HydraNet Academic: Interactive Platform with Automatic Interpretation for the Analysis and Learning of Hydraulic Networks in Civil Engineering

HydraNet Academic: Plataforma Interactiva con Interpretación Automática para el Análisis y Aprendizaje de Redes Hidráulicas en Ingeniería Civil[1]

E. O. Ladino-Moreno

DOI: https://doi.org/ 10.22517/23447214.26020
Scientific and technological research paper

***Abstract*— This article presents HydraNet Academic, an online computational platform intended to assist the analysis and learning of hydraulic networks in civil engineering. The system enables the modeling of pipe systems in series and parallel configurations through an interactive graphical interface, integrating hydraulic calculations based on the Darcy–Weisbach equation and friction factor estimation using the Colebrook–White method. The platform incorporates georeferencing functions that contribute to the automatic acquisition of terrain elevations and the geometric calculation of pipe lengths, thereby improving the spatial consistency of the hydraulic model. In addition, HydraNet Academic includes an automatic results interpretation module grounded in criteria established by the Technical Regulations of the Drinking Water and Basic Sanitation Sector. The results obtained show consistency with classical cases reported in the literature and with simulations performed using EPANET, supporting its usefulness as an academic tool for the analysis and understanding of the hydraulic behavior of pipe networks.**

***Keywords*— Darcy–Weisbach, Educational software, EPANET, Hydraulic analysis, Hydraulic networks, HydraNet Academic**

***Resumen*— Este artículo presenta HydraNet Academic, una plataforma computacional en línea diseñada para contribuir al análisis y el aprendizaje de redes hidráulicas en ingeniería civil. El sistema permite modelar sistemas de tuberías en configuraciones en serie y en paralelo mediante una interfaz gráfica interactiva, integrando cálculos hidráulicos basados en la ecuación de Darcy-Weisbach y la estimación del factor de fricción mediante el método de Colebrook-White. La plataforma incorpora funciones de georreferenciación que contribuyen a la adquisición automática de elevaciones del terreno y al cálculo geométrico de las longitudes de las tuberías, mejorando así la consistencia espacial del modelo hidráulico. Además, HydraNet Academic incluye un módulo de interpretación automática de resultados basado en los criterios establecidos por el Reglamento Técnico del Sector de Agua Potable y Saneamiento Básico. Los resultados obtenidos muestran consistencia con casos clásicos reportados en la literatura y con simulaciones realizadas con EPANET, lo que respalda su utilidad como herramienta académica para el análisis y la comprensión del comportamiento hidráulico de las redes de tuberías.**

***Palabras clave*— Análisis hidráulico, Darcy–Weisbach, EPANET, HydraNet Academic, Redes hidráulicas, Software educativo.**

I. INTRODUCTION

Within civil engineering education, pipe systems constitutea fundamental component, as they form the basis for the design and operation of essential infrastructures such as drinking water supply networks, sewerage systems, irrigation systems, and various industrial facilities. The study of hydraulic networks enables the understanding of the interaction among flow rate, pressure, energy, and system geometry, as well as the application of conservation principles and fundamental laws of fluid mechanics. For this reason, their instruction occupies a central role in civil engineering curricula and related academic programs. Moreover, the increasing complexity of water supply systems has promoted the use of computational tools such as EPANET for the efficient analysis and design of pipe networks [1].

In a complementary manner, computational tools for process optimization have proven effective in improving efficiency and strengthening academic learning through practical applications [2]. Likewise, the integration of hydraulic and hydrological modeling with GIS tools in academic settings has demonstrated its contribution to meaningful learning by Moreover, the sectorization of distribution networks has become an effective strategy for increasing operational and energy efficiency through the application of approaches based on graph theory and

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multiobjective optimization, which allow the analysis of multiple operating scenarios, even in complex systems with pumping stations [6]. Therefore, explicit algorithms have been proposed for the analysis and adjustment of pipe networks under steady-state conditions, based on the reformulation of hydraulic equilibrium equations and on iterative methods such as Newton–Raphson, enabling the determination of design, operation, and calibration parameters that accurately satisfy pressure and flow constraints at critical nodes and pipes [7].

Likewise, the calibration of hydraulic models for distribution networks is recognized as a critical and complex stage, which has motivated the development of global optimization approaches linked to hydraulic engines such as EPANET, capable of simultaneously estimating calibration parameters and their associated uncertainties, thereby overcoming the limitations of traditional methods and reinforcing the reliability of model predictions [8].

However, the learning of hydraulic analysis presents recurrent conceptual difficulties, particularly in the interpretation of head losses, the hydraulic gradient, and the distribution of pressures along a network. The mathematical abstraction of the models, together with the limited spatial visualization of results in traditional approaches, often hinders a comprehensive understanding of the hydraulic behavior of the system, generating gaps between theoretical formulation and practical application.

In the educational context, virtual learning objects supported by structured guides have proven effective in facilitating virtual practices related to pipe networks [9]. Consequently, computational modeling of distribution networks has become a fundamental tool for predicting pressures and flow rates, evaluating system performance, and supporting design and operational decisions in complex hydraulic networks [10], [11].

In this context, the use of computational tools such as HydraNet has become a relevant support for learning hydraulic network analysis, both in academic settings and during the early stages of professional practice. HydraNet enables the integration of geometric modeling, hydraulic computation, and results interpretation within an interactive visual environment, enhances the understanding of physical phenomena and the validation of fundamental concepts through reproducible simulations. The platform is available online at: https://www.edgarladino.com/hydranet.

II. METHODOLOGY

A. Design

The development of HydraNet Academic was based on an incremental methodological approach oriented toward scientific software engineering, which integrates classical hydraulic modeling with interactive analysis environments. A modular structure implemented in JavaScript was adopted, in which hydraulic calculation routines, network visualization components, and automatic PDF report generation modules are clearly separated.

The design prioritized criteria of reproducibility and academic validation, ensuring the traceability of the physical parameters involved, such as flow rate, velocity, head losses, and nodal pressures, through a logical step-by-step simulation and verification workflow. This methodology enabled the translation of theoretical hydraulic models, based on the Darcy–Weisbach and Colebrook–White equations, into a computational environment that is both comprehensible and operational for educational and research contexts. Additionally, a user-centered design philosophy was adopted, incorporating visual feedback tools, interactive alerts, and real-time data validation, as illustrated in Fig. 1. Each system component was evaluated through controlled iterations, ensuring numerical stability, result accuracy, and graphical consistency. Moreover, the methodology emphasized the transparency of hydraulic calculations by allowing direct access to the system's core functions, thereby supporting its use as a training environment in hydraulic engineering courses.

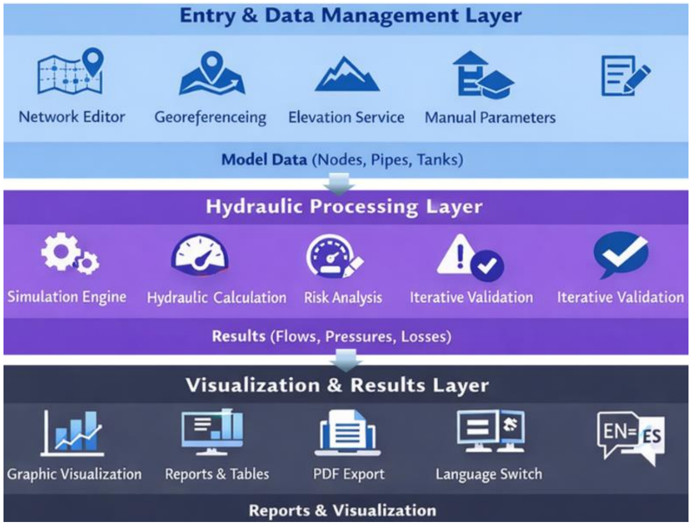


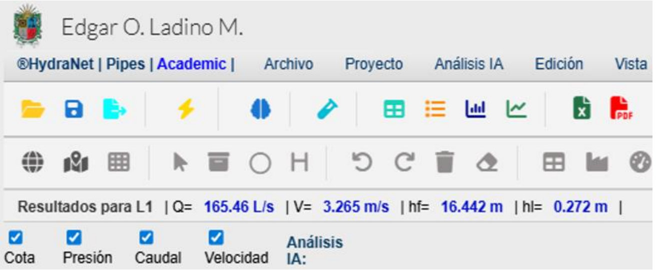
Fig. 1. Functional architecture of the *HydraNet Academic* platform.

Therefore, this methodology is consistent with the principles of computational hydraulic modeling proposed by Rossman [12], who establishes the need to ensure traceability, numerical stability, and systematic validation when implementing the Darcy–Weisbach and Colebrook–White equations in hydraulic simulation environments widely used in academic and research contexts. HydraNet Academic presents a client-based architecture, fully executable within a web browser, organized into well-defined functional layers. The first layer corresponds to the logical engine, which is responsible for data storage, physical parameter validation, execution of hydraulic algorithms, and generation of numerical results.

The second layer consists of the visual interface, developed using HTML5 and the Canvas API, where the hydraulic network is dynamically represented through nodes, tanks, and pipes. The third layer integrates external interaction services, including the embedded map, the topographic elevation service, and the PDF-based results export module. This lightweight architecture allows hydraulic simulations to be executed directly within a standard web browser, without requiring local installation or server-side dependencies. The architectural design was conceived under principles of modularity and interoperability, such that each function, from elevation retrieval to the generation of hydraulic gradient plots, remains decoupled from the graphical interface.

This separation contributes to system debugging, maintenance, and extensibility. HydraNet incorporates specific routines for series networks, parallel networks, and mixed configurations, maintaining independence between the resolution of the mathematical model and its visual representation. Likewise, as shown in Fig. 1, the architecture enables the storage of structured results and their linkage with cartographic information, consolidating an integrated platform for numerical simulation, georeferencing, and automated technical documentation.

The HydraNet Academic web platform was conceived as an interactive didactic environment that enables the construction, simulation, and analysis of hydraulic networks on a georeferenced cartographic base. Upon session initiation, the system loads a base map that serves as support for the insertion of tanks, nodes, and pipes with real spatial coordinates. Each element is characterized by physical parameters such as diameter, length, roughness, and local losses, which can be edited through dynamic modal windows, as shown in Fig. 2.



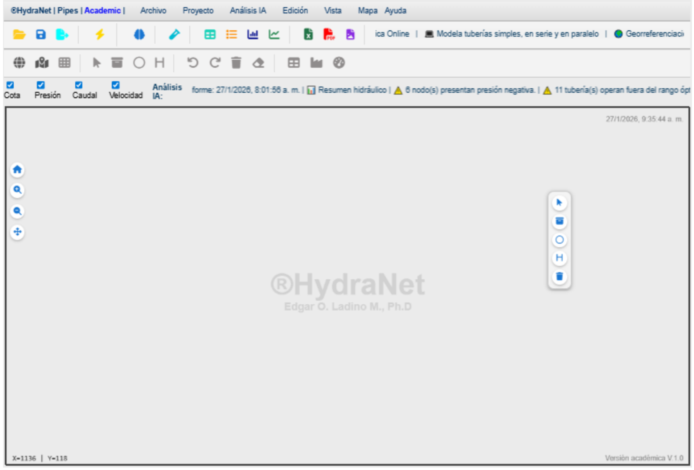
Resultados para L1 | Q= 165.46 L/s | V= 3.265 m/s | hf= 16.442 m | hl= 0.272 m |

☑ Cota ☑ Presión ☑ Caudal ☑ Velocidad

Fig. 2. Main toolbar and analysis icons of the *HydraNet Academic* platform.

The main system workflow includes automatic validation of network connectivity, execution of the iterative hydraulic calculation, and visualization of pressure gradients and head losses. Once the simulation is completed, the system automatically generates result tables, velocity plots, loss histograms, and a technical report in PDF format with an academic structure. The user can explore results by individual element, modify system properties, or analyze the overall hydraulic behavior through integrated graphical representations. Moreover, the platform incorporates dynamic language functions, zoom control, and cartographic layer management, reinforcing its interactive and educational character.

This usage workflow (Fig. 3) enables a progressive transition from theoretical formulation to visual interpretation and technical documentation of hydraulic analysis. Notably, the development of hydraulic modeling tools validated through direct comparison of their results with EPANET has proven to be an effective strategy for ensuring the accuracy, reproducibility, and reliability of flow rate and velocity calculations in water distribution networks [13].



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forme: 27/1/2026, 8:01:56 a. m. | Resumen hidráulico | ⚠ 6 nodo(s) presentan presión negativa. | ⚠ 11 tubería(s) operan fuera del rango óp

27/1/2026, 9:35:44 a. m.

X=1136 | Y=118

Fig. 3. Initial interactive workspace of the HydraNet Academic platform.

B. *Instruments*

HydraNet Academic implements a steady-state hydraulic model for pressurized pipe networks, grounded in the energy balance between tanks and nodes, under the assumptions of incompressible, one-dimensional, and fully developed flow. Friction head losses in each pipe are calculated using the Darcy–Weisbach equation, expressed as:

$$h_f = f\frac{L}{D}\frac{V^2}{2g} \tag{1}$$

where h_f is the friction head loss (m), f is the dimensionless friction factor, L is the pipe length (m), D is the internal diameter (m), V is the mean flow velocity (m/s), and g is the acceleration due to gravity (m/s²). Local losses are incorporated through dimensionless coefficients K, according to:

$$h_l = K\frac{V^2}{2g} \tag{2}$$

The friction factor f is determined from the implicit Colebrook–White formulation, as a function of the Reynolds number and the absolute roughness of the pipe, according to:

$$\frac{1}{\sqrt{f}} = -2log_{10}\left[\frac{\varepsilon}{3.7D} + \frac{2.51}{Re\sqrt{f}}\right] \tag{3}$$

where ε represents the absolute roughness (m) and Re denotes the Reynolds number. The kinematic viscosity of the fluid is represented by ϑ (m^2/s). Likewise, the Colebrook–White equation is solved numerically using an iterative procedure, ensuring convergence of the friction factor for each pipe, since this parameter appears implicitly in the formulation of turbulent flow [14].

Furthermore, the global hydraulic solution of the network is obtained through an iterative scheme that adjusts the flow rate until satisfying the equality between the hydraulic head available between tanks and the sum of friction and local head losses in each branch. In series configurations, the flow rate is updated using a successive correction procedure based on the following relationship:

$$Q_{i+1} = Q_i\sqrt{\frac{\Delta H}{\sum h}} \tag{4}$$

where ΔH is the head difference between the end tanks and $\sum h$ represents the total head loss calculated for the current flow rate. Additionally, the Darcy–Weisbach friction factor can be efficiently evaluated using explicit formulations derived from the Colebrook–White equation, reducing computational cost without compromising the accuracy required for the hydraulic analysis of complex networks [15]. **Therefore, the solution of flow rate and head loss problems in pipes is constrained by the implicit nature of the Colebrook–White equation, which has motivated the development of formulations and numerical procedures that reduce the need for repetitive calculations and improve the efficiency of hydraulic analysis** [16]. In parallel or mixed networks, initial flow rates are assigned to each branch and are iteratively adjusted until head losses are equalized between alternative paths, ensuring hydraulic continuity. Once convergence is achieved, as shown in Fig. 4, the total hydraulic head propagates throughout the network, and nodal pressures are computed as the difference between the total head and the geometric elevation of each node.

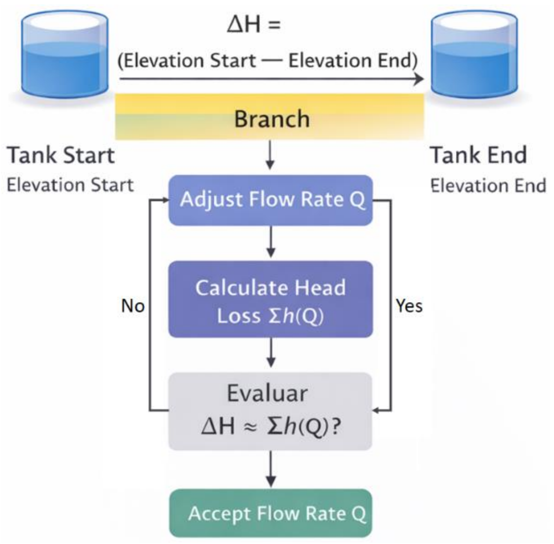


Fig. 4. Iterative hydraulic convergence scheme implemented in HydraNet Academic

Importantly, the global hydraulic solution of the network is obtained through an iterative scheme of successive flow rate correction, following the classical approach proposed by Hardy Cross, in which the flow rate is adjusted until the equality between the available hydraulic head and the sum of friction and local head losses in the system is satisfied [17].

C. *Procedure*

In this context, the modeling procedure implemented in HydraNet Academic adopts an explicit structure of the fundamental hydraulic elements of the system, defining nodes, pipes, and tanks as the basic components for network representation [18]. Nodes are considered connection points at which pressures and hydraulic heads are evaluated, pipes represent the conveyance elements with specific geometric and hydraulic properties, and tanks are modeled as constanthead boundary conditions. This step-by-step organization enables the construction of series, parallel, or mixed network configurations, ensuring topological coherence and direct support for the application of the iterative hydraulic calculation scheme implemented in the system.

The georeferencing of hydraulic elements is carried out through the integration of an interactive base map, which allows real geographic coordinates to be assigned to nodes and tanks during their creation or editing. Based on these coordinates, the system automatically queries an elevation service to assign terrain elevations, ensuring altimetric consistency. Furthermore, when pipe routing is performed directly on the map, the length of each segment is automatically calculated using geodesic distances between the defined vertices, eliminating the need for manual estimations and ensuring geometric accuracy within the hydraulic model. The tool employed is the Google Maps JavaScript API (Fig. 5), specifically through two of its integrated services:

1). Maps and geographic projection: for cartographic visualization, coordinate capture, and conversion between canvas coordinates and real geographic coordinates (latitude and longitude)

2). Elevation service (Google Elevation Service): for the automatic retrieval of terrain elevations, expressed in meters above sea level (m a.s.l.), associated with nodes and tanks based on their geographic coordinates.

Viscosidad: 1.00e-6 m²/s | Nodos: 16 | Tanques: 2 | Tuberías: 19 | Presión Máx: 101.06 m (Nodo N1) | Caudal Máx: 165.46 L/s (Tub. L5)

Fig. 5. Georeferenced hydraulic network over a Google Maps basemap.

Therefore, applications of geographic information systems are recognized as a key component for the analysis and management of water systems, as they integrate spatial information, graphical interfaces, and hydraulic data within a coherent operational environment [19].

Thus, this combination enables precise georeferencing of the hydraulic model and the automatic assignment of elevations directly from topographic data provided by Google. The generation of hydraulic results in HydraNet Academic is performed once convergence of the iterative calculation process is achieved, systematically producing flow rates, velocities, friction and local head losses, as well as pressures and hydraulic heads at nodes and tanks. These results are presented in an integrated manner through tables, plots, and visualizations over the modeled network, supporting technical analysis and the identification of hydraulic behavior patterns throughout the system. Additionally, the system incorporates an automatic interpretation module based on operational criteria and recommended ranges established by the Technical Regulations of the Drinking Water and Basic Sanitation Sector (RAS).

Based on these criteria, HydraNet Academic evaluates flow velocities, pressure levels, and head losses, issuing qualitative assessments regarding the hydraulic adequacy of the design. In particular, iterative methods have been developed for the analysis of hydraulic networks that ensure rapid convergence and numerical stability in both open and closed systems [20].

III. RESULTS

A. *Results of the hydraulic analysis using HydraNet Academic*

The results of the hydraulic analysis generated by HydraNet Academic include the detailed determination of nodal pressures, pipe velocities, and friction and local head losses along each network segment. The system automatically identifies the nodes with the maximum and minimum pressures, enabling evaluation of the hydraulic gradient and verification of compliance with recommended operational ranges. Likewise, the pipe conveying the highest flow rate is explicitly identified, as well as those associated with the highest velocities and head losses, providing relevant information for the hydraulic diagnosis of the design. Result interpretation is supported by visualization tools based on color scales applied over the network, allowing the spatial identification of critical zones or areas operating under adequate conditions. These representations are complemented by summary tables that consolidate the hydraulic values of each element, enabling rigorous quantitative analysis and a clear technical interpretation. Overall, this approach supports the understanding of system hydraulic behavior and contributes to design evaluation and adjustment processes in academic contexts of hydraulic engineering.

B. Functional validation and comparison with EPANET

For the functional validation of HydraNet Academic, a closed pressurized hydraulic circuit was constructed, consisting of two tanks (T1 and T2), sixteen intermediate nodes, and nineteen pipes, arranged in series, parallel, and multiple-branch configurations.

TABLE II
COMPARISON OF FLOW RATES IN PIPES
(EPANET VS *HYDRANET ACADEMIC*)

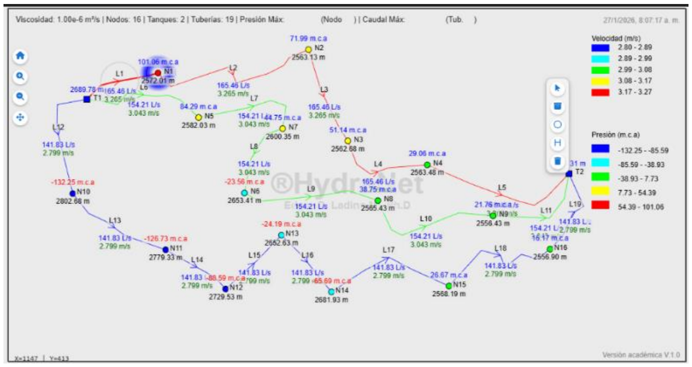
Pipe	EPANET Flow (L/s)	HydraNet Flow (L/s)
L1	165.46	165.46
L2	165.46	165.46
L5	165.46	165.46
L12	141.83	141.83
L19	141.83	141.83

The complete model data, including network geometry, hydraulic parameters, and the simulation results used for this validation, are publicly available at the following link: [https://doi.org/10.5281/zenodo.18394510].

The system exhibits significant elevation differences between nodes, generating a variable hydraulic gradient and zones with both positive and negative pressures, a condition suitable for evaluating the robustness of the numerical model. The same geometric and hydraulic scheme was implemented in EPANET 2 and in HydraNet Academic, using identical diameters, lengths, roughness values, and local loss coefficients, as observed in the comparative visualizations of the model.

The comparison was performed at the level of specific hydraulic results, contrasting nodal pressures and flow rates in representative pipes of the system. Table I presents the comparison of nodal pressures obtained using EPANET and HydraNet Academic, whereas Table II summarizes the comparison of pipe flow rates. Visually, the values reported by EPANET and those obtained with HydraNet coincide in magnitude and spatial distribution, including the identification of the node with the maximum pressure (N1), the node with the minimum pressure (N10), and the pipe conveying the highest flow rate (L5), thereby confirming the functional equivalence between both simulation approaches.

Fig. 6 presents the spatial distribution of the validation hydraulic circuit, showing the location of nodes, tanks, and pipes, as well as the spatial variation of pressures and flow rates throughout the network.



Viscosidad: 1.00e-6 m²/s | Nodos: 16 | Tanques: 2 | Tuberías: 19 | Presión Máx: (Nodo) | Caudal Máx: (Tub.)

Fig. 6. Hydraulic network simulation results displayed in *HydraNet Academic.*

Table II presents a detailed comparison of flow rates obtained in representative pipes of the hydraulic circuit using EPANET and HydraNet Academic. The values reported for each pipe show exact correspondence between both systems, covering pipes with identical hydraulic roles as well as those conveying the highest flow rates within the network.

TABLE I
COMPARISON OF PRESSURES AT NODES
(EPANET VS *HYDRANET ACADEMIC*)

Node	EPANET Pressure (m.w.c.)	HydraNet Pressure (m.w.c.)
N1	101.056	101.056
N2	71.992	71.992
N3	51.136	51.136
N5	84.293	84.293
N10	-132.252	-132.252

This level of agreement indicates that the flow distribution computed by HydraNet Academic accurately matches the results produced by EPANET for steady-state conditions. Consequently, these results confirm that the hydraulic model implemented in HydraNet Academic reliably reproduces flow rate calculations, thereby supporting its functional validity for the analysis and evaluation of pressurized hydraulic networks.

The validation hydraulic circuit implemented in EPANET consists of a pressurized network composed of two tanks, multiple intermediate nodes, and pipes with different hydraulic configurations, in which the spatial distribution of flow rates and pressures under steady-state conditions is observed.

Consequently, Fig. 7 illustrates the complete layout of the network, showing nodal pressure values, including sectors with both positive and negative pressures, as well as the flow rates circulating through each pipe, reflecting the hydraulic gradient generated by the head difference between the end tanks. This representation constitutes a fundamental visual reference for the direct comparison of the hydraulic results obtained using HydraNet Academic.

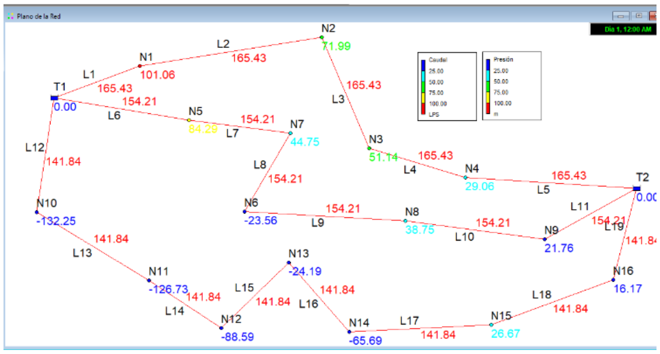
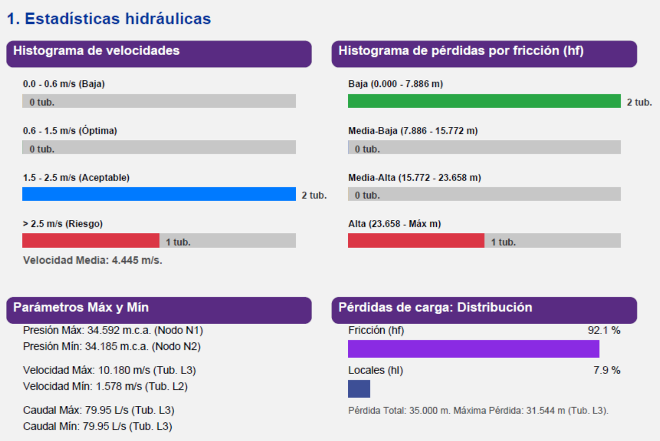


Fig. 7. Hydraulic simulation results obtained with EPANET for the validation network.

The automatic analysis performed by HydraNet Academic summarizes the hydraulic behavior of the network through statistical indicators of velocities, head losses, and pressures. The histograms indicate a concentration of pipe segments within acceptable velocity ranges, although at least one pipe exhibits elevated values that suggest a potential hydraulic risk condition. Additionally, friction losses are predominantly concentrated at low levels, with a single segment registering the maximum energy dissipation. The extreme values further allow identification of the node with the highest pressure and the pipe operating under the most hydraulically demanding condition, as shown in Fig. 8.


1. Estadísticas hidráulicas

Histograma de velocidades

0.0 - 0.6 m/s (Baja)
0 tub.
0.6 - 1.5 m/s (Óptima)
0 tub.
1.5 - 2.5 m/s (Aceptable)
2 tub.
> 2.5 m/s (Riesgo)
1 tub.
Velocidad Media: 4.445 m/s.

Histograma de pérdidas por fricción (hf)

Baja (0.000 - 7.886 m)
2 tub.
Media-Baja (7.886 - 15.772 m)
0 tub.
Media-Alta (15.772 - 23.658 m)
0 tub.
Alta (23.658 - Máx m)
1 tub.

Parámetros Máx y Mín

Presión Máx: 34.592 m.c.a. (Nodo N1)
Presión Mín: 34.185 m.c.a. (Nodo N2)
Velocidad Máx: 10.180 m/s (Tub. L3)
Velocidad Mín: 1.578 m/s (Tub. L2)
Caudal Máx: 79.95 L/s (Tub. L3)
Caudal Mín: 79.95 L/s (Tub. L3)

Pérdidas de carga: Distribución

Fricción (hf) 92.1 %
Locales (hl) 7.9 %
Pérdida Total: 35.000 m. Máxima Pérdida: 31.544 m (Tub. L3).

Fig. 8. Automatic statistical analysis of velocities, head losses, and pressures using HydraNet Academic.

IV. DISCUSSION

A. *Technical analysis of the results*

The hydraulic interpretation of the results obtained using HydraNet Academic reveals a coherent system behavior, in which the distribution of flow rates, pressures, and head losses responds appropriately to the geometric configuration and the imposed loading conditions. Energy consistency is reflected in the balance between the available head difference between tanks and the total losses calculated along the pipes, which confirms the physical consistency of the hydraulic model and the stability of the iterative process employed.

B. *Academic and didactic implications*

The academic and didactic implications of HydraNet Academic are reflected in its capacity to support the conceptual learning of hydraulic network analysis through the direct visualization of fundamental variables such as flow rate, pressure, and head losses. The integration of numerical results with graphical representations contributes to reducing the learning curve associated with traditional hydraulic models, strengthening the understanding of the underlying physical principles. Likewise, the system constitutes a useful tool for training and technical validation in educational contexts, as it allows results to be contrasted, scenarios to be analyzed, and hydraulic design criteria to be reinforced in a structured and reproducible manner.

C. *Scope and limitations of the system*

The HydraNet Academic version is deliberately limited to the analysis of simple pipe networks in series and parallel configurations, applicable to steady-state circuits, with the objective of supporting training processes and conceptual validation. The analysis of more complex networks, including distributed demands, multiple sources, advanced operating conditions, or extensive design scenarios, is addressed through HydraNet Professional, which is conceived as a complementary tool for professional and larger-scale applications. In all cases, computational capacity and the size of the models that can be analyzed depend directly on the resources of the user’s equipment, since the system is executed locally within the browser environment.

V. CONCLUSIONS

HydraNet Academic demonstrated hydraulic consistency and functional equivalence with EPANET in the simulation of pressurized networks under steady-state conditions, accurately reproducing nodal pressures and pipe flow rates for the analyzed validation circuit.

The integration of georeferencing, automatic calculation of elevations and pipe lengths, and regulatory-based interpretation of results strengthens the understanding of hydraulic system behavior and adds academic value to the processes of analysis and technical validation of pipe networks.

The platform is established as an effective didactic tool for teaching hydraulic network analysis, as it reduces the operational complexity of traditional modeling approaches and enables a clear transition between theoretical formulation, numerical simulation, and results interpretation, while maintaining a clearly defined scope relative to more advanced professional applications.

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