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Applying the WaterGEMS Software to Conduct a Comparison of the Darcy-Weisbach and Hazen-Williams Equations for Calculating the Frictional Head Loss in a Selected Pipe Network

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ABSTRACT

Darcy-Weisbach (D-W) is a typical resistance equation in pressured flow; however, some academics and engineers prefer Hazen-Williams (H-W) for assessing water distribution networks. The main difference is that the (D-W) friction factor changes with the Reynolds number, while the (H-W) coefficient is a constant value for a certain material. This study uses WaterGEMS CONNECT Edition update 1 to find an empirical relation between the (H-W) and (H-W) equations for two 400 mm and 500 mm pipe systems. The hydraulic model was done, and two scenarios were applied by changing the (H-W) coefficient to show the difference in the results of head loss. The results showed a strong relationship between both equations with correlation coefficients of 0.999, 0.998, and 0.993 for 500 mm pipes and 0.998, 0.999, and 0.996 for 400 mm pipes for the applied scenarios. The results also showed that the head loss when using the (H-W) equation for the old pipe is more than the (D-W) equation.

Keywords: Hydraulic roughness, frictional head loss, WaterGEMS.

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استخدام برنامج WaterGEMS لمقارنة خسائر الاحتكاك في شبكة انابيب محددة باستخدام معادلتي Darcy–Weisbach و Hazen–Williams

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الخلاصة

تعتبر معادلة Darcy-Weisbach المعادلة النموذجية لحساب خسائر الاحتكاك في الانابيب بينما يعتمد الكثير من المهندسين والاكادميين على استخدام معادلة Hazen-Williams في تصميم وتقييم شبكات المياه . ان الاختلاف الرئيسي بينهما هو ان معامل الاحتكاك في معادلة (H-W) يعتمد على Reynolds number في حين ان معامل الاحتكاك في معادلة (H-W) هو قيمة ثابتة يعتمد على مادة الانبوب. في هذه الدراسة تم استخدام برنامج WaterGEMS لايجاد علاقة بين معادلتي (D-W) و (H-W) وبعد ان تم عمل النموذج الهايدروليكي تم تطبيق سيناريوهين مختلفين عن طريق تغيير معامل احتكاك (H-W) لمقارنة الفروقات بين القيم الناتجة. اظهرت النتائج وجود علاقة قوية بين المعادلتين مع معاملات ارتباط (0.993,0.998,0.999) للانابيب ذات القطر 500 ملم و (0.996,0.999,0.998) للانابيب ذات القطر400 ملم كما اظهرت الدراسة ان خسائر الاحتكاك في الانابيب القديمة عند استخدام معادلة (H-W) اكبر من الخسائر الناتجة عند استخدام معادلة (D-W).

الكلمات الرئيسية : الخشونة الهيدروليكية, خسائر الاحتكاك, WaterGEMS .

1. INTRODUCTION

A major impediment to long-term growth is a lack of safe drinking water. Consistent population growth and the expected effects of climate change, which have become a tangible reality, contribute to increasing pressure on limited water resources and the need to reconsider water management methods, which require review and evaluation of performance **(Nasier and Abdulrazzaq., 2022)**. For a good performance system, the frictional head loss is the major parameter of the hydraulic design of any plumbing and water supply distribution system. For a pipe to be suitable for commercial usage, its flow characteristics and frictional losses per length of pipe must fall within a specified range **(Jamil and Mujeebu, 2019)**. (H-W) and (D-W) are the two most commonly used equations for pressured flow. Despite the widespread use of the (H-W), the (D-W) has a more plausible basis and is appropriate for evaluating a critical situation through water distribution. However, both frictional equations give approximately the same results **(Elhay and Simpson, 2011)**. Using the empirical equation (H-W), each type of pipe material has a different coefficient (C) to calculate the headloss. In contrast, the (D-W) coefficient of friction (f) is a function of the Reynolds number and the material property (absolute roughness) **(Uribe et al., 2015; Abbas and Mohammed, 2020)**. The (H-W) equation can only be used for water and is applied to a pipe with a turbulent flow, whereas the (D-W) equation may be used for any fluid and applies to all fluid flow. However, compared to the other equations, the (H-W) equation is easy to use **(Valiantzas, 2005)**. WaterGEMS is a hydraulic modeling program that includes enhanced interoperability, GIS model construction, optimization, and asset management features. WaterGEMS is an easy-to-use environment for engineers to study, design, and optimize water distribution systems. Therefore, this program was used to conduct the study **(Mehta et al., 2017)**. Five hydraulic models were constructed to present an empirical relationship between the (D-W) and (H-W) equations. The head loss in pipes was estimated for varied pipe diameters (15 mm to 50 mm) and with different discharges. The correlation coefficient between the (D-W) and (H-W) equations' head loss was 0.999, while the R^2 value for the trend line of head loss values obtained by these equations was 0.9993 **(Jamil and Mujeebu, 2019)**. To convert the (H-W) coefficient to (D-W) friction coefficient, three networks were solved by considering five scenarios for different values of $C_{H.W.}$ Analyzing the pipe network shows that the (H-W) equation and the relationships, which use both pipe diameter and Reynolds number for converting $C_{H.W}$ to (f), yield acceptably close results to when the (D-W) equation is used. However, the application of the relationship, which uses pipe diameter for converting $C_{H.W}$ to (f) does not achieve accurate results in some cases, especially for lower values of $C_{H.W}$ **(Niazkar et al., 2017)**. This study aims to find the correlation coefficient for the head losses obtained from the two mentioned equations.

2. HAZEN-WILLIAMS AND DARCY-WEISBACH EQUATIONS

The (H-W) equation was empirically derived in 1933 as Eq. (1), and it is frequently used in pressure pipeline system analysis, such as in water supply systems **(Larock et al., 2000)**:

$$h_f = \frac{KL}{D^{4.87}}\left(\frac{Q}{C}\right)^{1.85} \quad (1)$$

where:
h_f = head loss (m).
K = constant (1.32 for US units,0.85 for SI units).
L = pipe length (m).
D = pipe diameter (m).
Q = flow rate (m^3/s).
C = Hazen-Williams coefficient ranges from 80 for coarse pipes to about 150 for smooth pipes.

The (D-W) equation is often regarded as the most accurate approach for calculating friction losses. It is written as Eq. (2) **(Ntengwe et al.,2015):**

$$h_f = f\frac{L}{D}\frac{v^2}{2g} \quad (2)$$

where:
h_f = head loss (m).
f = Darcy-Weissbach friction coefficient.
L = pipe length (m).
D = pipe diameter (m).
v = flow velocity (m/s).
g = gravitational acceleration (m/s^2).

To calculate the head loss in pipes using the (D-W) equation, the friction factor must be calculated separately, which is not easy. The internal surface roughness height, pipe diameter, and flow all play a role in determining the friction factor. It also depends on the Reynolds number, as in Eq. (3), which depends on viscosity and density, which are factors of the fluid temperature.

$$Re = \frac{\rho \, v \, d}{\mu} \quad (3)$$

where:
Re = Reynolds number (dimensionless).
ρ = flow density (kg/m^3).
v = average flow rate (m/s).
d = pipe diameter (m).
μ = dynamic viscosity (kg m/s).

3. METHODOLOGY

3.1 Study Area

AL-Yarmouk region is a part of Baghdad, Iraq, located on the Karkh side (33°17'49.6"N 44°20'19.5" E) with an area of around 4.82 km^2 and six districts (608,610,612,614,616,618) according to the division of the Municipality of Baghdad. It consists of many residences, schools, mosques, recreational areas, the municipal council, the civil defense, and the police station. The region has seen significant growth in the number of residents in the last several years and the unplanned cutting of houses. Despite its residential status, the region currently features a wide variety of dining and entertainment areas, making it a popular destination for locals and other people.
The French company SOBEA built the AL-Yarmouk water network in 1984, which is still in use today. It has not been replaced until today; therefore, it is constantly subjected to fractures when the pressure in the network increases over 24 m. As a result of corrosion and sedimentation, the inner walls of the pipes have formed biofilm layers. The Municipality of Baghdad is responsible for maintaining this system, consisting of water pipes ranging from (250 to 600 mm) which are the main pipes in the region. The study area and layout of the main pipes in the region are shown in **Fig.1**.

Figure 1A. The study area.

Figure 1B. The study area with the main pipes in the network using GIS.

3.2 Building Network

AL- Yarmouk water network was built using WaterGEMS CONNECT Edition update 1 and ArcMap 10.8 based on the calibration and verification processes. A hydraulic model must be calibrated to accurately represent the measurements taken in the field with the predicted values. In contrast, the purpose of the verification is to check that the modifications made during the calibration process were reasonable and that the calibrated model will produce accurate results **(Bashar et al., 2015)**. The calibration was done using the (H-W) equation as the friction method analysis with a C value of 120. The whole procedure for building the network is explained in the manuscript **(Abdulsamad and Abdulrazzaq, 2022).**

3.3 Application

The water distribution network analysis process always includes the calculation of flow roughness as one of its necessary components. Because this analysis requires multiple iterations, during which the flow rate and Reynolds number may be different from the previous iteration, the flow resistance coefficient, which changes depending on the flow, should be modified in each iteration of the analysis **(Niazkar et al.,2017)**. In this study, the (H-W) and (D-W) equations were used for analyzing the pipes in the network with a diameter of 400 mm and 500 mm and then applying two scenarios in which the friction coefficient is changed. **Fig. 2** shows the pipe labels for both 400 mm and 500 mm pipes.

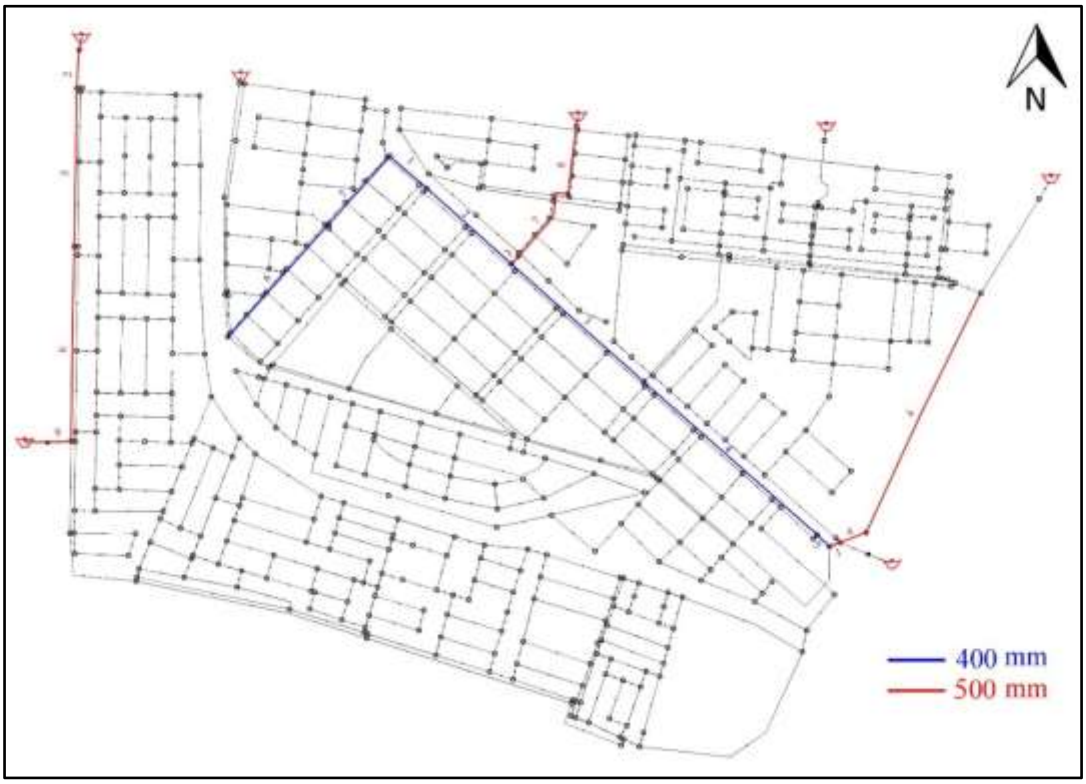

Figure 2. Pipes labels using WaterGEMS.

4. RESULTS AND DISCUSSIONS

After the hydraulic model was done, head loss in 400 mm and 500 mm pipes were analyzed using (H-W) and (D-W) equations. In general, for both equations, a decrease in pipe diameter leads to increased head loss. Values obtained by employing both equations indicated an extremely high positive correlation. The values were found to be 0.999, 0.998, and 0.993 for C coefficients of 120, 130, and 140, respectively, for pipes with a diameter of 500 mm. while pipes with a diameter of 400 mm have correlation values of 0.998, 0.999, and 0.996. The relationship between the head loss equations is shown in **Fig.3** and **Fig.4**.
As a result of the linear relationship between (D-W) and (H-W), the equations between these two values for 500 mm and 400 mm pipes may be restated in terms of the examined variables as shown in Eq. (4) and Eq. (5), respectively:

$$(D\text{-}W) = -0.19 + 0.97\ (H\text{-}W) \tag{4}$$

$$(D\text{-}W) = -0.01 + 0.91\ (H\text{-}W) \tag{5}$$

The study also showed that head loss resulting from the (H-W) equation for rough ductile iron pipe C (120) is more than the (D-W) equation. In contrast, the (H-W) equation shows a lower head loss when the pipe is more than the value of C (120) than the (D-W) equation. The reason for this is that the (D-W) equation uses a friction factor that is not mainly influenced by the type of pipe materials or the age of the pipe, whereas the (H-W) equation uses a roughness coefficient that primarily depends on the internal surface roughness of each pipe and depends secondarily on pipe diameter. **Fig.5** and **Fig.6** show the results of the head loss analysis using the (H-W) and (D-W) equations. It should be noted that the flow in each pipe is different from the flow in the other pipe. **Fig.7** shows the analysis of flow in a pipe network.

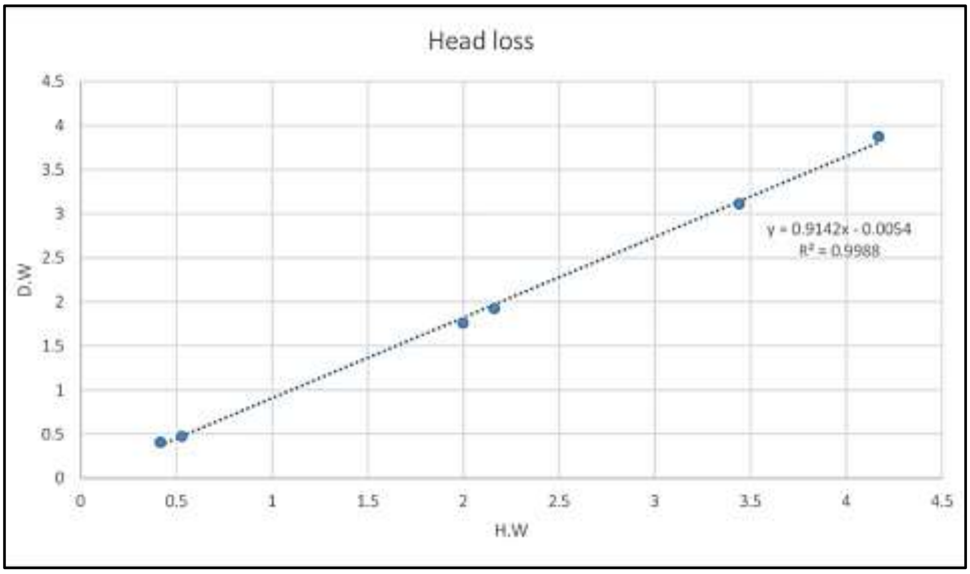

Figure 3. Darcy-Weisbach vs. Hazen-Williams equations for pipes with a diameter of 500 mm with a C coefficient of 120.

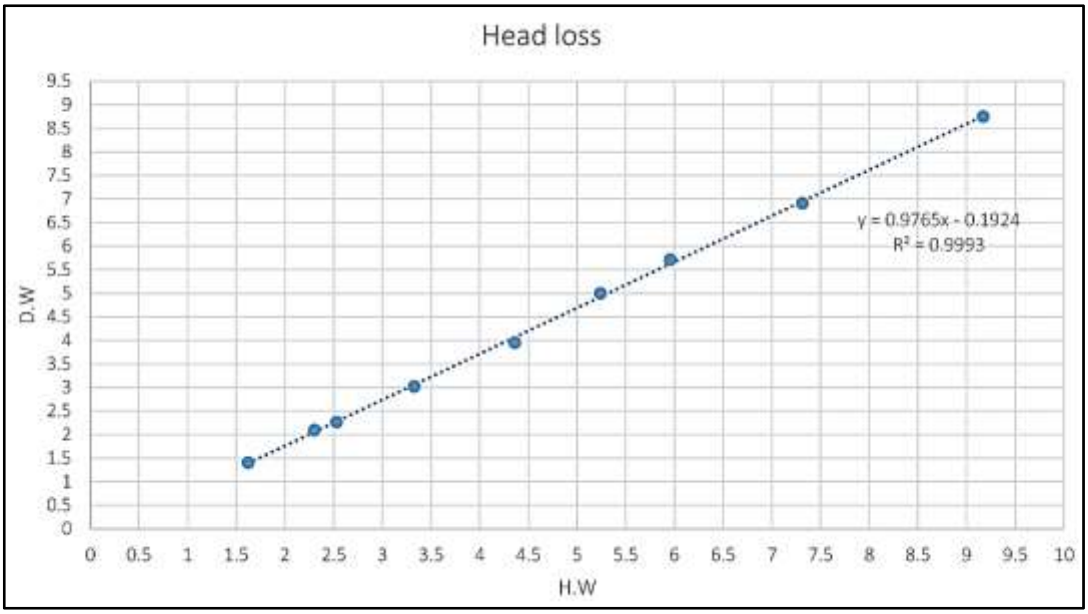

Figure 4. Darcy-Weisbach vs. Hazen-Williams equations for pipes with a diameter of 400 mm with a C coefficient of 120.

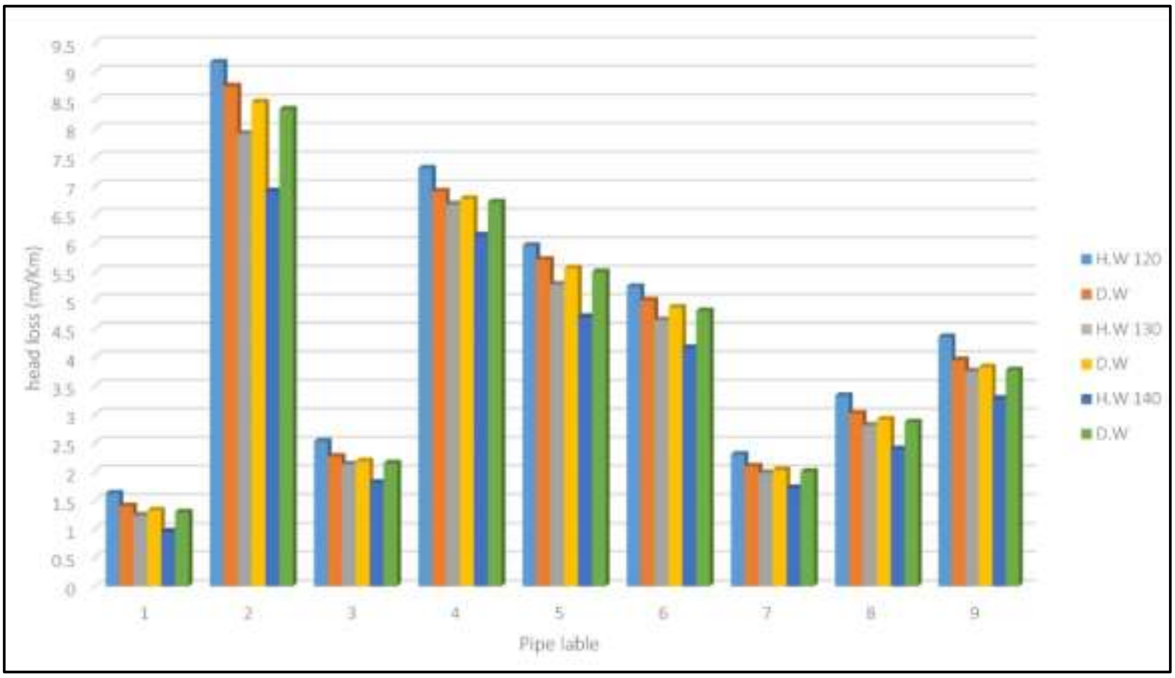

Figure 5. Results of head loss analysis for applied scenarios using both equations for pipes with a diameter of 500 mm.

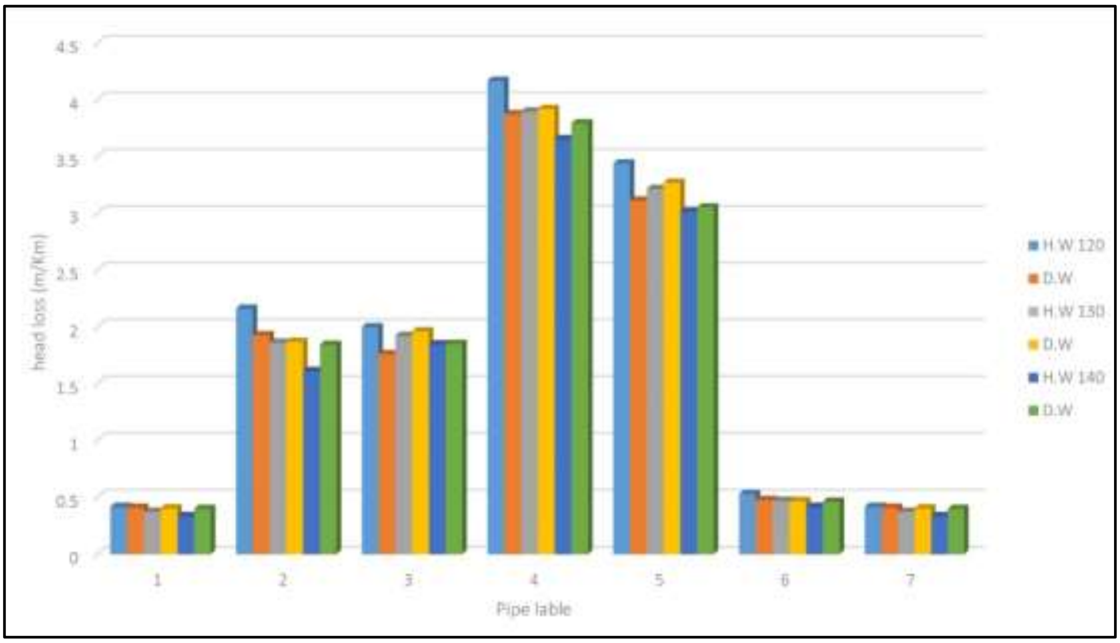

Figure 6. Results of head loss analysis for applied scenarios using both equations for pipes with a diameter of 400 mm.

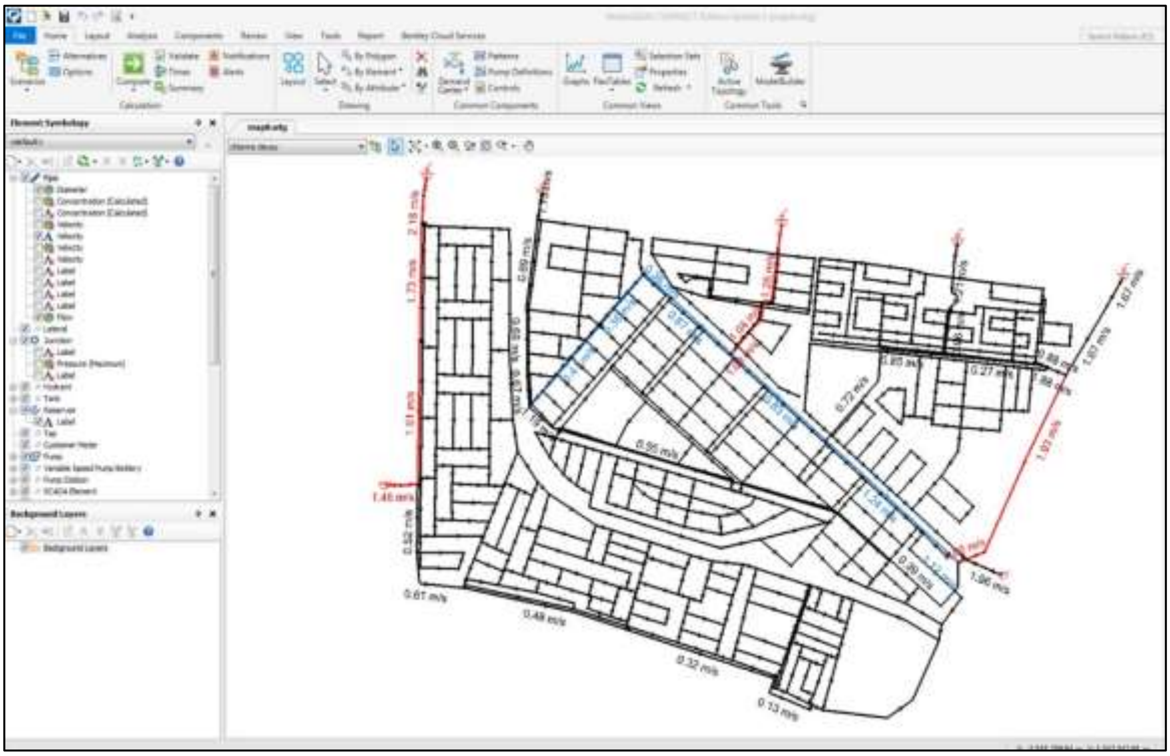

Figure 7. Analysis of the pipe network using WaterGEMS.

5. CONCLUSIONS

In this research, the frictional head loss was determined using (H-W) and (D-W) equations, and the results were very similar. It also can be concluded that:

A- water distribution network with old pipes can be presented with more accurate results using the (H-W) equation as a friction method analysis if the flow is in a steady state.

B- The head loss results from the (H-W) equation for old pipes is more than from the (D-W) equation, while if the analysis is done for a new network, the (D-W) equation gives head loss more than the (H-W) equation.

C- The correlation coefficient between the (H-W) and (D-W) equations is very high, considering that the correlation coefficient value between them is almost equal to one, which is statistically regarded to be a very strong relationship.

NOMENCLATURE

m^3/s: cubic meter per second.
m/s: meter per second.
m/s^2: meter per square second.
kg/m^3: kilogram per cubic meter.
kg m/s: kilogram multiplied by a meter per second.

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