UT
CB
Universitatea Tehnică
de Construcţii Bucureşti

Ministry of Education and Research

Technical University of Civil Engineering Bucharest.
Faculty of Hydrotechnics
Department of Hydraulics, Sanitary Engineering and Environmental Protection
Doctoral School

# DOCTORAL THESIS
## - Summary -

---

# Adaptation of the pressure-based algorithm used by EPANET 2.2 to the provisions in force for different situations.

---

**Supervising professor:**

Prof.univ.dr.ing.Andrei-Mugur GEORGESCU

**PhD student:**

Eng. Lakhdari Hocine

**Academic year : 2025**

# 1. Abstract

The design and maintenance of drinking water networks aim to ensure water of good quality, in sufficient quantity, and under adequate pressure.
To optimize their management, a numerical model that accurately reflects reality is essential.
EPANET, developed by the EPA in the 1990s, is today the reference tool for hydraulic modeling.
Its version 2.2 (2020), free and open source, brings notable improvements.
Two simulation methods exist: Demand-Driven Analysis (DDA) and Pressure-Driven Analysis (PDA).
DDA assumes that demands are always met, regardless of the available pressure.
PDA, more realistic, establishes a relationship between pressure and effective consumption.
It is particularly suitable for simulating low-pressure conditions.
In PDA, flow rates vary as a function of pressure, according to coefficients defined by the user.
The objective of the thesis is to correctly determine these coefficients based on standards, and then to compare different numerical models.

**Keywords:** Flow, Water Distribution Network, calibration, Pressure, Epanet, Demand Driven Analysis, Pressure Driven Analysis.

## Table of Contents

**4. COMPARATIVE STUDY OF DIFFERENT METHODS FOR CALCULATING CONSUMPTION FLOW RATES IN DRINKING WATER SUPPLY SYSTEMS.**

**5. CALIBRATION OF COEFFICIENTS IN THE FLOW RATE CALCULATION FORMULA BASED ON THE AVAILABLE PRESSURE AT NODES ACCORDING TO DIFFERENT STANDARDS.**

**6. COMPARISON BETWEEN FLOW-BASED ANALYSIS AND PRESSURE-BASED ANALYSIS FOR A WATER DISTRIBUTION SYSTEM SERVING A POPULATION.**

## 3. General Introduction

The evaluation of the performance of a drinking water distribution network mainly depends on the reliability of this high-quality network, which ensures a continuous supply of potable water in sufficient quantity to customers (subscribers) at an appropriate pressure throughout the system.

The reason why pressure must be adequate is that reservoirs help balance the pressure and enable the system to meet peak demand, provide fire protection, and respond to other emergency situations without causing undue water retention. Main looped water pipes prevent water stagnation and minimize inconvenience to subscribers during maintenance or repairs. Since water quality deteriorates as the residence time in the network increases, and the rate of this deterioration partly depends on the characteristics of the distribution system, a high-quality network contains as few dead-end pipes as possible and ensures adequate flow and water renewal.

System performance is considered deficient when it fails to meet both pressure requirements and user demand under partial failure conditions. Such partial failures in a network may result from abnormally high customer demand, fire-fighting operations, and damage to water mains, as well as power outages, mechanical pump or valve failures, and even acts of sabotage that could lead to one or more of these situations.

Therefore, maintenance is a crucial component of a safe drinking water supply network. It is essential for water suppliers to have adequate financial mechanisms to properly maintain and renew their distribution networks.

Currently, the calculation of water distribution networks is a common challenge in the hydraulic field. These calculations rely either on charts, catalogs, and tables for selecting pipe diameters or on the use of computer programs and software.

The purpose of such calculations is to determine the geometric and hydraulic parameters of the pipes that make up the network. Accurate calculations combined with proper implementation greatly facilitate the work of network managers and ensure customer satisfaction, meaning that future operational problems will be minimized.

Today, computer based solutions serve as rapid and efficient tools for network calculation and design. Since the development of modeling techniques, particularly during the 1970s, many software programs have been created for water modeling, simulation, and management such as LOOP, EPANET, Piccolo, WATERCAD, H2ONet, GHydraulics, and Porteau, among others. These programs focus on network balancing and use various computational methods and algorithms.

However, the problem of calculating pressurized water distribution networks has become increasingly complex; traditional algorithms are no longer sufficient to meet the need for accurate solutions. Pressure-based algorithms do not assume fixed consumption flows at the nodes but rather variable flows depending on the available pressure at the restrictive node. Nevertheless, the relationship between consumption flow rate and pressure must be specified by the user performing the simulation, by introducing certain coefficients into the numerical model (EPANET 2.2).

The main objective of this thesis is to correctly determine these coefficients based on the current standards for different categories of consumers. After establishing an appropriate method for determining the coefficients, numerical models will be developed for several case studies, and their results will be compared.

This thesis aims to provide researchers, managers, engineers, and students with insights into the real challenges faced by high-rise buildings regarding their potable water supply, and to propose practical solutions in this field.

The present thesis is composed of three chapters:

- The first chapter sheds light on the different methods used to calculate consumption flow rates in potable water supply systems according to various standards applied in the European Union and the southern Mediterranean region.
- The second chapter focuses on the calibration of coefficients to be introduced into the calculation formula as a function of the pressure available at the nodes for the different applicable standards.
- The third chapter is devoted to the application of the developed method using the EPANET 2.2 software.

At the end of the thesis, we will obtain, on the one hand, an appropriate method for determining the coefficients used in pressure-based algorithms, and on the other hand, a set of coefficients for different categories of consumers in accordance with the various calculation standards.

## 4. Comparative Study of Different Methods for Calculating Consumption Flows in Water Distribution System

### 4.1. Introduction

This chapter presents a comparative study of the different methods used to calculate consumption flows in drinking water supply systems (DWS), based on the standards in force in countries of the European Union (Romania, Italy, Germany) and in countries of the southern Mediterranean region (Algeria, Tunisia, Egypt). The main objective is to analyze these methodologies and their application in the design and optimization of hydraulic infrastructures.

The chapter explores key concepts such as:

- **Annual Average Flow ($Q$MA):** A reference basis for assessing seasonal and daily variations.
- **Hourly Peak Coefficient ($K_h$):** The ratio between the maximum hourly flow and the annual average flow, used for sizing distribution networks.
- **Daily Peak Coefficient ($K_j$):** Represents the variation in consumption from one day to another, important for planning the capacity of treatment and pumping stations.
- **Monthly and Weekly Variation Coefficients:** Influence the overall management of the water network.

### 4.2. Main Formula by Country

This chapter presents the approaches used in several countries:

### 4.2.1. Northern Mediterranean Countries (European Countries)

**4.2.1.1. Methods Used in Romania :** Based on standards STAS 1343-66 and NP 133, with calculations relying on the average daily flow ($Q_{zi\ med}$), the maximum daily flow ($Q_{zi\ max}$), and the maximum hourly flow ($Q_{o\ max}$). [1],[2]

**4.2.1.2. Methods Used in Italy** : Approaches based on per capita allocation (150–250 ℓ/day/person), average daily flow ($Q_{mg}$), daily coefficients (Cg), hourly coefficients ($K_h$) and instantaneous coefficients (Cp). [3],[4],[5]
-Use of peak coefficients adapted to urban / rural areas.[6],[7],[8]

**4.2.1.3. Methods Used in Germany :** Based on standards DIN 4046, DIN 1988-300, DVGW W 410, introducing peak factors ($f_d$, $f_h$). [9],[10],[11],[12], Also includes empirical formulas (Poss & Hacker, 1980). [13],[14],[15],[16],[17]

### 4.2.2. Southern Mediterranean countries (North African countries) :

**4.2.2.1. Methods Used in Algeria :** Calculations based on allocation (d), average daily consumption, daily (Kj) and hourly (Kh) [18],[19],[20], as well as margins (20 – 30 %), and losses (20–50 %).[21],[22],[23],[24]

**4.2.2.2. Methods Used in Tunisia**: Calculations integrating demographic evolution, future daily consumption ($C_0$), daily coefficients (Kj) ranging from 1,3 to 1,6 and hourly coefficients ($K_h$) ranging from 1,5 to 3,5.

- Average consumption: approximately: ~100 ℓ/day/person (1997, SONEDE).
- Consumption categories: domestic, public, industrial, tourism, and agricultural.

Calculation based on:

- Specific consumption (Cs),
- Population growth and lifestyle changes (annual growth 1.9%, +3 %/ year increase in consumption)
- Application of daily, monthly, and hourly peak coefficients. [25], [26], [27]

**4.2.2.3. Methods Used in Egypt**:

Main steps:

Estimation of population (using arithmetic, geometric, or decreasing rate methods).

Determination of current and future consumption rates.

Calculation of design flows:

- $Q_{\text{max daily}}$ = daily consumption × population.
- $Q_{\text{max hourly}}$ = hourly consumption × population.
- Addition of fire flow ($Q_{\text{fire}}$).

Approach based on average annual consumption, maximum monthly consumption (1,25 à 1,5 times the average), , maximum daily consumption (1,6 à 1,8 times the average) and maximum hourly consumption ( ≈ 2,5 times the average). [28], [29], [30]

**Global Comparison :**

- **European countries** use highly detailed and standardized norms (STAS, DIN, EN), emphasizing peak coefficients for network design.
- **Southern countries** often adopt and adapt these norms to account for climate conditions, high losses, population growth, and local circumstances (aging networks, more variable seasonal consumption).

This section compares two main approaches:

**Normative and Technical (Europe)**: based on standards (DIN, STAS, NP133, EN 805) and peak coefficients.

**Empirical and Statistical (Southern Mediterranean)**: based on actual consumption data, demographic projections, and network losses.

**Table 1:** The different methods for calculating water consumption rates in various European countries.

| **Country**<br>**The flow rates** | **Germany** | **Italy** | **Romania** |
|---|---|---|---|
| **Average daily flow rate** | $Q_{avgj} = \frac{V_J}{365}$ | $Q_{avgj} = N.c$ | $Q_{zimed} = \frac{1}{1000}\sum_{k=1}^{n}\left[\sum_{i=1}^{m} N(i)\,q_s(i)\right]_K$ |
| **Maximum daily flow rate** | $Q_{\max j} = f_T.Q_{avgj}$ | $Q_{\max j} = Q_{avgj}.K_1$ | $Q_{zi\max} = \frac{1}{1000}\sum_{k=1}^{n}\left[\sum_{i=1}^{m} N(i)\,q_s(i)\,K_{zi}(i)\right]_K$ |
| **Maximum daily flow rate** | $Q_{h\max} = f_H \frac{Q_{\max j}}{24}$ | $Q_{h\max} = \left(\frac{Q_{\max j}}{24}\right).K_2$ | $Q_{orar\max} = \frac{1}{1000}\,\frac{1}{24}\sum_{k=1}^{n}\left[\sum_{i=1}^{m} N(i)\,q_s(i)\,K_{zi}(i)\,K_0(i)\right]_K$ |
| **Peak flow (Qp)** | $Q_P = Q_{h\max} + Q_{Losch}$ | $Q_P = Q_{avgj}.K_P$ | $Q_{\max} = K.Q_{med}$ |

**Table 2:** Different methods of calculating water consumption flow in different North African countries.

| pays<br>Les débits | Algérie | Tunisie | Égypte |
|---|---|---|---|
| **Average daily flow rate** | $Q_{moy\,j} = \frac{N \times D}{1000}$ | $Q_{jm} = \sum_i N_{oi}.C_{oi}$ | $Q_{av} = N \times q$ |
| **Maximum daily flow rate** | $Q_{\max j} = Q_{moy\,j} \times K_j$ | $Q_{j\max} = K_{pert}.K_j.Q_{jm}$ | $Q_{\max\ daily} = (1,6\text{à}1,8) \times Q_{aver}$ |
| **Maximum hourly flow rate** | $Q_h = \frac{Q_{\max j} \times K_h}{24}$ | $Q_{h\max} = \frac{K_{pert}.K_h K_j.Q_{jm}}{24}$ | $Q_{\max\ hourly} = 2,5 \times Q_{aver}$ |
| **Peak flow (*Q*p)** | $Q_p = Q_{moy\,j}.K_p$ | $Q_{ph} = K_{ph}.Q_{pj}$<br>$Q_{pj} = K_{pj}.Q_{mj}$ | $Q_{des} = Q_{av} \times P$ |

**Table 3**: Comparison of methods and parameters used for calculating water consumption flow in different countries.

| **Element** | **Allemagne** | **Italie** | **Roumanie** | **Algérie** | **Tunisie** | **Égypte** |
|---|---|---|---|---|---|---|
| **Standards Used** | DVGW W400, DIN EN 805 | UNI/TS 11445, EN 805 | STAS 1343/1-91, EN 805, NP 133-2022 | MRE, DTR | SONEDE | Normes nationales (Code égyptien) |
| **Specific Consumption (ℓ / day/person)** | 120 –130 | 150 –180 (tourist areas) | 50–150 (Depending on region) | 120–150 (raised) | 110–130 | 100–140 |
| **Daily Coefficient Kj** | 1.5 – 2.0 | 1.6 – 2.2 | 1.20 – 2.0 | 2.0 – 2.5 | 1.8 – 2.3 | 2.0 – 2.6 |
| **Hourly Coefficient Kh** | 2.5 – 3.0 | 2.8 – 3.5 | 2.0 – 2.8 | 3.0 – 4.0 | 2.5 – 3.5 | 3.2 – 4.2 |

Objective and Purpose of this Comparative Assessment of Drinking Water Consumption Flow Calculation Standards in European and North African countries:

* **Normative Comparison:** Study the methods for calculating consumption flows according to European standards (EN 806, DIN 1988, SR 1343, ….. etc.) and those in force in southern Mediterranean countries (Algeria, Tunisia, Egypt, …… etc.).

* **Methodological Analysis**: Identify the differences between the approaches, particularly regarding calculation formulas, simultaneity coefficients, consumption profiles, and water use patterns.

* **Impact on Design**: Assess the effect of these differences on the sizing of potable water supply networks and installations.

* **Local Relevance:**: Evaluate the adequacy of these methods in relation to local specificities such as climate, water resources, socio-economic context, and technical capacities.

* **Harmonization Perspectives**: Propose pathways for adapting or harmonizing approaches with a view to regional cooperation, water management optimization, and sustainability.

### 4.3. Conclusion

This chapter included a description and analysis of the various methods used to calculate consumption flow rates in drinking water supply systems and networks in the countries of the European Union and the southern Mediterranean countries. A bibliographic study was carried out, including a detailed explanation of these different methods.

These calculation methods vary considerably from one country to another, reflecting different social, economic, and climatic contexts. European standards (STAS, DIN, EN, etc.) are often more detailed, while the southern Mediterranean countries adopt the same standards; however, they adapt their approaches to local constraints, resource limitations, and population growth.

The scope of application of these methods lies in the design of urban water distribution networks and various associated hydraulic structures.

## 5. Calibration of the Coefficients to be Introduced in the Flow Rate Calculation Formula According to the Available Pressure at the Nodes for the Different Applicable Standards.

### 5.1. Determination of the Coefficients for Different Cases

According to the formula expressing the emitter’s flow rate as a function of pressure, given by the following relation:

$$q = C.P^{\gamma} \tag{1}$$

where: q : is the flow, p : is the pressure, C : is the discharge coefficient, , and γ is the pressure exponent. This relation concerns urban water distribution networks.

Nowadays, the problem of calculating pressurized distribution networks has become increasingly complex; traditional algorithms are no longer able to meet the need for accurate solutions.

The main issue lies in the fact that pressure-based algorithms do not consider consumption flow rates at the nodes as fixed values, but rather as variables depending on the available pressure at the restrictive node.

However, the law governing the variation of consumption flow rate as a function of pressure must be correctly determined and precisely defined by establishing a set of coefficients based on the applicable standards for different categories of consumers.

- Regarding the determination of these coefficients according to the current standards applied in different countries, two countries were selected: Algeria and Romania.

The data were mainly taken from DTU for Algeria, and from the **Official Journal of Romania**, Part I, N°. 1167 bis / 6.XII.2022 (monitorul oficial al româniei, partea I, Nr. 1167 bis/6.XII.2022) for Romania.

Several cases were considered, in which it was assumed that there were as many housing units as possible on each floor and that the building was very tall, i.e., the building is large and contains several apartments (6 to 7 per floor) and has multiple stories (R+10 floors), similar to those found in the Lacul Tei district in Bucharest, Romania, as illustrated in Figure 01.

**Figure 1:** Apartment block in Romania (city of Lacul Tei- Bucuresti. Photo on: 22/02/2024).

As for Algeria, the building consists of 2 to 4 apartments per floor with a height of ground floor + 4 stories (R+4), as seen in the city of N'gaous, Batna Province, Algeria (Figure 02). According to the principle of calculating the flow rate of a building, in order to estimate the probable flow rates required to supply a building with 1 to 10 apartments per floor and up to 10 floors, each case will be analyzed individually to determine the corresponding coefficients (C) and (γ). These coefficients will then be used to graphically represent the variation curve of the flow rate as a function of the available pressure for each case.

**Figure 2:** Apartment block in Algeria (city of N'gaous- Algeria. Photo on: 01/04/2024).

### 5.1.1. Méthodologie de calcule pour l'alimentation en eau

Step 01

**Specify the number of devices per household :**

This section involves determining the number of devices used per household on one hand, and estimating the bandwidth allocated for each type of device on the other, using the data from Tables 1 and 2.

**Table 1.** Basic flow rates of devices according to Romanian DTU 60 standards.

| Device type | Flow (ℓ/s) |
|---|---|
| Sink | 0,2 |
| Washbasin | 0,2 |
| Shower | 0,2 |
| Bathtub | 0,33 |
| hand Washbasin | 0,1 |
| Washing machine | 0,2 |
| WC with flushing tanksss | 0,12 |
| / | |

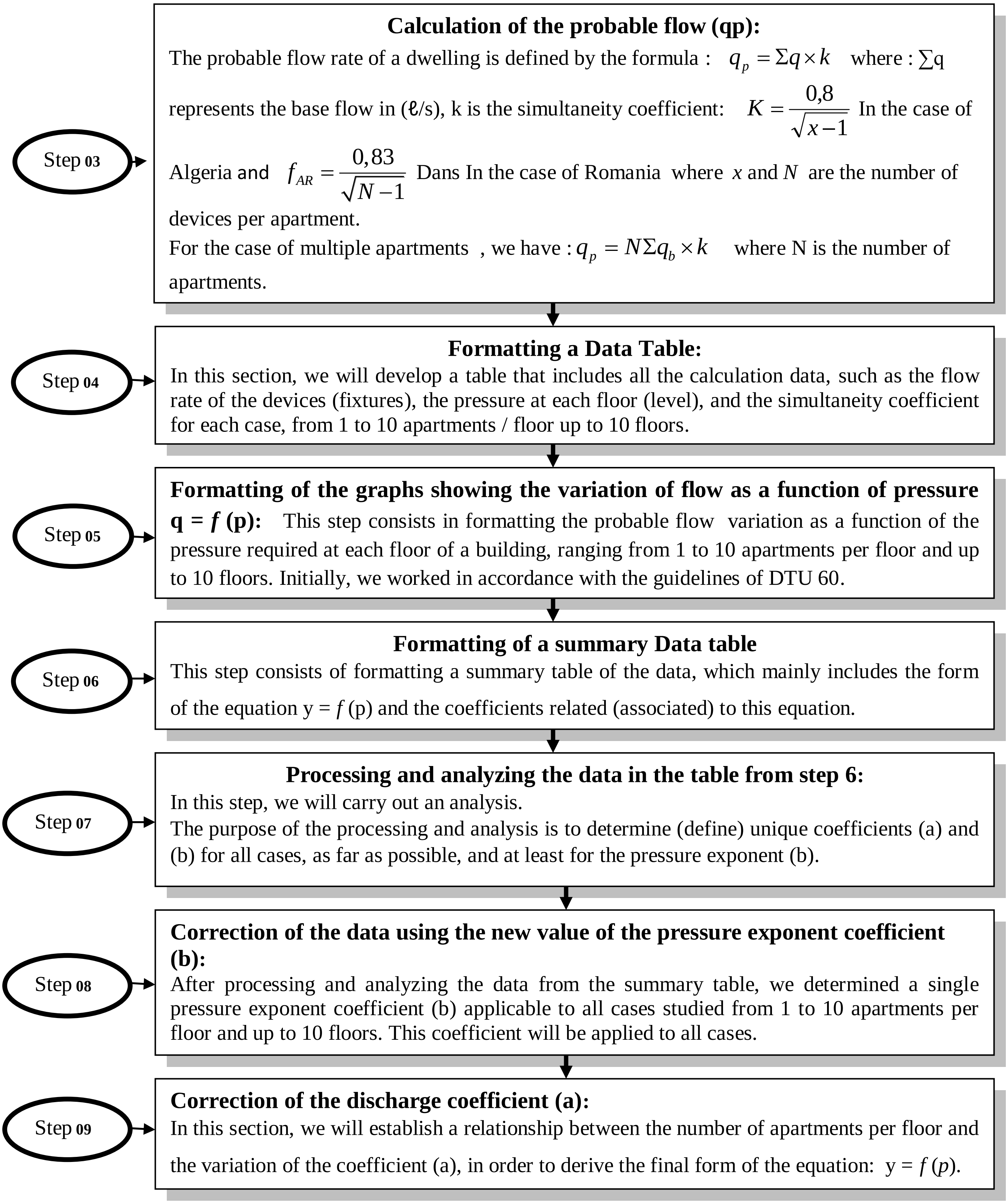
**Table 2.** Basic flow rates of devices according to Romanian standards.

| Device type | Flow (ℓ/s) | Unité (Ui) |
|---|---|---|
| Handwashing dishes | 0,2 | 2 |
| Handwashing sink | 0,15 | 1,5 |
| Shower | 0,2 | 2 |
| Bathtub | 0,25 | 3 |
| Toilet sink | 0,1 | 1 |
| Toilet bowl with wash tank | 0,12 | 1 |
| Washing machine | 0,2 | 2 |
| Dishwasher | 0,2 | 2 |

Step 02

**Calculation of the total flow required for an apartment called basic flow (qp) :**

In this part, we will calculate the basic flow (qb) which represents the sum of the basic flow of each device present in a apartment using the calculation formula apartment the conditions specified of the DTU-60 Standards (table 1 and 2).



Step 03

**Calculation of the probable flow (qp):**

The probable flow rate of a dwelling is defined by the formula : $q_p = \Sigma q \times k$ where : $\sum$q represents the base flow in (ℓ/s), k is the simultaneity coefficient: $K = \frac{0,8}{\sqrt{x-1}}$ In the case of Algeria and $f_{AR} = \frac{0,83}{\sqrt{N-1}}$ Dans In the case of Romania where $x$ and $N$ are the number of devices per apartment.

For the case of multiple apartments , we have : $q_p = N\Sigma q_b \times k$ where N is the number of apartments.

Step 04

**Formatting a Data Table:**

In this section, we will develop a table that includes all the calculation data, such as the flow rate of the devices (fixtures), the pressure at each floor (level), and the simultaneity coefficient for each case, from 1 to 10 apartments / floor up to 10 floors.

Step 05

**Formatting of the graphs showing the variation of flow as a function of pressure q = *f* (p):** This step consists in formatting the probable flow variation as a function of the pressure required at each floor of a building, ranging from 1 to 10 apartments per floor and up to 10 floors. Initially, we worked in accordance with the guidelines of DTU 60.

Step 06

**Formatting of a summary Data table**

This step consists of formatting a summary table of the data, which mainly includes the form of the equation y = *f* (p) and the coefficients related (associated) to this equation.

Step 07

**Processing and analyzing the data in the table from step 6:**

In this step, we will carry out an analysis.

The purpose of the processing and analysis is to determine (define) unique coefficients (a) and (b) for all cases, as far as possible, and at least for the pressure exponent (b).

Step 08

**Correction of the data using the new value of the pressure exponent coefficient (b):**

After processing and analyzing the data from the summary table, we determined a single pressure exponent coefficient (b) applicable to all cases studied from 1 to 10 apartments per floor and up to 10 floors. This coefficient will be applied to all cases.

Step 09

**Correction of the discharge coefficient (a):**

In this section, we will establish a relationship between the number of apartments per floor and the variation of the coefficient (a), in order to derive the final form of the equation: y = *f* (*p*).

**Figure 3:** Flowchart of the calculation methodology according the guidelines of the two standards applied in the case of Algeria and Romania (Flowchart summarized from the document: [31], [32], [33]).

### 5 .1.1.1. Note on the Case of Romania

According to the Official Journal of Romania, Part I, N°. 1167 bis / 6.XII.2022 (monitorul oficial al româniei, partea I, Nr. 1167 bis/6.XII.2022)

Dimensioning and sizing Water Supply Installations calculation of Flow Rates for Cold and Hot Water Distribution Pipes.

Several methods may be used to determine the design flow rates for cold and hot water distribution pipes, as follows:

For residential buildings, the design flow rate of cold and hot potable water distribution pipes must be determined by applying and using Methods A and B described below. The method involves the use of consumption units, called (Ui), and specific flow (*Q*s) assigned to fittings (batteries and taps), whose values are given in Table (ANNEX 2.1 A).

**Table 4.** ANNEX 2.1 A [32]

The specific water flow rates (*Q*s), the consumption units (Ui), the minimum internal diameter of the cold or hot water supply pipe, and the operating pressure of the various domestic and sanitary fittings, as defined for residential buildings, used in sizing calculations.

| Sanitary installation mounted (installed) in an apartment or building / residential building | $Q_s$, minimum required flow supplied by the fitting or valve. | Consumption unit, Ui for a fitting | Minimum inner diameter of the cold or hot water supply pipe for the respective fitting |
|---|---|---|---|
| | [ℓ /s] | [-] | [mm] |
| BATTERIES for: | | | |
| Washbasin mounted in a bathroom equipped with a washbasin and a toilet bowl (secondary bathroom) | 0,10 | 1 | 10 |
| Washbasin installed in a bathroom equipped with at least a washbasin, toilet bowl, bathtub or shower. | 0,15 | 1,5 | 10 |
| Bidet | 0,10 | 1 | 10 |
| Shower | 0,20 | 2 | 12 |
| Washer, battery ½” | 0,20 | 2 | 12 |
| Washer, battery ¾" | 0,33 | 3 | 13 |
| Bathtub,with capacity <150 ℓ | 0,25 | 3 | 13 |
| Bathtub,with capacity >150 ℓ | 0,33 | 4 | 13 |
| Shower cabin with multijet panel | According to the manufacturer's data sheet | 4 | According to the manufacturer's data sheet |
| **Other equipment** | According to the manufacturer's data sheet | | |

| TAPS for | | | |
|---|---|---|---|
| Toilet bowl with flushing cistern | 0,12 | 1 | 10 |
| Toilet bowl with faucet (pressure washing) | 1,5 | 15 | Minimum tap diameter |
| Dishwasher, faucet | 0,20 | 2 | 12 |
| Washing machine, faucet | 0,20 | 2 | 12 |
| Double-function tap, 1/2" | 0,25 | 3 | Minimum tap diameter |
| Double-function tap, 3/4" | 0,42 | 4 | Minimum tap diameter |

### 5 .1.1.1.1. Calculation of consumption flow

**- calculated flow ($Q_c$) for water distribution pipes in residential buildings (methods A and B)**

The sizing of distribution pipes in residential buildings (apartments, single-family houses, terraced houses, or similar) is carried out using several calculation methods, depending on the consumption area, as follows:

- **Méthode A -** used for the distribution area located inside the apartment or residential building and for sections with **U < 15**; this method allows the direct determination of the minimum pipe diameters, without calculating the flow rates. For the evaluation of the design flow rates, Method B.1 shall be applied.

**- Méthode B -** used to determine the design flow rates required for sizing; for the distribution area located inside apartments or residential buildings and for sections with U < 15, Method B.1 is applied; for the area outside the apartments or residential buildings and for common zones with U ≥ 15, Method B.2 is used.

**- For Method B**

**- The design flow rate for sizing distribution pipes in residential buildings.**

Method B is applied to determine the design flow rate used for sizing water distribution pipes installed in residential buildings; the values required for its determination (U) and (Qs,i) are considered from ANNEX 2.1 A.

The following methods are differentiated:

- For the distribution area contained within the apartments/residential buildings and for the sections with U<15, method B.1 is applied;
- For the area contained outside the apartments/residential building, respectively in the common areas, and for the sections with U≥15, method B.2 is used.

The following preliminary steps are necessary:

**Step 1 :**

The sum of the specific flow rates of all the fittings supplied by each section is determined;

$$Q_{S,tot} = \sum n_i \times Q_{S,i} \qquad \text{en } (\ell/s) \tag{2}$$

in which:

$n_i$ : is the number of fittings of the same type ,i, that supply water; ;
$Q_{s,i}$ : the specific water flow rate of a fitting of type i (ℓ/s), with values considered from Annex 2.1A ;
$Q_{s,tot}$ : total specific water flow rate for a section, (ℓ/s);

For cold water distribution pipes, the sum of the specific flow rates for the taps and faucets supplied with water is determined; $Q_{s,tot,\,AR}$ is obtained

**Step 2:**

The value of the simultaneity coefficient is determined for each section, depending on the number N of sanitary fixtures supplied by it:

- Simultaneity coefficient for the cold water sections:

$$f_{AR} = \frac{0{,}83}{\sqrt{N-1}} \tag{3}$$

**Step 3:**

In this stage, the design flow rate is determined by applying the following calculation methods:

**Method B.1**, for U < 15:

The design flow rates for each section of the cold and hot water distribution networks are determined in accordance with the following conditions:

- For sections supplying only one sanitary fixture, the design flow rate of that section is equal to the flow rate of the fitting (tap or respective faucet), expressed in (ℓ/s); the minimum diameter adopted for this section cannot be smaller than the diameter specified in ANNEX 2.1A, corresponding to the respective fitting.
- For sections supplying more than one sanitary fixture, the following calculation formulas are applied :

$$Q_{C,AR} = Q_{S,tot,AR} \times f_{AR} + 0{,}03 \qquad \text{en } (\ell/s) \tag{4}$$

**Method B.2,** for U ≥ 15 :

The following calculation relations apply:

$$Q_{C,AR} = Q_{S,tot,AR} \times f_{AR} \qquad \text{en } (\ell/s) \tag{5}$$

- The specific water flow rates ($Q$s), the consumption units (Ui), and the operating pressure (Pu) of the sanitary fixtures are given in ANNEX 2.1A. The operating pressure values from ANNEX 2.1 are of a recommendatory nature and are not mandatory compared to the values provided in the manufacturers' technical documentation. [32]

### 5.2. Case Study

- Estimation of probable flow rates based on the number of apartments and floors. This study focuses on estimating probable flow rates according to the number of dwellings and floors in buildings, using established national standards. In Algeria, the French DTU 60 standards have been adapted, while calculations in Romania are based on its official regulations (monitorul oficial al româniei, partea I, n° 1167 bis /6.XII.2022). The analysis covers buildings ranging from 1 to 10 apartments per floor, up to a total of 10 floors. The methodology is presented in detail for two specific scenarios: buildings with 4 apartments per floor in three Algerian cities, and buildings with 7 apartments per floor in the Tei-Colentina district of Romania. The same approach is applied to other configurations.

### 5.2.1. Algerian Case

In this case, we present the procedure for the case of 4 apartments / floor on 10 floors.

**Table 5:** Estimated probable flow rates for the case of (04) apartments/floor on 10 floors.

| **Floor** | | **GF** | **F-1** | **F-2** | **F-3** | **F-4** | **F-5** | **F-6** | **F-7** | **F-8** | **F-9** | **F-10** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **DESIGNATION** | | **pressure required per stage in (m)** | | | | | | | | | | |
| | | **5** | **8** | **11** | **14** | **17** | **20** | **23** | **26** | **29** | **32** | **35** |
| **Type of sanitary appliance / apartment** | **Flow (ℓ/s)** | **Basic flow rate of sanitary appliances according to the type and number of apartments in (ℓ/s)** | | | | | | | | | | |
| **Sink** | **0,2** | 0,8 | 1,6 | 2,4 | 3,2 | 4 | 4,8 | 5,6 | 6,4 | 7,2 | 8 | 8,8 |
| **Washbasin** | **0,2** | 0,8 | 1,6 | 2,4 | 3,2 | 4 | 4,8 | 5,6 | 6,4 | 7,2 | 8 | 8,8 |
| **Shower** | **0,2** | 0,8 | 1,6 | 2,4 | 3,2 | 4 | 4,8 | 5,6 | 6,4 | 7,2 | 8 | 8,8 |
| **Bathtub** | **0,33** | 1,32 | 2,64 | 3,96 | 5,28 | 6,6 | 7,92 | 9,24 | 10,56 | 11,88 | 13,2 | 14,52 |
| **Wash Basin hand wash** | **0,1** | 0,4 | 0,8 | 1,2 | 1,6 | 2 | 2,4 | 2,8 | 3,2 | 3,6 | 4 | 4,4 |
| **Washing machine** | **0,2** | 0,8 | 1,6 | 2,4 | 3,2 | 4 | 4,8 | 5,6 | 6,4 | 7,2 | 8 | 8,8 |
| **Toilet with flush tank** | **0,12** | **0,48** | **0,96** | **1,44** | **1,92** | **2,4** | **2,88** | **3,36** | **3,84** | **4,32** | **4,8** | **5,28** |
| **TOTAL** | **1,35** | **5,4** | **10,8** | **16,2** | **21,6** | **27** | **32,4** | **37,8** | **43,2** | **48,6** | **54** | **59,4** |
| **Number of apartment** | | 4 | 8 | 12 | 16 | 20 | 24 | 28 | 32 | 36 | 40 | 44 |
| **Number of sanitary appliance** | | 28 | 56 | 84 | 112 | 140 | 168 | 196 | 224 | 252 | 280 | 308 |
| **Coefficient of simultaneity** | | 0,154 | 0,108 | 0,088 | 0,076 | 0,068 | 0,062 | 0,057 | 0,054 | 0,050 | 0,048 | 0,046 |
| $Q_{\text{probable}}$ | | **0,831** | **1,165** | **1,423** | **1,640** | **1,832** | **2,006** | **2,166** | **2,314** | **2,454** | **2,586** | **2,712** |

**- Graphical representation**

As shown in Figure 4, the graphical representation illustrates the variation in probable flow rate ($q_p$) as a function of the required pressure for the Algerian case (4 apartments / floor).

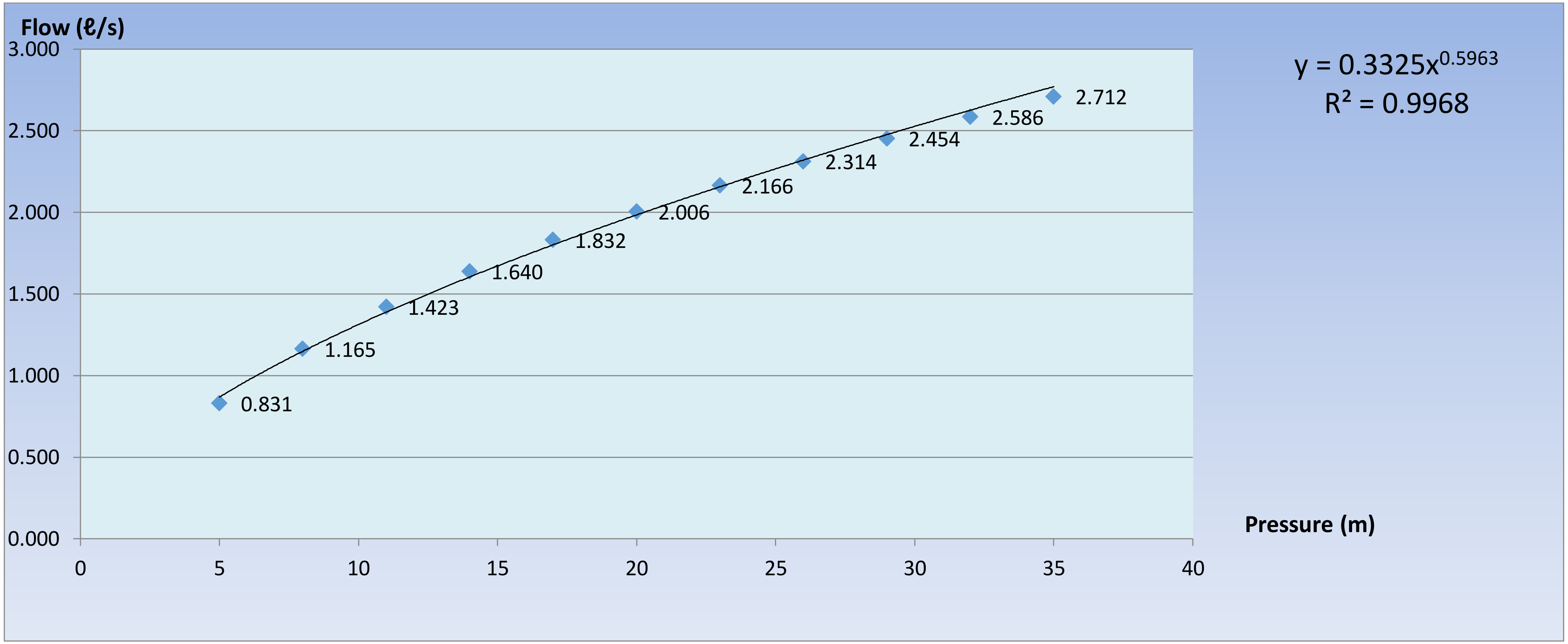


**Figure 4:** Graphical representation of the variation in probable flow ($q_p$) as a function of the required pressure.

### 5.2.2. Case of Romania

In this case, we present the procedure for the case of 7 apartments / floor over 10 floors.

**Table 6:** Estimated probable flow rates for the case of (7) apartments/floor over 10 floors.

| **Floor** | | | **GF** | **F-1** | **F -2** | **F -3** | **F -4** | **F -5** | **F -6** | **F -7** | **F -8** | **F -9** | **F -10** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Pressure of each floor (m)** | | | | | | | | | | | | | |
| **DESIGNATION** | | | **5** | **8** | **11** | **14** | **17** | **20** | **23** | **26** | **29** | **32** | **35** |
| **Type of sanitary appliance / apartment** | **Flow (ℓ/s)** | **Unit (Ui)** | **Débit de base des appreils selon le type et le nombre de logement ($Q_{s,\ tot}$) en (ℓ/s)** | | | | | | | | | | |
| **Handwashing** | 0,2 | 2 | 1,4 | 2,8 | 4,2 | 5,6 | 7 | 8,4 | 9,8 | 11,2 | 12,6 | 14 | 15,4 |
| **Handwashing sink** | 0,15 | 1,5 | 1,05 | 2,1 | 3,15 | 4,2 | 5,25 | 6,3 | 7,35 | 8,4 | 9,45 | 10,5 | 11,55 |
| **Shower** | 0,2 | 2 | 1,4 | 2,8 | 4,2 | 5,6 | 7 | 8,4 | 9,8 | 11,2 | 12,6 | 14 | 15,4 |
| **Bathtub** | 0,25 | 3 | 1,75 | 3,5 | 5,25 | 7 | 8,75 | 10,5 | 12,25 | 14 | 15,75 | 17,5 | 19,25 |
| **Wc sink** | 0,1 | 1 | 0,7 | 1,4 | 2,1 | 2,8 | 3,5 | 4,2 | 4,9 | 5,6 | 6,3 | 7 | 7,7 |
| **Wc bowl with wash tank** | 0,12 | 1 | 0,84 | 1,68 | 2,52 | 3,36 | 4,2 | 5,04 | 5,88 | 6,72 | 7,56 | 8,4 | 9,24 |
| **Washing machine** | 0,2 | 2 | 1,4 | 2,8 | 4,2 | 5,6 | 7 | 8,4 | 9,8 | 11,2 | 12,6 | 14 | 15,4 |
| **Dishwasher** | 0,2 | 2 | 1,4 | 2,8 | 4,2 | 5,6 | 7 | 8,4 | 9,8 | 11,2 | 12,6 | 14 | 15,4 |
| **TOTAL** | **1,42** | **14,5** | **9,94** | **19,88** | **29,82** | **39,76** | **49,7** | **59,64** | **69,58** | **79,52** | **89,46** | **99,4** | **109,34** |
| **The results** | | | **Number of apartments** | | | | | | | | | | |
| | | | 7 | 14 | 21 | 28 | 35 | 42 | 49 | 56 | 63 | 70 | 77 |
| | | | **Number of sanitary appliances per apartment and per floor** | | | | | | | | | | |
| | | | 56 | 112 | 168 | 224 | 280 | 336 | 392 | 448 | 504 | 560 | 616 |
| | | | **Coefficient of simultaneity** | | | | | | | | | | |
| | | | 0,112 | 0,079 | 0,064 | 0,056 | 0,050 | 0,045 | 0,042 | 0,039 | 0,037 | 0,035 | 0,033 |
| | | | **Probable flow rate (total specific flow rate) $Q_{s.\ tot}$ en (ℓ/s)** | | | | | | | | | | |
| | | | **1,112** | **1,566** | **1,915** | **2,210** | **2,470** | **2,705** | **2,921** | **3,122** | **3,311** | **3,489** | **3,659** |

## - Graphical representation

Figure 5 illustrates the relationship between the probable flow (qp) and the required pressure. It also illustrates the variation in probable flow rates according to Romanian standards (7 apartments / floor), confirming the increasing demand on the upper floors.

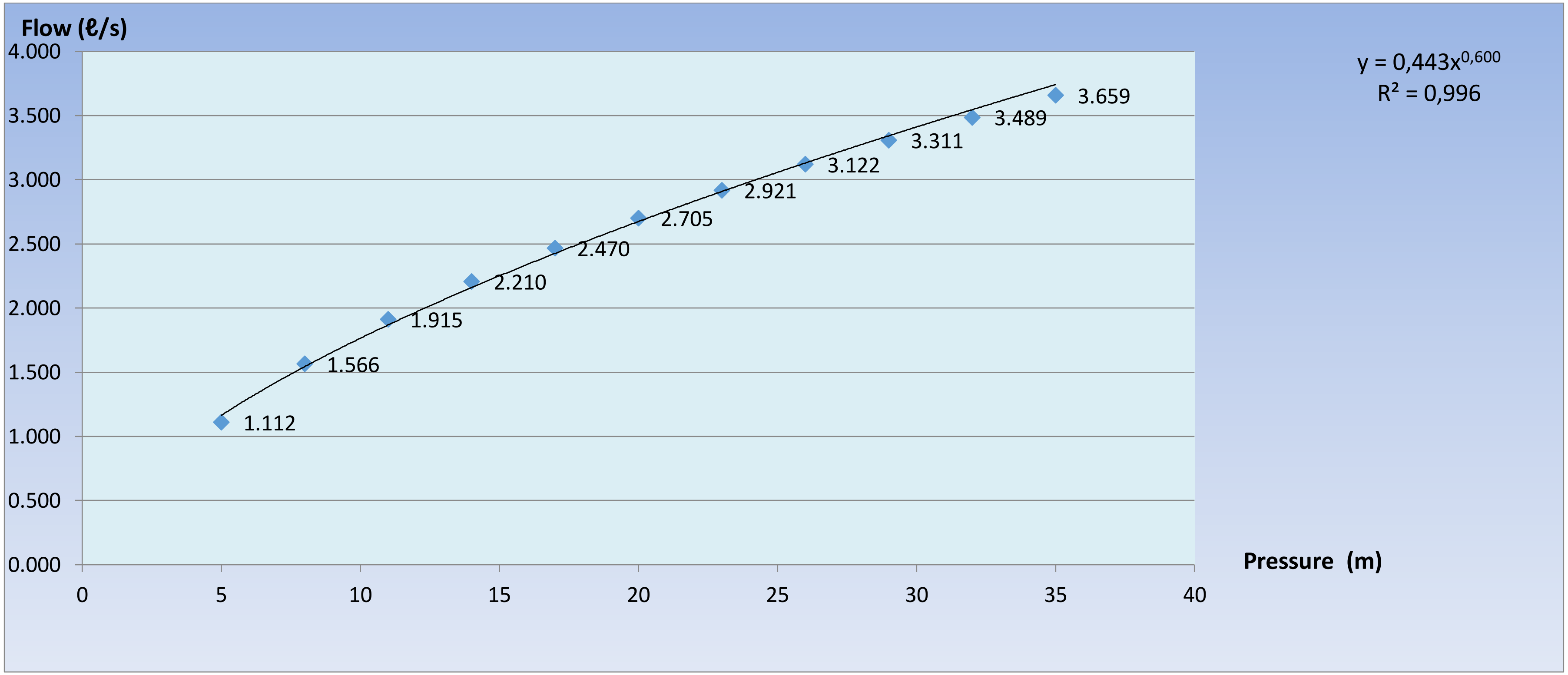


**Figure 5:** Graphical representation of the probable flow variation (qp) as a function of the required pressure.
(Case of 7 apartments / floor on 10 floors)

### 5.3. Results and Discussion

As part of the investigation of the discharge coefficient (C) and the pressure coefficient (γ) related to the emitter formula (1), and following a study conducted on two cases: Algeria and Romania the results obtained from the two following tables (6) and (7) are as follows:

### 5.3.1 Case of Algeria

The coefficients determined for Algeria are presented in Table 6, showing the variation of the discharge coefficient C as a function of the number of apartments per floor.

**Table 7:** The coefficients adopted (Case of Algeria).

| Designation | Form of the equation | Coefficients | |
|---|---|---|---|
| | $q = c\, p^{\gamma}$ | c | γ |
| 1 apartment/floor out of 10 floors | $y = 0,176\, x^{0,600}$ | 0,176 | 0,600 |
| 2 apartment/floor out of 10 floors | $y = 0,242\, x^{0,600}$ | 0,242 | 0,600 |
| 3 apartment/floor out of 10 floors | $y = 0,292\, x^{0,600}$ | 0,292 | 0,600 |
| 4 apartment/floor out of 10 floors | $y = 0,334\, x^{0,600}$ | 0,334 | 0,600 |
| 5 apartment/floor out of 10 floors | $y = 0,370\, x^{0,600}$ | 0,370 | 0,600 |
| 6 apartment/floor out of 10 floors | $y = 0,403\, x^{0,600}$ | 0,403 | 0,600 |
| 7 apartment/floor out of 10 floors | $y = 0,432\, x^{0,600}$ | 0,432 | 0,600 |
| 8 apartment/floor out of 10 floors | $y = 0,460\, x^{0,600}$ | 0,460 | 0,600 |
| 9 apartment/floor out of 10 floors | $y = 0,486\, x^{0,600}$ | 0,486 | 0,600 |
| 10 apartment/floor out of 10 floors | $y = 0,510\, x^{0,600}$ | 0,510 | 0,600 |

The relationship between coefficient C and the number of apartments is shown in Figure 6 (case of Algeria).

**- Graphical representation:**

C = *f* (N) This curve represents the variation of coefficient C as a function of the number of apartments per floor.

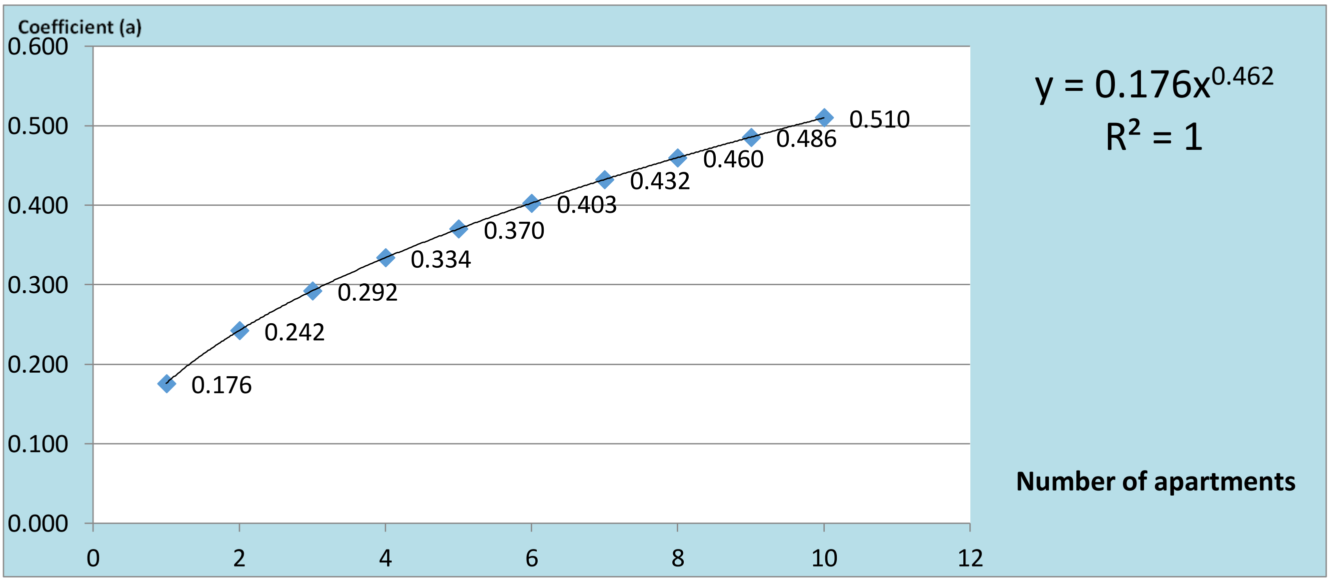


**Figure 6:** Curve showing the variation of coefficient C as a function of the number of apartments per floor. Curve of the equation: $y = 0,176\, x^{0,462}$

### 5.3.2. Case of Romania

As shown in Table 8, the coefficients adopted by Romania also indicate consistent pressure exponent values, with slight differences in C compared to Algeria.

**Table 8:** The coefficients adopted (Case of Romania).

| Designation | Form of the equation | Coefficients | |
|---|---|---|---|
| | $q = c \cdot p^{\gamma}$ | C | γ |
| 1 apartment/floor out of 10 floors | $y = 0{,}178x^{0{,}600}$ | 0,178 | 0,600 |
| 2 apartment/floor out of 10 floors | $y = 0{,}246\,x^{0{,}600}$ | 0, 246 | 0,600 |
| 3 apartment/floor out of 10 floors | $y = 0{,}297x^{0{,}600}$ | 0,297 | 0,600 |
| 4 apartment/floor out of 10 floors | $y = 0{,}340\,x^{0{,}600}$ | 0,340 | 0,600 |
| 5 apartment/floor out of 10 floors | $y = 0{,}377x^{0{,}600}$ | 0,377 | 0,600 |
| 6 apartment/floor out of 10 floors | $y = 0{,}411x^{0{,}600}$ | 0,411 | 0,600 |
| 7 apartment/floor out of 10 floors | $y = 0{,}442x^{0{,}600}$ | 0,442 | 0,600 |
| 8 apartment/floor out of 10 floors | $y = 0{,}470x^{0{,}600}$ | 0,470 | 0,600 |
| 9 apartment/floor out of 10 floors | $y = 0{,}497x^{0{,}600}$ | 0,497 | 0,600 |
| 10 apartment/floor out of 10 floors | $y = 0{,}522x^{0{,}600}$ | 0,522 | 0,600 |

The relationship between coefficient C and the number of apartments is shown in Figure 7 (case of Romania).

**- Graphical representation:** C = *f* (N)

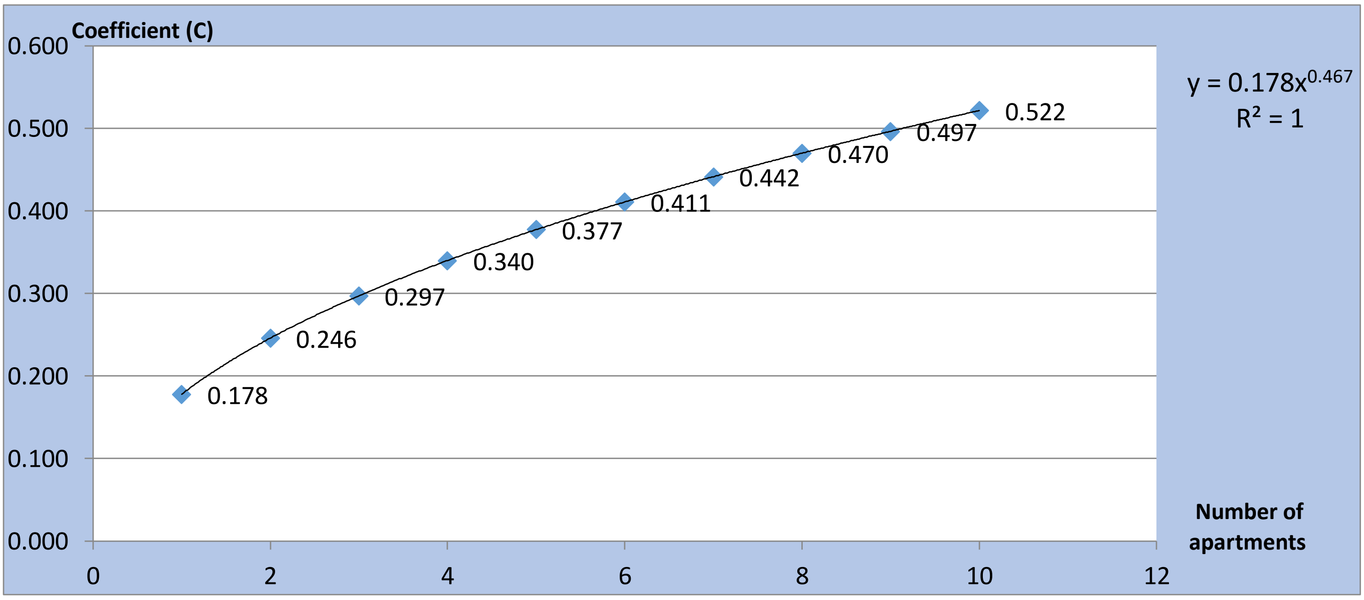


**Figure 7.** Curve of variation of the coefficient (C) as a function of the number of apartments per floor Curve of the equation: $y = 0.178\,x^{0.467}$.

## 5.4. Conclusion

This chapter included a study on determining the coefficients to be entered in the calculation program in order to perform an analysis based on the variations in flow rate as a function of the available pressure at the nodes, according to the applicable standards.

In this study, we observed and noted from the graphs that:
From a mathematical point of view, it is a nonlinear regression model. This type of regression follows a power law model of the form: $y = a.\,x^b$

This required determining the variables (a) and (b), which represent the coefficients to be entered in the EPANET 2.2 program.

The main objective of this work was to determine the coefficients for the equation: $q = c\,p^\gamma$, which represents the emitter flow equation as a function of node pressure.
where: q : flow, p : pressure, C : discharge coefficient, , and $\gamma$ is the pressure exponent.

- To achieve this, we adopted the previously presented methodology to calculate the probable flow rate for two cases (Algeria and Romania).

By applying this methodology, we were able to determine the coefficients (*a*) and (*b*) corresponding to the mathematical equation: $y = a\,x^b$ for each case.

We noted that the difference between the two formulas is minimal, which is due to the types of equipment used by households in both Algeria and Romania.
Similarly, when comparing the tables of base flow rates according to the French standard NF DTU 60.11P1-1. and the Romanian standards (monitorul oficial al româniei, partea i, nr. 1167 bis/6.xii.2022) and standard (STAS 1478-90).
we observed a slight difference in the estimated flow rates for buildings. For example, for washbasins the French standard gives : 0.20 ℓ/s while the Romanian gives 0.15 ℓ/s and for bathtubs 0.33 ℓ/s versus 0.25 ℓ/s respectively).

We also observed differences in the formulas for calculating the simultaneity coefficient: in Romania, the formula is defined as : $f_{AR} = \frac{0,83}{\sqrt{N-1}}$ ; while in Algeria it follows the French standards, which use : $K = \frac{0,8}{\sqrt{x-1}}$
This slight difference between the two constants (0.8 in the French standards and 0.83 in the Romanian standards) can be explained by:

● The difference between 0.83 and 0.8 results from experimental data and analyses conducted in each country regarding the use of sanitary installations.

- Romania adopted the 0.83 coefficient based on local studies of water use frequency and distribution.
- France adopted the 0.8 coefficient following its own observations on installation usage.

● Moreover, the difference between these two constants is probably due to several factors:
- Building typology: In Romania and France, the use of sanitary installations may vary according to the type of building (residential, hotel, industrial, ……….. etc.).

- Consumption habits: Depending on lifestyle, the frequency and duration of water usage points may differ between the two countries.
- Design safety: The slightly higher coefficient in Romania (0.83 vs 0.8) may reflect a more conservative approach, offering a greater safety margin in system design.

Finally, the difference between the two coefficients is relatively small (0.83 vs 0.8), but it reflects national particularities in terms of water consumption habits and plumbing design philosophy. Romania adopts a slightly higher value, probably for safety reasons and to better adapt to the specific requirements of local infrastructure.

## 6. Comparison between DDA and PDA for a (WDS) Serving a Given Population.

In this chapter, the coefficients calculated and derived in the second chapter were applied to different categories of consumers, and a comparative case study was conducted using the two calculation analyses currently employed in EPANET 2.2. For the pressure-based analysis, the flow variation coefficients defined in the second chapter were used. The observed differences according to the location of the city in the two countries were also studied.

### 6.1. Hydraulic simulation and analysis methods

We generally use two approaches for hydraulic modeling in EPANET: Demand-Driven Analysis (DDA) and Pressure-Driven Analysis (PDA). The model-based methodology for identifying distribution sites was tested in four Algerian cities and one Romanian city under real distribution scenarios. The water distribution networks of these cities cover their entire urban areas, and the population of these cities is listed in Table 9 below.

**Table 9**. Number of Population in each city.

| The cities | N’gaous | Ras El Aioun | New town of massinissa | Tei-Colentina |
|---|---|---|---|---|
| **population** | 33619 | 19850 | 40 000 | 40 000 |

In these figures, the simulation was carried out for two cases: demand-driven analysis (DDA) and pressure-driven analysis (PDA). The previously defined parameters were integrated into the numerical model of the PDA case at the nodes corresponding to the type of building they supply.

To the best of our knowledge, the buildings in the Algerian cities studied each have five floors (a ground floor and four upper floors) and contain four apartments per floor. In contrast, the buildings in the city of Tei-Colentina, Romania, generally have eleven floors (a ground floor and ten upper floors) and contain seven apartments per floor, as previously explained.

Thus, the parameters introduced into the numerical models for each city are as follows:

- For the four Algerian cities, the values were based on the equation derived from Table 10.

**Table 10.** Coefficients determined for the case of Algeria.

| Designation | Form of the equation | Coefficients | |
|---|---|---|---|
| | $q = c.\ p^{\gamma}$ | c | γ |
| 4 apartment / floor on 10 floors | $q = 0{,}334\ p^{0{,}6}$ | 0,334 | 0,6 |

- For the city of Tei-Colentina in Romania, the values were calculated based on the equation presented in Table 11.

**Table 11.** Coefficients determined for the case of Romania.

| Designation | Form of the equation | Coefficients | |
|---|---|---|---|
| | $q = c.\ p^{\gamma}$ | c | γ |
| 7 apartment / floor on 10 floors | $q = 0{,}442\ p^{0{,}6}$ | 0,442 | 0,6 |

## 6.2. Simulation and Analysis for Cities

### 6.2.1. Analysis for the City of N'gaous

### 6.2.1.1. DDA (Demand-Driven Analysis)

As shown, the water distribution network of the city of N'gaous was simulated using demand-driven analysis (DDA) conditions. Figure 8 illustrates the pressure distribution and resulting flow rate, while Figure 9 presents the pressure and velocity results.

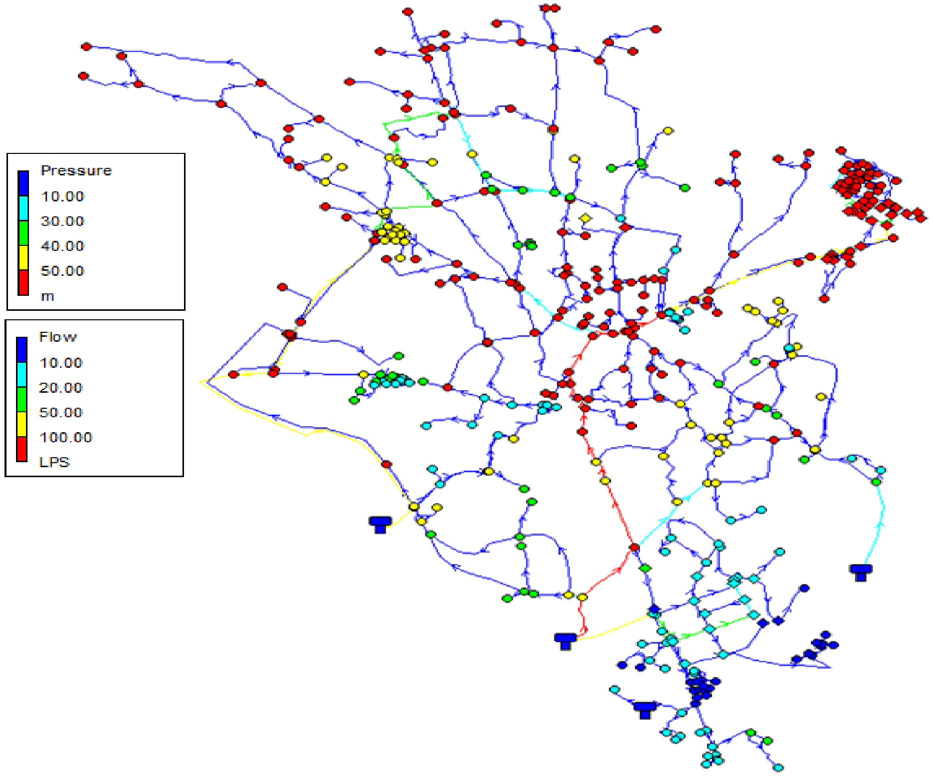


Figure **8.** Water distribution network of the city of N'gaous, simulation: Pressure – flow.

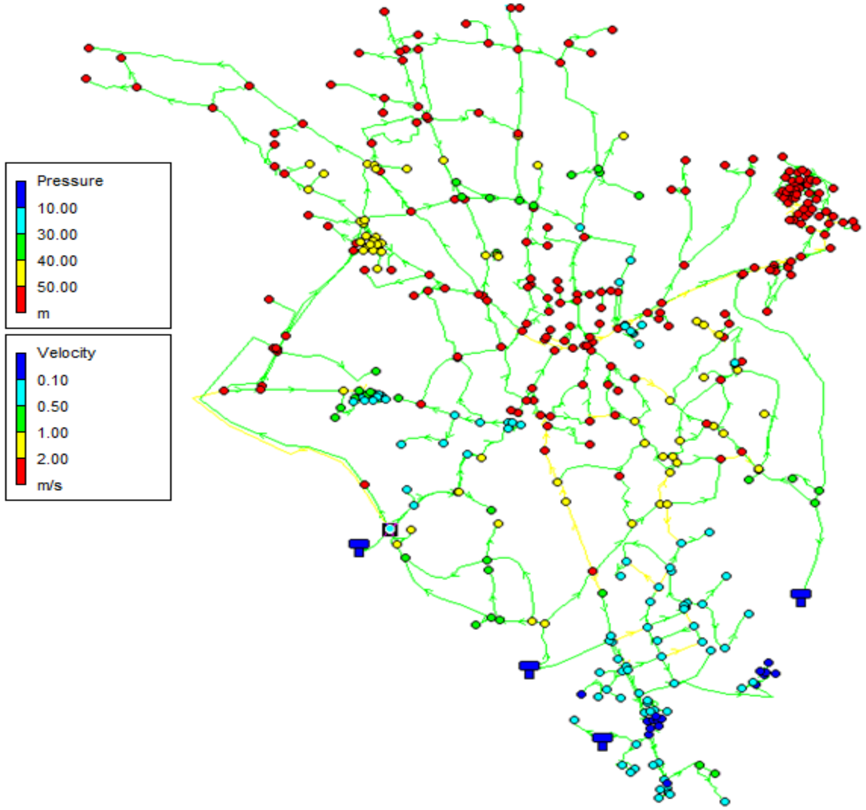


Figure **9.** Water distribution network of the city of N'gaous, simulation: Pressure – velocity.

### 6.2.1.2. PDA (Pressure Driven Analysis)

As illustrated, the water distribution network of N'gaous city was simulated under pressure analysis (PDA) conditions. Figure 10 illustrates the pressure distribution and resulting flow rate, while Figure 11 presents the pressure and velocity results.

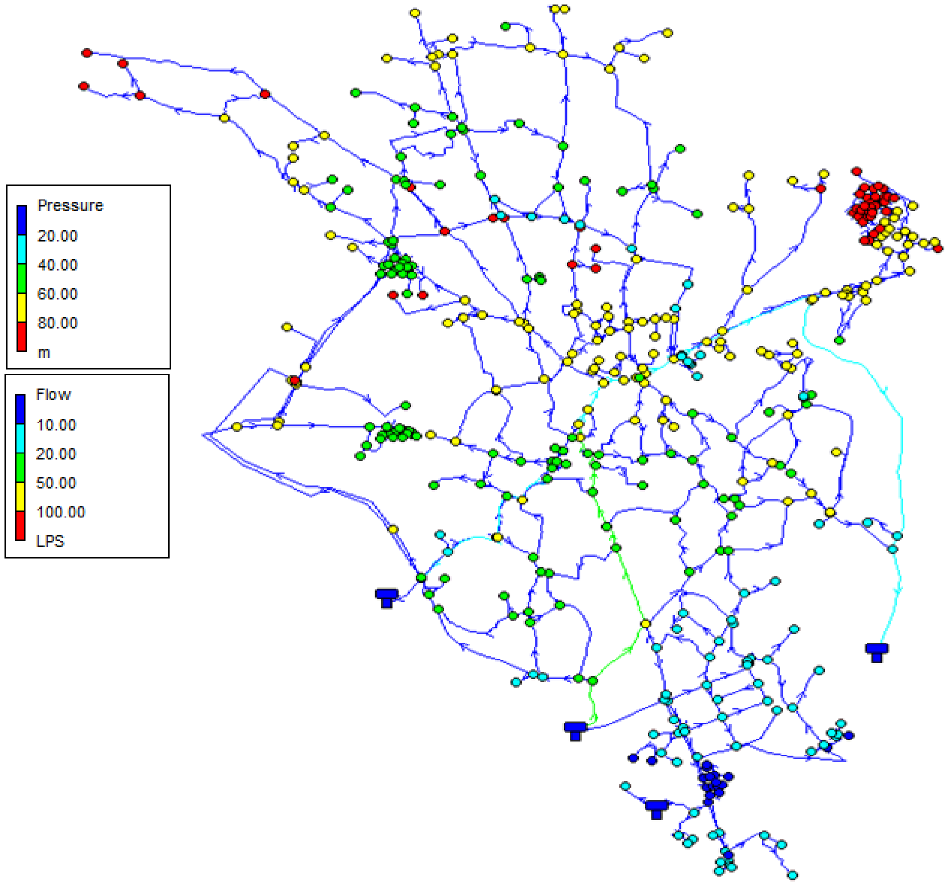


**Figure 10.** Water distribution network of the city of N’gaous, simulation: Pressure – flow.

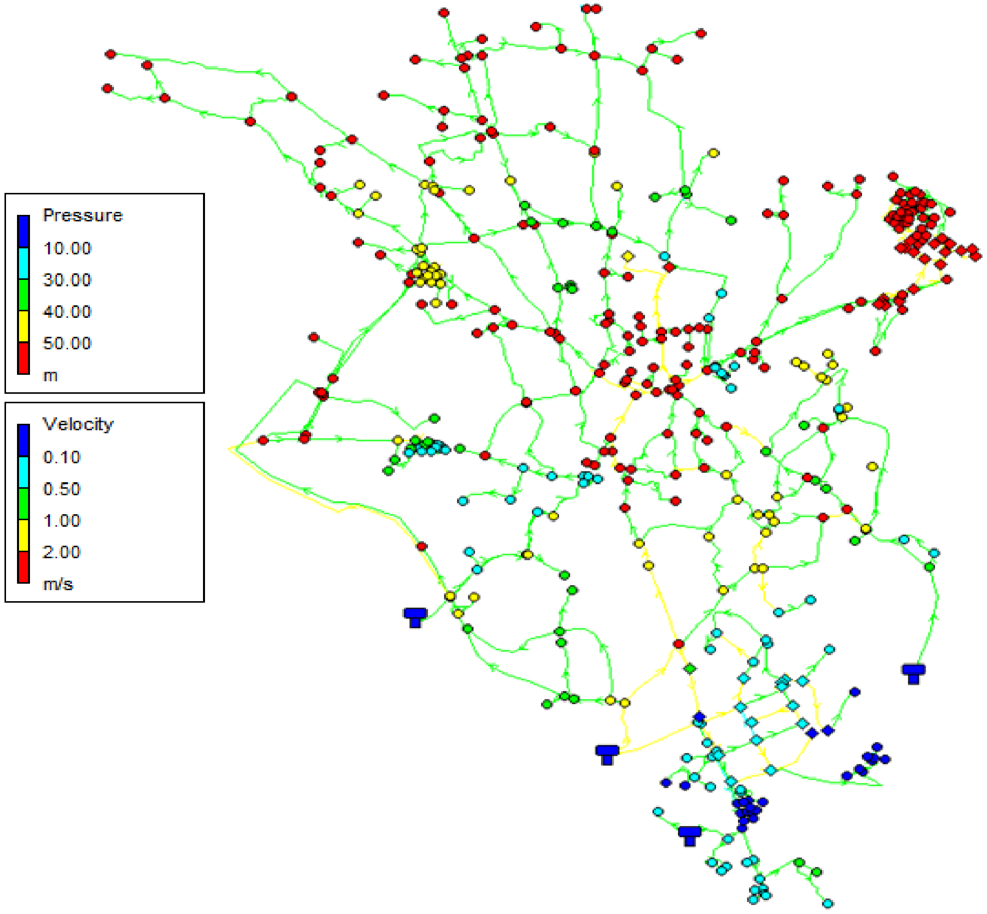


**Figure 11.** Water distribution network of the city of N’gaous, simulation: Pressure – velocity.

## 6 .2.2. Analysis for the City of Ras El Aioun

### 6.2.2.1. DDA (Demand Driven Analysis)

As shown, the water distribution network of the city of Ras El Aioun was simulated using demand-driven analysis (DDA) conditions. Figure 12 illustrates the pressure distribution and resulting flow rate, while Figure 13 presents the pressure and velocity results.

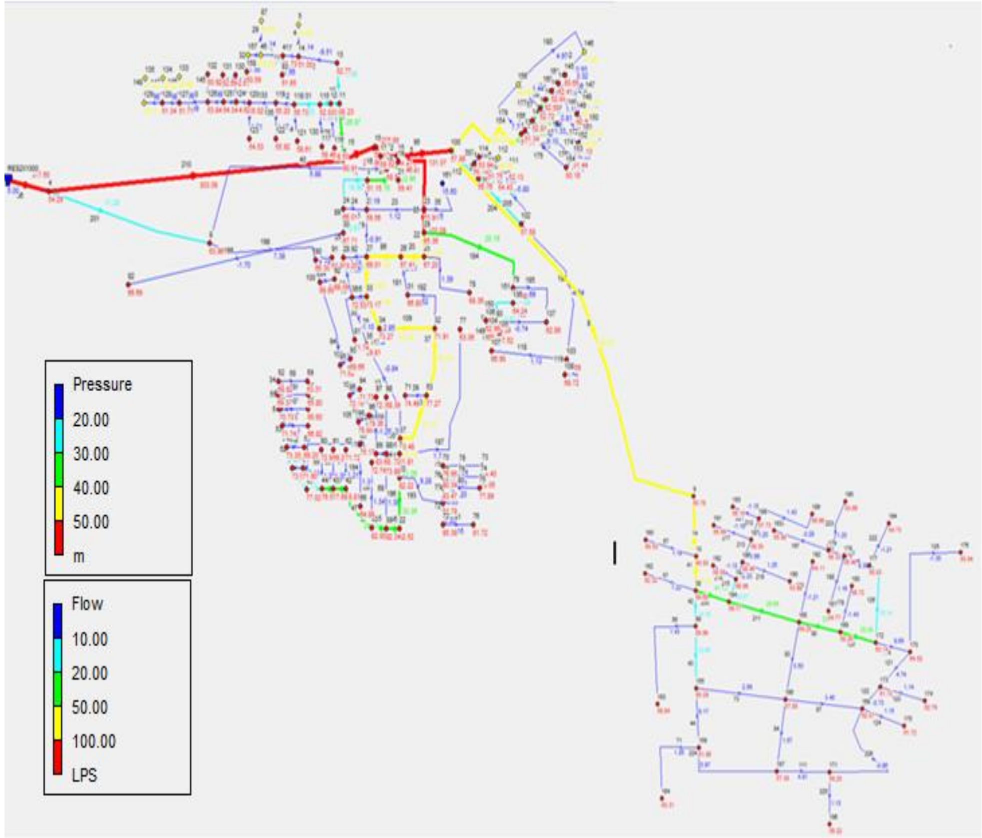


**Figure 12.** Water distribution network of the city of Ras El Aioun, simulation: Pressure – flow.

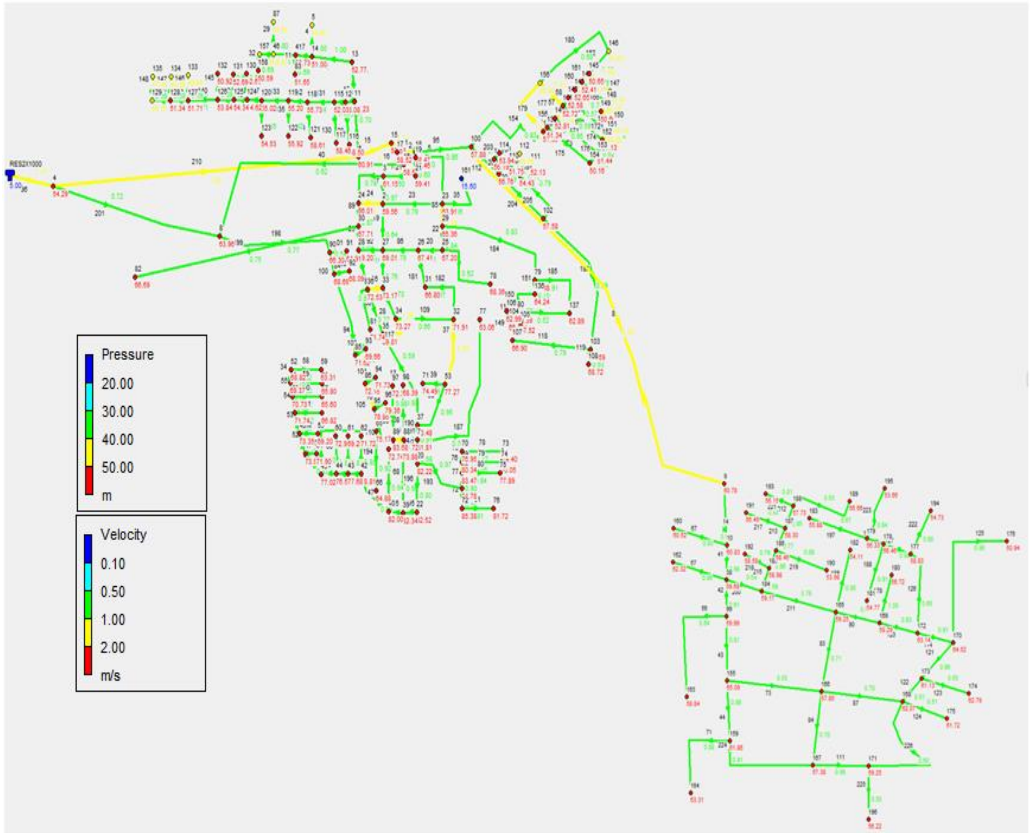


**Figure 13.** Water distribution network of the city of Ras El Aioun, simulation: Pressure – velocity.

### 6.2.2.2. PDA (Pressure Driven Analysis)

As shown, the water distribution network of Ras El Aioun city was simulated under pressure-based analysis (PDA) conditions. Figure 14 shows the pressure distribution and resulting flow rate, while Figure 15 presents the pressure and velocity results.

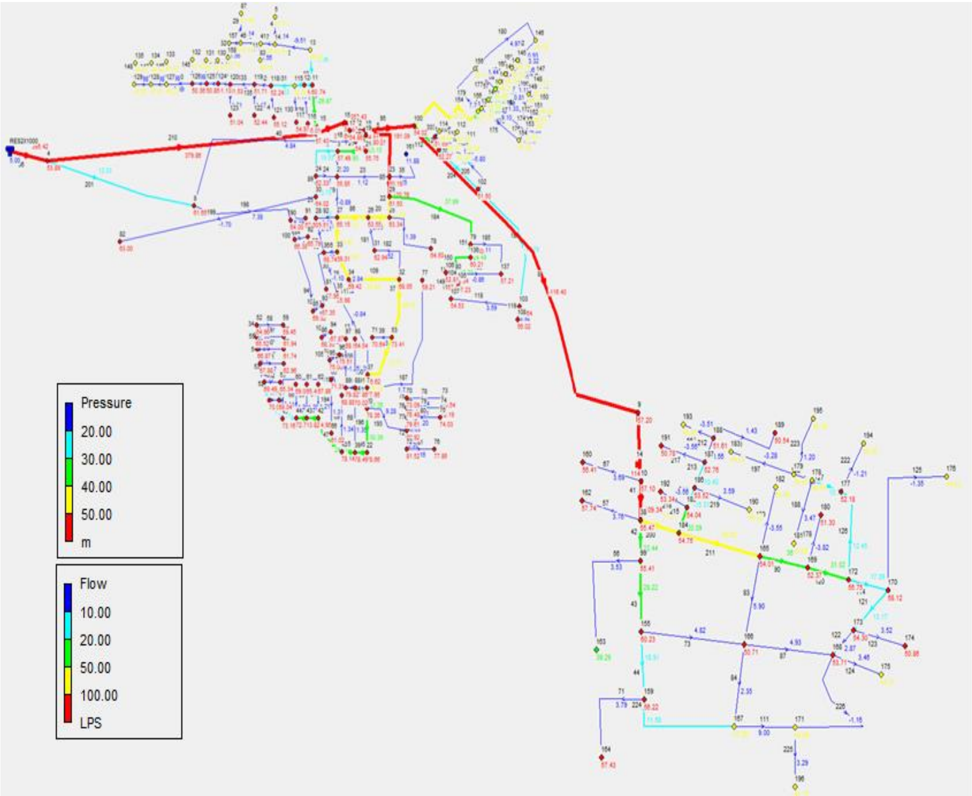


**Figure 14.** Water distribution network of the city of Ras El Aioun, simulation: Pressure – flow.

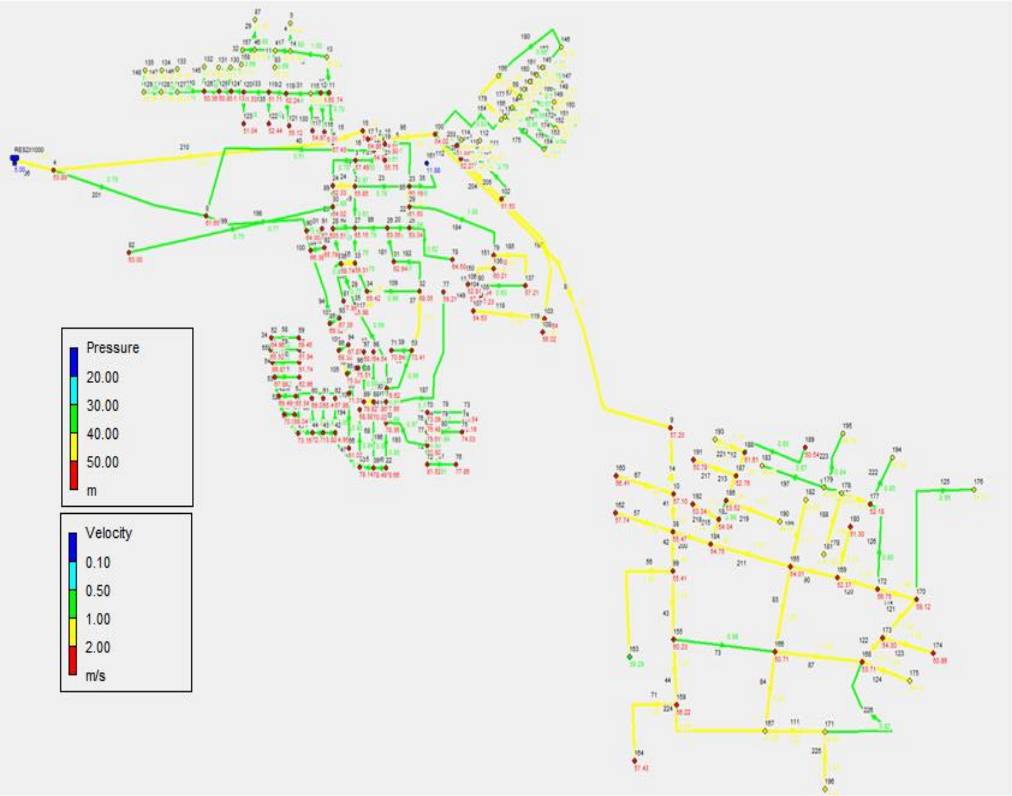


**Figure 15.** Water distribution network of the city of Ras El Aioun, simulation: Pressure – velocity.

### 6.2.3. Analysis for the New Town of Massinissa

#### 6.2.3.1. DDA (Demand-Driven Analysis)

As shown, the water distribution network of the new town of Massinissa was simulated using demand-driven analysis (DDA) conditions. Figure 16 shows the pressure distribution and resulting flow rate, while Figure 17 presents the pressure and velocity results.

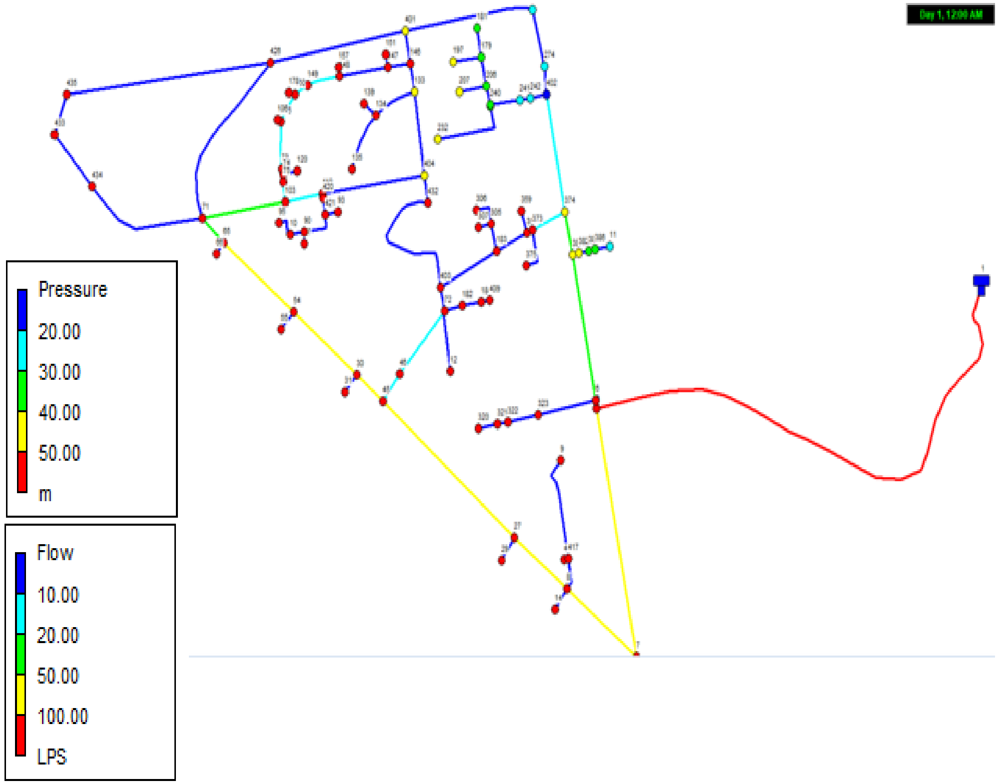


**Figure 16.** Water distribution network of the city of Massinissa, simulation: Pressure – flow.

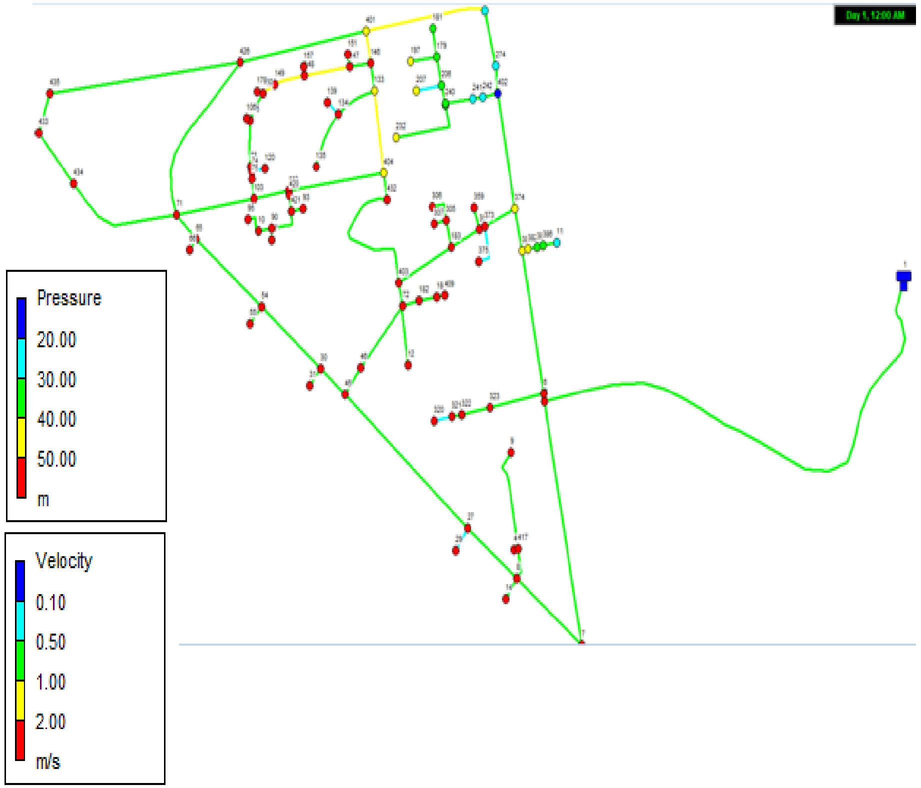


**Figure 17.** Water distribution network of the city of Massinissa Simulation: Pressure – velocity.

#### 6.2.3.2. PDA (Pressure Driven Analysis)

As shown, the water distribution network of the new town of Massinissa was simulated under pressure analysis (PDA) conditions. Figure 18 shows the pressure distribution and resulting flow rate, while Figure 19 presents the pressure and velocity results.

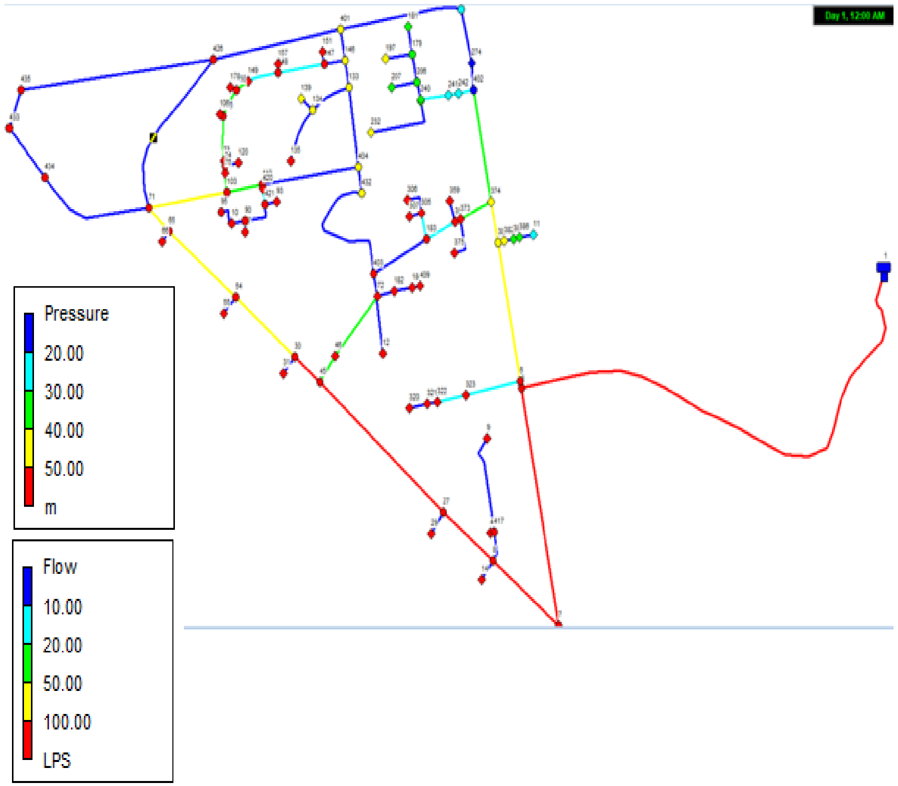


**Figure 18.** Water distribution network of the city of Massinissa, Simulation: Pressure – flow.

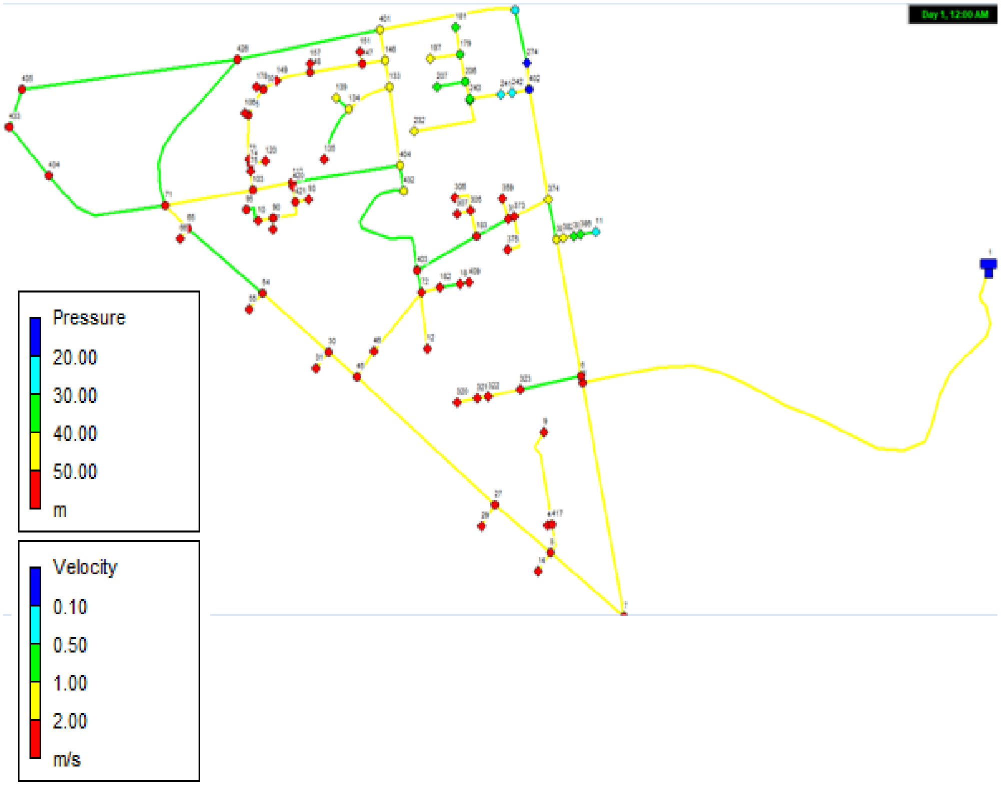


**Figure 19.** Water distribution network of the city of Massinissa, Simulation: Pressure – velocity.

### 6.2.4. Analysis for the city of Tei-Colentina (Bucharest)

#### 6.2.4.1. DDA (Demand-Driven Analysis)

As illustrated, the water distribution network of the city of Tei-Colentina was simulated using a demand-driven analysis (DDA). Figure 20 illustrates the pressure distribution and the resulting flow rate, while Figure 21 presents the pressure and velocity results.

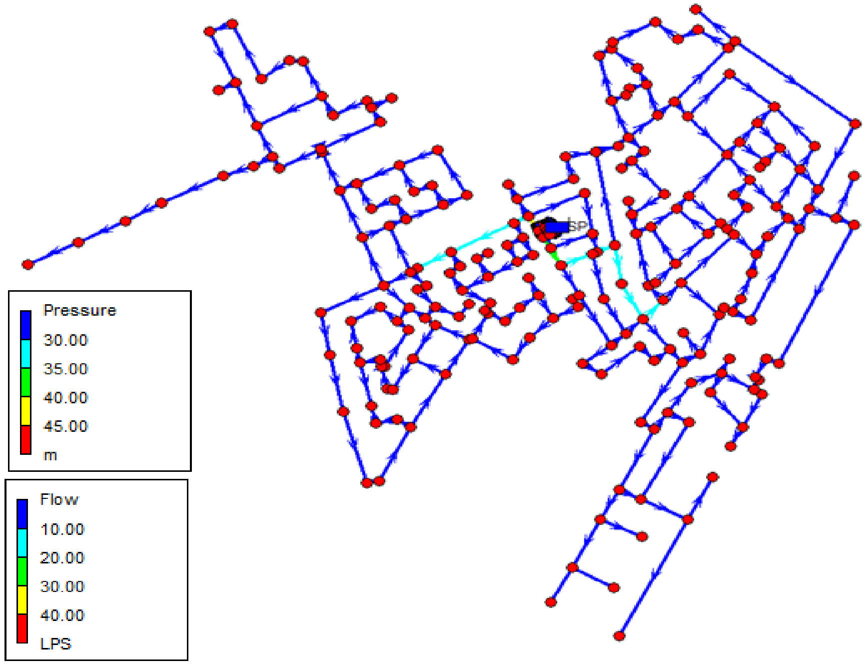


**Figure 20.** Water distribution network of the city of Tei-Colentina, Simulation: Pressure – flow.

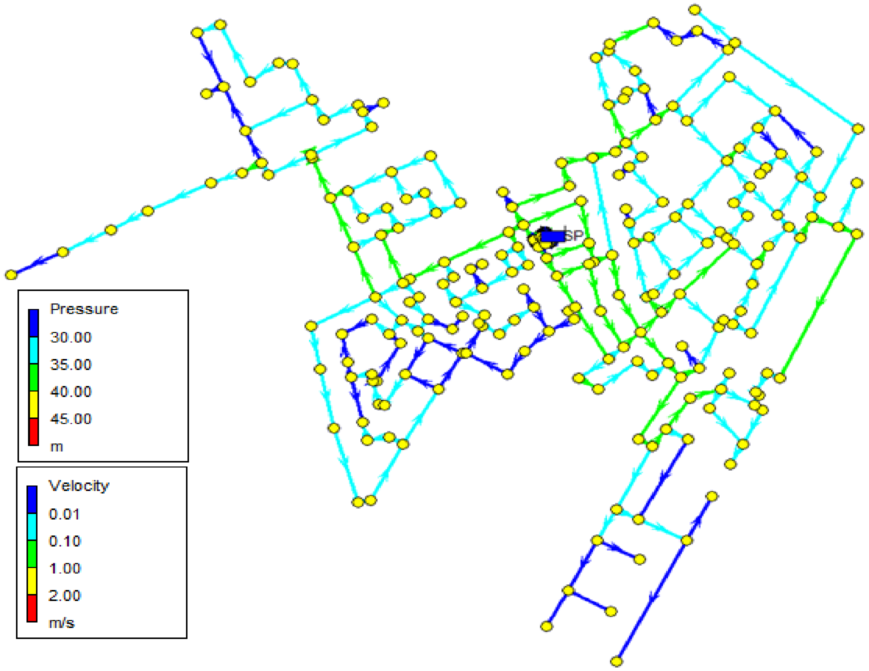


**Figure 21.** Water distribution network of the city of Tei-Colentina, Simulation: Pressure – velocity.

### 6.2.4.2. PDA (Pressure Driven Analysis)

As shown, the water distribution network of the city of Tei-Colentina was simulated under pressure-driven analysis (PDA) conditions. Figure 22 illustrates the pressure distribution and the resulting flow rate, while Figure 23 presents the pressure and velocity results.

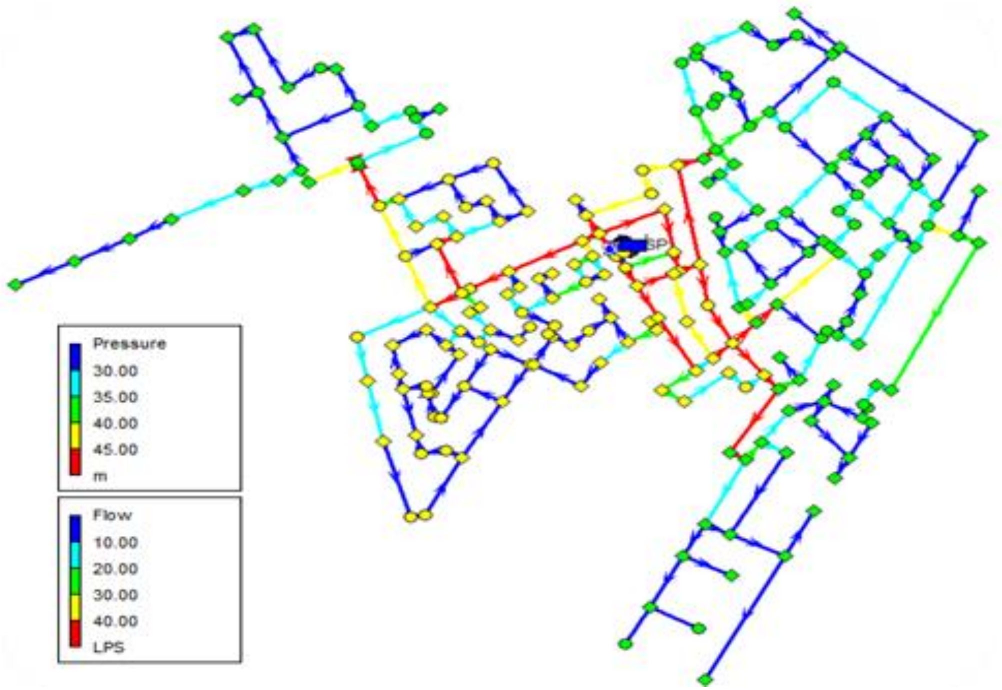


**Figure 22.** Water distribution network of the city of Tei-Colentina, Simulation: Pressure – flow.

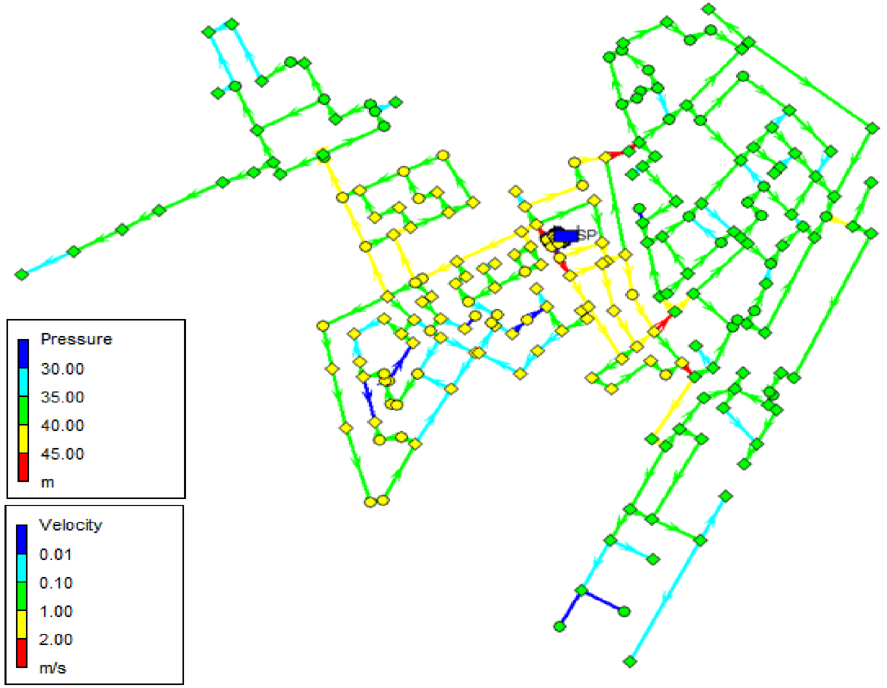


**Figure 23.** Water distribution network of the city of Tei-Colentina, Simulation: Pressure – velocity.

## 6. 3. Results and Discussion

### 6. 3.1. Simulation Results by City

### 6. 3.1.1. City of N'gaous

| Problems detected | Suggested improvements |
|---|---|
| Insufficient pressure at altitude and at the end of the network | (Diameter too small → pressure losses). |
| | Rebalance the supply areas by sector zing the network. |

- **Analyse DDA (Demand Driven Analysis):**

  - Pressures are relatively high, ranging from 14 m to 66 m, with all demands fully met. as shown in Figures (8) and (9).

  - This may seem ideal but does not reflect reality if the pressure were to drop or in the event of network overload

- **Analyse PDA (Pressure Driven Analysis) :**

  - Results show more realistic pressure in high-altitude areas or at the end of the network. as shown in Figures (10) and (11).

  - In some nodes, demand is only partially met, and speeds vary more.

  - We notice a progressive loss of pressure, revealing weak points in the network.

### 6. 3.1.2. Ville de Ras El Aioun

| Problems detected | Suggested improvements |
|---|---|
| Areas with insufficient flow during periods of high consumption. | - Construction of a surge reservoir. |
| | - Strengthen the network mesh to avoid isolated terminal areas. |

- **DDA (Demand Driven Analysis) :**

  - Hypothesis: All demands are met regardless of pressure.

  - Relatively high pressures, for example, from (54.29 m to 65.15 m) in the nodes. as shown in Figures (12) and (13).

- **PDA (Pressure Driven Analysis) :**

  - Slightly lower pressures than in DDA.

  - Allows observation of areas where pressure is insufficient to meet demand. as shown in Figures (14) and (15).

### 6. 3.1.3. New town of Massinissa

| Problems detected | Suggested improvements |
|---|---|
| Heavy reliance on a single reservoir. | - Add pressure reducers in low areas. |
| | - Set up a backup system in case the main channel is shut down. |

- **DDA analysis** :
  - From Figure (16) and (17) Stable data, all consumed requests are taken into account.

- **PDA analysis** :
  - Some requests are partially satisfied.

- Pressure drops slightly at certain points, reflecting the real constraints of the network. As shown in the figure (18) and (19).

### 6. 3. 1.4. Residential area Tei-Colentina

| Problems detected | Suggested improvements |
|---|---|
| The building network is complex because of the (high buildings), here the pressure is variable | - Installation of booster pumps in buildings. |
| | - Dynamic pressure control with installation of pressure reducers. |

- **DDA analysis** :
  - Provides optimistic results: demand is assumed to be fully supplied. As shown in the figure (20) and (21).

- **PDA analysis** :
  - From Figure (22) and (23) highlights critical low pressure areas (e.g. pressures around 15 m).
  - Better modeling of the impact of pumps, pressure losses and urban topography.

So, through these results, we can make a comparison between the two analyses (DDA) and (PDA) as shown in the following Table 12:

**Tableau 12.** Comparaison entre DDA et PDA.

| Criteria | DDA (Demand Driven Analysis) | PDA (Pressure Driven Analysis) |
|---|---|---|
| **Assumption** | Demand is always met regardless of pressure | Demand depends on available pressure |
| **Use** | Normal operating case | Abnormal operating conditions: leak, fire, breakdown |
| **Reliability in critical cases** | Low (can generate negative pressures) | High (takes into account actual degradation) |
| **Resolution** | Continuity and loop equations | Based on DDA with addition of pressure-demand relation. |
| **Estimated pressure** | Generally overestimated | More realistic, especially in low-lying areas or at the end of the network. |
| **Estimated flow rate** | Fixed (constant) in all cases. | Varies with pressure. |
| **Network sizing** | Less conservative (underestimates real needs) | More conservative and realistic (better adapted infrastructure) |

The comparative analysis of the four urban networks shows that:

- Traditional methods (DDA) may overestimate the actual performance of the networks, especially under variable pressure conditions.

- The (PDA) approach allows for a better understanding of hydraulic behavior, taking into account the nonlinear relationship between flow and pressure.

The data from the simulations clearly show that Algerian networks, although important, require technological updates and hydraulic optimization (better management of pressures, flows, water losses, etc.) to ensure efficient (good quality, waste-free, and cost-effective) and sustainable (long-term, even in the face of growing demand or limited resources) service.

### 6. 4. The discussion

Through these special models of the study areas, we note the following:

We applied the simulation to two drinking water distribution network models in two cities in two different countries. These two models differ in terms of the water distribution system: the first model uses a gravity distribution system, and the second uses a pumped distribution system.

There are main parameters for comparison:

- **Flow**

- Flow rates at different points in the network are essential parameters for comparing the two approaches. DDA considers them as fixed, while PDA calculates them based on pressures.

- DDA provides a more detailed representation or assessment of consumption flows in the various network pipes, making it possible to identify areas potentially subject to capacity problems, while PDA analysis may underestimate these flows by not taking losses into account.

**- Pressure**

►**For the gravity distribution system** (Figures. 8, 12, 16), the pressure depends on the position and location of the reservoir, i.e., the reservoir has a higher point (elevated) than all the buildings in the city, thus ensuring good distribution and pressure, thereby reducing energy costs. In summary, the distribution in such a pattern depends on the topographic relief.

► **For the pumped distribution system** (Figure 20), this type is characterized by the fact that from intake to distribution to the tap, the drinking water network constantly uses pumps. Therefore, the pressure here depends on the type of pump and their characteristic parameters (operating flow rate ($Q$), geodetic head (Hg), total head (HMT) … etc.) and variable consumer demands. Such as the water distribution network in the « Residential area Tei-Colentina ».

**- Water flow velocity in pipes:**

European (EN 805) and Romanian (NP 133-2022) standards recommend economic velocities between ~0.5–2.0 m/s. In the Romanian pumped system studied, velocities (0.3 m/s) were below standard, linked to oversized pipes and discrete pump control, which caused either surplus or deficit flows. because the problem is that this section of the network distribution is not an isolated system, but part of the main network. Consequently, its operation is directly influenced by the hydraulic conditions and control strategies of the larger system, which exacerbates the issue of low velocities.

In EPANET, when performing a Pressure Driven Analysis (PDA), the introduction of discharge coefficients and the emitter exponent has a direct impact on the modeling of flow rates at nodes based on the available pressure.

From what has been observed:

- Unlike Demand Driven Analysis (DDA), where demand at nodes is fixed, PDA adjusts flow rates at nodes based on available pressure.

- When the pressure drops below a certain threshold value, the delivered flow rate is reduced in accordance with the orifice emission equation (n°1): $q = C.P^{\gamma}$

Where: q: flow rate, c: discharge coefficient, It was determined with a variable value between: (0,176 - 0,510) in the case of Algeria. And between: (0,178 - 0,522) in the case of Romania. This coefficient varies according to the number of apartments on each floor of the building (see tables 7 and 8). P : is the nodal pressure, $\gamma$ : pressure exponent (generally between 0.5 and 0.6 for orifices), It was determined with a value of 0,6.

The formulas deduced for each of the two cities are:

- The 04 cities of Algeria: $q = 0{,}334 . p^{0{,}6}$
- Tei-Colentina District: $q = 0{,}442 . p^{0{,}6}$

We observed that the difference between the two formulas is minimal, due to the type of equipment used by households either in Algeria or in Romania.

The same applies when we look at the basic flow rate tables, according to the French standard NF DTU 60.11P1-1. And the Roman standards : (monitorul oficial al româniei, partea i, nr. 1167 bis/6.xii.2022) and standard (STAS 1478-90).

There is a slight difference in the estimated flow rates in buildings, for example, for (sinks French standards: 0.20 ℓ/s and Roman standards 0.15 ℓ/s while for bathtubs 0.33 ℓ/s vs 0.25 ℓ/s.( See Tables 1 and 2).

The same can be observed for the formula for calculating the simultaneity coefficient, given that in Romania, the formula is as follows: $f_{AR} = \frac{0{,}83}{\sqrt{N-1}}$ ; while those applied in Algeria are based on the French standards, which are: $K = \frac{0{,}8}{\sqrt{x-1}}$

This slight difference between the two constants (0, 8 in the French standards) and (0, 83 in the Roman standards) is:

● The difference between 0.83 and 0.8 comes from experimental data and analyses conducted in each country on how sanitary facilities are used.

- Romania adopted the coefficient of 0.83 based on local studies on the frequency of use and the distribution of water consumption.
- France adopted the coefficient of 0.8 following its own observations on the use of the facilities.

● Furthermore, the difference between these two constants is probably due to several factors:

- Building typology: In Romania and France, the use of sanitary facilities can vary depending on the building type (residential, hotel, industrial ...etc.).
- Consumption habits: Depending on lifestyle, the frequency and duration of use of water consumption points can differ between the two countries.
- Design safety: The slightly higher coefficient in Romania (0,83 versus 0,8) may indicate a more conservative approach, providing a greater safety margin for system design.

Ultimately, the difference between the two coefficients is relatively small (0.83 versus 0.8), but reflects national particularities in terms of water consumption and plumbing design philosophy. Romania adopts a slightly higher value, likely for safety reasons and to adapt to the specific requirements of local infrastructure.

**- Pipe Diameters**

- When designing a network, a DDA-based model could lead to an overestimation of diameter requirements, as the calculations assume full demand satisfaction.
- In PDA, since demand varies with pressure, the model can help identify network sections requiring reinforcement (increased diameters) to improve distribution.

For example, in Figures (8, 12, 14,16,18,22), the red pipe sections appear to require modification since they represent higher flow rates and indicate pipes near their maximum capacity or very high flow rates in response to significant demand or possibly leaks.

Regarding coefficient calibration, taking into account the discharge coefficient and the emitter exponent allows for a more realistic simulation of network behavior under low-pressure conditions in EPANET with PDA.

- Regarding the comparison between demand-driven analysis (DDA) and pressure-driven analysis (PDA)

In EPANET, when comparing a demand-driven analysis (DDA) model and a pressure-driven analysis (PDA) model, it is essential to understand their fundamental differences and how discharge coefficients and the emitter exponent influence the results.

- Demand driven analysis model (DDA)

In this model:

- Demand (Flux) at nodes is fixed and always satisfied, regardless of the pressure level.

- It assumes that the network can always supply the requested flow, which is unrealistic in the case of insufficient pressure.

- It does not take into account the effect of pressure variations on the water supply.

- Pressure driven analysis model (PDA)

In this model:

- The supplied flow depends on the pressure available at each node.

- If the pressure is below a critical value, the distributed flow rate decreases according to a pressure-flow rate relationship defined by the transmitter.

Therefore, we can draw a comparison between demand-based analysis and pressure-based analysis in the case of realistic hydraulic network modeling.

The PDA provides more realistic pressure results, especially in low-pressure areas, unlike the DDA, which can overestimate pressures.

- PDA allows for more accurate modeling of network pressure variability, which is essential for infrastructure design. - PDA focuses on assessing network pressures, providing a more realistic representation of the service conditions offered to users.

- Regarding pressure and flow, in both analysis cases

• Flow-based analysis (DDA) and

• Pressure-based analysis (PDA), this must be done under two conditions:

$$\begin{cases} \text{Flow rate: } Q_{\text{DDA}} \neq Q_{\text{PDA}} \text{ (Varies with pressure)} \\ \text{Pressure: } P_{\text{(DDA)}} > P_{\text{(PDA)}}. \end{cases}$$

The flow-in state (DDA) is a theoretical state where all demands are met, but as soon as the pressure is insufficient, the analysis state moves to a pressure-based analysis state (PDA), where the flow is reduced based on the available pressure. This change allows for more realistic modeling of networks under hydraulic constraints.

## 7. General Conclusion

This study presents a comprehensive methodology for the simulation and calibration of water distribution networks using EPANET 2.2, with a particular focus on evaluating demand-driven analysis (DDA) and pressure-driven analysis (PDA) under realistic operating conditions. By calculating the discharge coefficients (C) and pressure exponents ($\gamma$) based on the national plumbing standards of Algeria and Romania, the research establishes a connection between theoretical hydraulic modeling, practical regulatory constraints, and consumer behavior.

The calibration process produced consistent values for the pressure exponent ($\gamma = 0.6$), while the discharge coefficient (C) varied according to the number of apartments per floor, ranging from 0.176 to 0.510 in Algeria and from 0.178 to 0.522 in Romania. These parameters proved essential for developing pressure dependent demand models that more accurately reflect flow conditions under variable pressure scenarios.

Case studies involving gravity-fed and pumped systems (in Algeria and Romania, respectively) demonstrated that while DDA assumes ideal conditions with fully satisfied demand, PDA reveals the network’s real limitations such as pressure deficits and unmet demands during peak consumption periods or infrastructure constraints. PDA simulations enabled the identification of critical nodes, underperforming zones, and design errors often concealed by DDA.

This work provides an innovative framework linking empirical regulatory data to hydraulic simulation parameters, thereby enhancing the realism and transferability of network models across different urban contexts. It highlights the necessity of using PDA, supported by properly calibrated coefficients, to enable informed decision-making in system design, infrastructure reinforcement, and operational management.

Finally, the study demonstrates that integrating country-specific standards into pressure-based simulation models not only improves their accuracy but also promotes a more resilient and adaptive approach to water distribution system management in diverse geographical and technical environments.

## 7.1. Original Contributions

As part of this research project, the following procedures were studied and applied:

The first part of the thesis initiated a comparative study of different methods for calculating consumption flow rates in water supply networks, in accordance with the standards in force in the European Union and in the southern Mediterranean region. The second part applied a parameter calibration method to be integrated into the flow calculation formula, based on the available pressure at the nodes, in line with current standards. The final part compared the flow-based analysis and the pressure-based analysis for a water distribution network serving a population. This work presents a comparative case study of the two calculation algorithms currently used in EPANET 2.2. In the pressure-based analysis, the flow variation coefficients defined in the second report were applied. The observed differences according to the location of different countries were also investigated.

The thesis topic provides several original contributions:

1. **Comparison of Standards:** A detailed analysis of flow rate calculation methods in six countries (Romania, Italy, Germany, Algeria, Tunisia, Egypt), highlighting the differences and similarities between European and Mediterranean approaches, thus offering a global and cross-border perspective.
2. **Coefficient Calibration :** Accurate determination of coefficients for the flow-pressure relationship $q = f(P)$ used in Pressure-Driven Analysis (PDA), adapted to local standards (e.g., Algeria and Romania), with validation through numerical models.
3. **Practical Validation :** Application of both Demand-Driven Analysis (DDA) and Pressure-Driven Analysis (PDA) to real-world case studies (Algerian cities, and Lacul Tei city in Romania), demonstrating the superiority of PDA in low-pressure scenarios.
4. **Numerical Modeling with EPANET 2.2** : Development of numerical models for multiple case studies, allowing validation of the calibrated coefficients and comparison of DDA and PDA performance.
5. **Application to Real Cases** : Implementation of the proposed methods on actual water distribution networks such as those in Algerian cities and the city of Lacul Tei (Romania) demonstrating their practical relevance.
6. **Comparison of DDA and PDA Methods**: A comparative assessment of results obtained from Demand-Driven Analysis (DDA) and Pressure-Driven Analysis (PDA), emphasizing the advantages of PDA under abnormal operating conditions.
7. **Analysis of Specific Challenges in High-Rise Building Networks** : Identification of issues related to pressure constraints and flow variations, along with proposed suitable technical solutions.
8. **Recommendations for Future Standards**: Suggestions for improving existing standards, based on the outcomes of simulations and international comparisons.
9. **Performance Analysis of Existing Simulation Methods:** Evaluation of current simulation approaches and proposal of improvements for modeling pressurized water networks.
10. **Validation of Proposed Hypotheses and Coefficients:** Validation through detailed hydraulic simulations confirming their effectiveness in real-world scenarios.

These original contributions combine theoretical advances (methodologies, formulas) with practical developments (applications, simulations), providing valuable tools for engineers, researchers, and managers of drinking water supply networks.

### 7.2. Research monitoring prospects

Based on the theoretical results and case studies conducted as part of this thesis, the following research directions can be developed:

#### 1. Generalization and Adaptation of Models

- **Application to various urban contexts and complex networks**: Extend the Pressure-Driven Analysis (PDA) to different geographical contexts, particularly regions with diverse networks or high urban density.

- **Application of the methodology to other countries**: Broaden the database and adjust the coefficients to improve the robustness and transferability of the models.

#### 2. Integration of Complementary Variables

- **Performance optimization**: Combine PDA analysis with leakage reduction strategies and energy optimization (pumping, pressure management).

- **Climatic factors and seasonal variability**: Consider the effects of climate change on water demand to adapt the models to future scenarios.

#### 3. Technological and Methodological Innovations

- Advanced software tools: Enhance EPANET capabilities by developing additional modules for the dynamic management of pressure variations and the detection of low-performance zones.

#### 4. Optimization and Sustainable Management

- **Rehabilitation of existing networks**: Use the research results to guide the design and upgrading of networks in areas with insufficient pressure or at risk of water shortage.

These perspectives propose a holistic and evolving approach to the management of drinking water distribution systems, taking into account technological, environmental, and operational challenges. The integration of new technologies and the extension of models to various contexts will ensure better adaptability of water supply systems to future needs.

## 8. Bibliographic references

[1] STANDARD ROMÂN, SR 1343-1 :( 2006) Alimentări cu apă: Determinarea cantităţilor de apă potabilă pentru localităţi urbane şi rurale.

[2] Ministerul Dezvoltării Regionale și Turismului. (2011). Normativ privind proiectarea, execuția și exploatarea sistemelor de alimentare cu apă și canalizare a localităților. Indicativ NP 133–2011. București: MDRT.

[3] Milano, V. (1996). *Acquedotti*. Hoepli Editore.ISBN 88-203-2292-7

[4] Conte, G. (2008). Nuvole e sciacquoni: Come usare meglio l'acqua, in casa e in città. Edizioni Ambiente. ISBN 978-88-89014-76-9.

[5] Da Deppo, L., Datei, C., Fiorotto, V., & Salandin, P. (2003). *acquedotti*. Cortina.

[6] Salvini, S. (2003). *Impianti idrici negli edifici. Dimensionamento delle reti e progettazione. Acqua di consumo, reti antincendio, piscine e sistemi di irrigazione. Con CD-ROM*. Hoepli Editore.

[7] Rimoldi, P. (2010). *Ingegneria idraulica urbana. Acquedotti e fognature. Manuale-tecnico pratico per la progettazione e la realizzazione delle opere* (Vol. 10). Maggioli Editore.

[8] Ippolito, G., & De Martino, G. (1995). *Appunti di costruzioni idrauliche*. Liguori.Editore ISBN- 13 978-88-207-2082-7

[9] Baur, A., Fritsch, P., Hoch, W., Merkl, G., Rautenberg, J., Weiß, M., & Wricke, B. (2019). *Mutschmann /Stimmelmayr Taschenbuch der Wasserversorgung*. Springer-Verlag.

[10] Klingel, P. (2010). *Von intermittierender zu kontinuierlicher Wasserverteilung in Entwicklungsländern* (Doctoral dissertation, Karlsruher Inst. für Technologie, Diss., 2010).

[11] Parra, S. (2020). Verfahren zur Bewertung von Trinkwassernetzen als Grundlage der Anpassungsplanung.

[12] Preininger, E. (1999). Wasserabgabe — Wasserverbrauch — Wasserbedarf. In: Brendel, G.,Edenhofner, M., Gaschler, H., Köhler, K.H., Preininger, E., Weigelt, R. (eds) Taschenbuch der Wasserversorgung. Vieweg+Teubner Verlag, Wiesbaden. https://doi.org /10.1007/978-3-322-93916-6_2

[13] Preininger, E. (2002). Wasserabgabe—Wasserverbrauch—Wasserbedarf. In *Taschenbuch der Wasserversorgung* (pp. 11-43). Vieweg+ Teubner Verlag, Wiesbaden.

[14] DVGW, A. W. (2004). 400-1: Technische Regeln Wasserverteilungsanlagen (TRWV); Teil 1: Planung Oktober 2004. *Wirtschafts-u. Verlagsges. Gas u. Wasser, Bonn*.

[15] Klingel, P. (2018). Modellierung von Wasserverteilungssystemen. *Wiesbaden: Springer Fachmedien Wiesbaden. doi*, *10*, 978-3. – ISBN 978–3–658–21270–4

[16] Hoch, W. (2014). Hydraulische Berechnungsgrundlagen. In *Mutschmann/Stimmelmayr Taschenbuch der Wasserversorgung* (pp. 59-112). Springer Vieweg, Wiesbaden.

[17] Mutschmann,J., & Stimmelmayr, F. (2007). Wasseraufbereitung. Taschenbuch der Wasserversorgung 14. *Vieweg Teubner Verlag, Wiesbaden, Germany*, *4*, 206. ISBN 978-3-8348-0012-1

[18] Zoungrana, D. (2003). Cours d'approvisionnement en eau potable. *Ecole inter-états d'ingénieurs de I'équipement rural, Ouagadougou, 143p*.

[19] BEDJAOUI, A. (2016). Alimentation en eau potable : *Manuel de cours*. Faculté des Sciences et Technologie, Département de Génie civil et d'Hydraulique, universite mohamed khider – BISKRA.

[20] Bonnin, J. (1977). *Hydraulique urbaine: appliquée aux agglomérations de petite et moyenne importance*. Paris.: Eyrolles.

[21] *GUERGAZI*, S. (2016). Alimentation en eau potable : *Manuel de cours*. Faculté des Sciences et Technologie, Département de Génie civil et d'Hydraulique, universite mohamed khider – BISKRA.

[22] Guide technique. (2017). Mémento technique Conception et dimensionnement des systèmes de gestion des eaux pluviales et de collecte des eaux usées – Version Décembre 2017

[23] Gomella, C., Guerrée, H., & Neveux, M. (1970). *La distribution d'eau dans les agglomérations urbaines et rurales*. Eyrolles. ISSN 0768-3510

[24] Dupont, A. (1974). *Hydraulique urbaine Tome 2, ouvrages de transport élévation et distribution des eaux. Edition* Eyrolles.

[25] Moussa, M. (2000). Alimentation en eau potable. *ENIT: Manuel de cours*.

[26] Rapport des statistiques (2019), Société Nationale d'Exploitation et de Distribution des Eaux (SONEDE), Tunisie.

[27] BENAMAR, N & MOUSSAOUI, A (2017) GUIDE DE PROJETS HYDRAULIQUES, Département de Génie Civil, Institut Supérieur des Etudes Technologiques de Gafsa, Tunisie

[28] Egyptian Code for Design and Implementation of Pipelines for Drinking Water and Sewage Networks, Sixth Edition 1998. (in Arabic)

[29] Egyptian Code of Practice for designing and installation of pipelines of drinking water and sanitation. 10th Edition, 2007. (in Arabic)

[30] Egyptian Code for Design Principles and Implementation Conditions for Pipelines Used in Drinking Water and Wastewater Networks, Code (102)/1, Edition May 2010 (in Arabic)

[31] Standard des normes française, NF DTU 60.11 P1-1:( 10 Août 2013) Travaux de bâtiment — Règles de calcul des installations de plomberie sanitaire et d'eaux pluviales — Partie 1-1 : Réseaux d’alimentation d’eau froide et chaude sanitaire. Indice de classement: P 40-202-1-1, ICS : 91.060.20 ; 91.140.70 ; 91.140.80

[32] MONITORUL OFICIAL AL ROMÂNIEI, PARTEA I, Nr. 1167 bis/6.XII.2022. Normativ privind proiectarea, execuţia şi exploatarea instalaţiilor sanitare aferente clădirilor, indicativ I9-2022 EMITENT: Ministerul Dezvoltarii, Lucrarilor Publice si Administratiei PUBLICAT ÎN: Monitorul Oficial nr. 1167 bis din 6 decembrie 2022.

[33] G.Dubreuil, A. Giraud, Calculs pratiques de plomberie sanitaire Eau froide, eau chaude, évacuations. Les éditions parisiennes (EDIPA), Editors, 2008. EAN13 : 9782862430904, ISBN13 : 978-2-86243-090-4.

# 9. LIST OF TABLES

## 10. LIST OF FIGURES.