+1
      W1['Vazão'] = y*qm-qm*W1['Comprimento'] + Qout - W1['Qout']


  else:
     W1['Vazão'] = y*qm-qm*W1['Comprimento'] - W1['Qout']


  W1['Vazão Fictícia'] = (W1['Vazão']+(W1['Vazão']-qm*1))/2
  W1['h1'] =10.65*(W1['Vazão Fictícia']/1000)**1.85*W1['Coeficiente C']**-1.85*(W1['Diâmetro']/1000)**-4.87

  Total1 = W1['h1'].sum()
  hd.append(Total1)
  hdi.append(y)

  n=W1['Vazão Fictícia'] < 0
  W1['Vazão Fictícia'][n]=0

  y=y+1
HD=pd.DataFrame(data=hd,columns=['Sum Esquerda'])
HDI=pd.DataFrame(data=hdi,columns=['Ponto de Seccionamento'])
HDDI = pd.concat([HDI,HD],axis =1)

###########################################################################################
# PROCESSO AUTOMATICO POR BAIXO
# Necessidade de colocar as variaveis de entrada novamente



# Vazao em marcha e C
Q = qm*(L1+L2+L3)
L= L1+L2+L3



#OBTENÇAO DOS DADOS DO TRECHO L1
n= 1
```

Fig. 6. Partial extract from the routine listing (a).

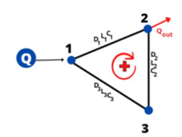
```
from decimal import Decimal
##############################
X1 = [HT['Diferença'].min()]
x1 = sum(X1)
index1 = HT['Diferença'].idxmin()
isump =HT['Sum Esquerda'][HT['Diferença'].idxmin()]
isumn =HT['Sum Direita'][HT['Diferença'].idxmin()]
######################################

X2 = [lowupDF['Diferença'].min()]
x2 = sum(X2)
index2 = lowupDF['Diferença'].idxmin()
qp = lowupDF['Qout Direita'][lowupDF['Diferença'].idxmin()]
qn = lowupDF['Qout Esquerda'][lowupDF['Diferença'].idxmin()]


if x2 < x1:
  print(' O ponto de seccionamento está preso no Qout')
  print(' O valor da vazão por cima Qout(+): ',round(qp,3), 'L/s')
  print(' O valor da vazão por baixo Qout(-): ',round(qn,3), 'L/s')
  print(' E a diferença entre as perdas de carga por cima e por baixo é de : ',x2, 'm')
  Qfp = (qm*L1 + qp +qp)/2
  Qfn1 = (qm*(L2 +L3) +qn + qm*L2 + qn)/2
  Qfn2 = (qm*L2  +qn + qn)/2
  u1 =10.65*(Qfp/1000)**1.85*C1**-1.85*(D1/1000)**-4.87*L1
  u2 =10.65*(Qfn1/1000)**1.85*C3**-1.85*(D3/1000)**-4.87*L3
  u22 = 10.65*(Qfn2/1000)**1.85*C2**-1.85*(D2/1000)**-4.87*L2
  print(' Pressão no ponto 1 : ', PA, 'm')
  print(' Perda de carga no Trecho 1-2 ',round(u1,3), 'm')
  print(' Perda de carga no  Trecho 1-3: ',round(u2,3), 'm')
  print('Perda de carga no Trecho 3-2',round(u1-u2,3),'m' )
  print()
  print('Balanço de carga : hf (Trecho 1-2) = hf(Trecho 1-3 + 3-2)')
  print('hf(trecho 1-2) = ' ,round(u1,3),'m')
  print('hf(trecho 1-3 + 3-2) : ',round(u2+u1-u2,3),'m')
  print('Vazões que chegam no ponto 2',round(qp,3),'+',round(qn,3),'=',round(qp+qn,3),'L/s')

  print(' Pressão no ponto 2 : ',round(CT1 - CT2  + PA - u1,3), 'm')
  print(' Pressão no ponto 3 : ',round(CT1 - CT3  + PA - u2,3), 'm')

else:
  print('O ponto de seccionamento está na posição: ',index1+1)
  print(' A soma de perda de carga por cima vale: ',round(isump,3), 'm')
  print(' A soma de perda de carga por baixo vale: ',round(isumn,3), 'm')
  print(' E a diferença entre as perdas de carga por cima e por baixo é de : ',x1 , 'm')

  if index1 > L1 and index1 < L1 + L2 :
    qf12 = ((index1*qm + Qout) + (index1-L1)*qm + Qout)/2
    h12  = 10.65*(qf12/1000)**1.85*C1**-1.85*(D1/1000)**-4.87*L1
    P2 = CT1 - CT2 + PA -h12

    qf13 = ((L1 + L2 + L3 - index1)*qm + (L1 + L2 + L3 - index1 - L3)*qm)/2
```

Fig. 7. Partial extract from the routine listing (b).

In the Results and Discussion section, screens with input and output data and a table with values of some simulated situations by the routine are presented.

IV. Results and Discussion

Fig. 8 presents a routine interface for input data. These are, sequentially, the flow to be distributed to the dwellings linearly along the sections (L/s/m), the residual flow at node 2 (L/s), the head at the upstream node 1 (m), and, for each section, the pipe diameter (mm), the length of the pipeline (m), the Hazen-Williams roughness coefficient (dimensionless), and the topographic elevation of the node (m).




```
Digite a vazão em marcha [L/s.m]: 0.02
Digite o valor da Vazão que sai em Qout [L/s]: 1
Digite o valor da pressão no ponto 1 [m]: 40

Para o Techo 1-2
Digite o valor do Diâmetro D1-2 [mm]: 50
Digite o valor do Comprimento L1-2 [m]: 100
Digite o valor do Coeficiente  C1-2 : 120
Digite o valor da cota topográfica do ponto 1 [m]: 700

Para o Techo 2-3
Digite o valor do Diâmetro D2-3 [mm] : 50
Digite o valor do Comprimento L2-3  [m]: 100
Digite o valor do Coeficiente  C2-3 : 120
Digite o valor da cota topográfica do ponto 2 [m]: 700

Para o Techo 3-1
Digite o valor do Diâmetro D3-1 [mm]: 50
Digite o valor do Comprimento L3-1 [m]: 100
Digite o valor do Coeficiente  C3-1 :
```

Fig. 8. Routine input data screen.

The possible scenarios, both contemplated by the routine, are graphically expressed in Figs. 9 and 10. The first concerns the situation in which the FSP is found at some intermediate point of a stretch, with the final flows of each section being null (it is the case where the total flow is being consumed by the dwellings, until it reaches zero, as if it were a dead end). The following reflects the situation in which the FSP is located exactly at node 2, making each section of the network have a contribution to the residual flow.

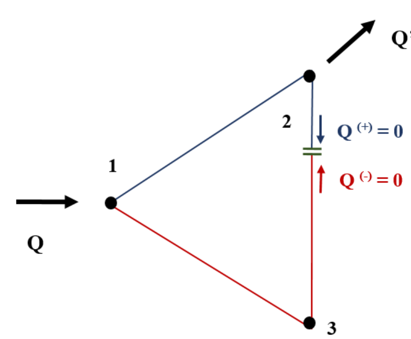


Fig. 9. FSP at some intermediate point of a stretch.

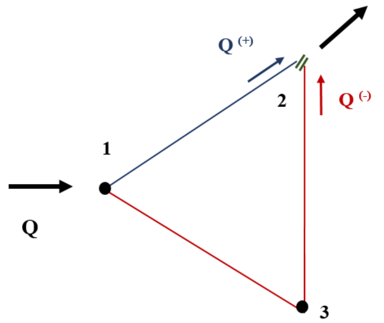


Fig. 10. FSP at residual flow node (node 2).

The routine is prepared to distinguish between the two cases represented by Figs. 9 and 10, and treat the question as such, with no need for the user to provide any additional information. Figs. 11 and 12 show the routine results screens. Fig. 11 depicts the situation shown in Fig. 9, while Fig. 12 contemplates the situation outlined in Fig. 10.

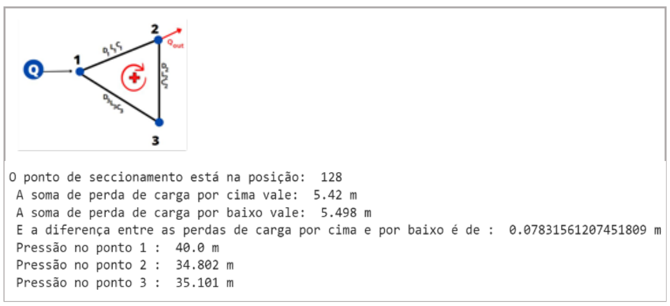


Fig. 11. Output data screen referring to the case of Fig. 9.

The results listed in Fig. 11 are the positioning of the FSP, counted in meters, from the upstream node (node 1), clockwise; the accumulated head loss in one direction and the other, from the upstream node to the FSP (m); the difference between the head losses (m); and nodal heads (m).

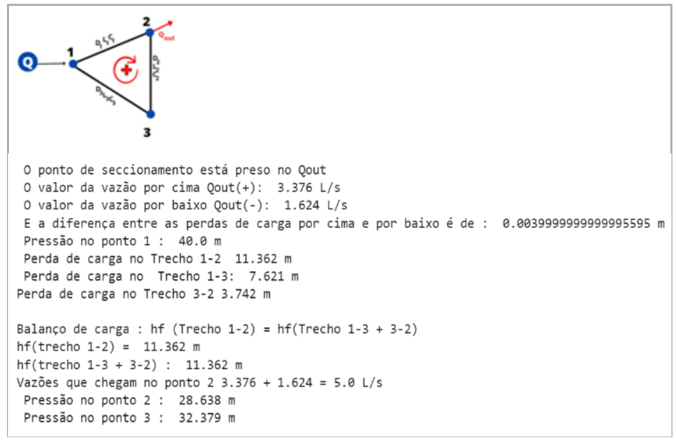


Fig. 12. Output data screen referring to the case of Fig. 10.

Fig. 12 provides as results the weighted contribution flows for the residual flow at node 2 referring to each of the sections (L/s); the accumulated head loss in one direction and the other, from the upstream node to the FSP (node 2) (m); the difference between the head losses (m); and nodal pressures (m).

Based on data simulated by the routine, Table 1 illustrates values referring to twelve hypothetical situations, the initial six referring to the context of Fig. 9, and the next six related to Fig. 10. The results of Fig. 11 refer to case 1 of Table 1, while those in Fig. 12 are addressed in case 7 of the same table.

Cases 1 and 7 are the references, with changes being made one by one in subsequent cases, in order to better verify the impacts caused by the variation in each input data. Situations 2 to 6 refer to unitary variations of case 1, with the changed input data shown in bold. Situations 8 to 12 present unit variations in relation to case 7, following the same pattern.

TABLE I. SIMULATED SITUATIONS

Case	L1	L2	L3	D1	D2	D3	C1	C2	C3	CT1	CT2	CT3	Q_R	q	P1	L_{FSP}	$Q^{(+)}$	$Q^{(-)}$	P2	P3
#01	100	100	100	50	50	50	120	120	120	700	700	700	1.0	0.02	40	128	0	0	34.802	35.101
#02	**50**	100	100	50	50	50	120	120	120	700	700	700	1.0	0.02	40	109	0	0	37.169	37.137
#03	100	100	100	**75**	50	50	120	120	120	700	700	700	1.0	0.02	40	180	0	0	38.639	38.227
#04	100	100	100	50	50	50	**140**	120	120	700	700	700	1.0	0.02	40	138	0	0	35.504	35.812
#05	100	100	100	50	50	50	120	120	120	700	**690**	700	1.0	0.02	40	128	0	0	44.802	35.101
#06	100	100	100	50	50	50	120	120	120	700	700	700	1.0	0.02	**50**	128	0	0	44.802	45.101
#07	100	100	100	50	50	50	120	120	120	700	700	700	5.0	0.01	40	100	3.376	1.624	28.638	32.379
#08	**50**	100	100	50	50	50	120	120	120	700	700	700	5.0	0.01	40	50	4.030	0.970	33.175	35.066
#09	100	100	100	**75**	50	50	120	120	120	700	700	700	5.0	0.01	40	100	4.828	0.172	37.159	37.603
#10	100	100	100	50	50	50	**140**	120	120	700	700	700	5.0	0.01	40	100	3.618	1.382	30.444	33.435
#11	100	100	100	50	50	50	120	120	120	700	**690**	700	5.0	0.01	40	100	3.376	1.624	38.638	32.379
#12	100	100	100	50	50	50	120	120	120	700	700	700	5.0	0.01	**50**	100	3.376	1.624	38.638	42.379

Where L1, L2, and L3 are the lengths of the sections (m); D1, D2, and D3 are the pipe diameters in each section (mm); C1, C2, and C3 are the Hazen-Williams roughness coefficients (dimensionless); CT1, CT2, and CT3 are the terrain altitudes of the nodes (m); Q_R is the residual flow (L/s); q is the linear flow distributed along the sections (L/s/m); P1 is the head at the upstream node 1 (m); L_{FSP} is the distance from the upstream node to the FSP, clockwise (m); $Q^{(+)}$ and $Q^{(-)}$ are the flows referring to each section, in both directions, contributing to the residual flow (L/s); P2 and P3 are the heads at nodes 2 and 3.

The difference in input data, representative of the characteristics of the network, between reference cases (#1 and #7) are only the flows distributed along the sections, 0.02 L/s/m and 0.01 L/s/m, and the residual flow in node 2, 1.0 L/s and 5.0 L/s, respectively in both. This expedient was adopted precisely to promote a distinction between the situation in Fig. 9 and that of Fig. 10.

Analyzing the results in Table 1, both for cases #2 to #6, which are variations of case #1, and scenarios #8 to #12, which are transitions from situation #7, bearing in mind the correlations indicated in (1), it becomes quite feasible to evaluate and understand the reasonableness of the displacements of the FSP, whether more to one direction or more to the other, as well as assimilating the greater or lesser contribution of one and the other section to the residual flow. However, the routine comes to ratify such assumptions and becomes essential to provide the exact values of the output variables.

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