Abdelhafid University Center Bousouf - Mila

2024-2025 Semester 1

Water distribution and collection:

HAS PART I: DRINKING WATER SUPPLY

– Lesson 2–

Chapter 02 : *Modeling and calibration of models in AEP systems.*

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Institute	**Department**	**Year**	**Speciality**
Science and Technology	GC and hydraulics	2nd year master's degree	Urban hydraulics

Course Objectives 2

- Understand the value of modeling in the management of drinking water networks.
- Know how to develop a hydraulic model from real data (geometry, consumption, pressures).
- Learn how to calibrate a model by comparing simulation results to field measurements.
- Use the model to analyze network operation and test operating scenarios.
- Identify the limitations of modeling and precautions for interpreting the results.

Introduction

Modeling is the schematic representation of an often complex reality. The general objective of modeling AEP systems is to understand or clarify the effects of a predictable, unobservable phenomenon.

Network operation modeling seeks to describe the hydraulic behavior of the various network devices. The aim is to reproduce what actually happens in the network using a hydraulic model.

The specific objectives of a modeling can be multiple:

- Detail certain network functions (speed, pressure)
- Evaluate storage and pumping capacities , etc.
- Simulate sensitive pipeline rupture scenarios or network reinforcement to examine its ability to meet new demand.
- Know the status of an existing network
- Know the quality of the water

II.1 Different types of models in AEP

There are several types of models:

II.2.1 Model for network dimensioning

The model allows for verification of the satisfaction of subscribers' requirements in terms of pressure and flow rate for a given network configuration. The purpose is to size the pipes and hydraulic devices. The condition of the pipes and the demand are assumed to be known.

The level of detail is important, all the pipes are represented.

II.1.2 Model for the analysis of hydraulic operation and diagnosis:

In this case, the model seeks to describe the operation of an existing network, by determining the state of the pipes through the measurement of the roughness of the pipes and the demand of the subscribers. For a network, data related to the topology of the network, the types of pipes, the typology of consumers, as well as measurements of pressure and flow rates at points of the network are assumed to be known.

Calibrating the model makes it possible to determine certain unknown parameters: roughness, consumption in order to get as close as possible to the actual operation of the network.

II.1.3 Model for network management

In this case, the model will be used to describe the behavior of supply sources, storage areas and pumping stations.

The purpose of this type of model is to optimize the use of water sources and minimize network operating costs by regulating water pumping and storage throughout the day. This model only considers large-diameter pipes used for water transport and distribution.

I1.1.4 Model for water quality measurement

In this case, the model seeks to describe the residence times (stagnation) of water in the network. Indeed, long residence times alter the quality of the water in the network. The purpose of the model is to measure the evolution of a product, for example chlorine, in the network and to measure its concentrations at specific points in the network.

II.2 Interests of modeling drinking water supply networks

Data modeling is a fundamental step in the design of databases that will be useful for the management of the drinking water network, it allows the real world to be translated in all its complexity, and through data structures.

Its purpose is to abstract reality by emphasizing phenomena of interest and eliminating what does not concern the objective pursued, which allows:

- **From a hydraulic point of view**

To understand the hydraulic functioning of the network over the different current and future horizons, and also to estimate the needs for strengthening and extending the network.

To obtain a view of the network's operation in all conditions at the desired level of precision.

Allows to determine failures and hidden black spots on the network, which would be the basis for establishing management schedules and short and long term reinforcement .

- **From an economic point of view**

On the operational side, it allows the study of critical situations linked to the unavailability of resources, storage or pumping structures or a main pipeline, or to search for the most suitable deposits for operating costs.

- **From a security point of view**

It allows for faster intervention and limits the damage that may be encountered in the event of fire or contamination .

It also allows for classification and identification of areas according to their degree of risk, and for planning intervention methods in advance.

II.3 Software for modeling drinking water supply networks

A multitude of software programs can be used to simulate the operation of the drinking water network and storage, production and regulation structures over a given period, taking into account the distribution of domestic, and possibly industrial and artisanal, consumption during the day.

Currently, there are several software programs for water modeling and management, among these software programs we can mention:

1. **ACQUIS**

AQUIS (B. Coelho & A. Andrade-Campos, 2014) is a tool for modeling and managing water distribution. It is a program that includes not only hydraulic simulation, but also network design and optimization. It integrates calibration, SCADA and GIS modules.

It has the ability to work in real time and online.

AQUIS was developed by the Danish company Sept Technologies, and is based on the technology of two established platforms - LICWATER and WATNET.

2. **Aquaadapt** ,

Which allows energy optimization for the entire network. It integrates a module called: SCADA.

3. ElyxAqua

ElyxAqua is a network mapping management software application dedicated to the water supply and sanitation industries. This solution is based on the modules of the Elyx software suite : Elyx Office, Elyx Web, Elyx Manager and Elyx Mobile.

4.EPANET

Epanet (Environmental Protection Agency EPA – USA) illustrates a typical example for modeling, sizing, balancing and simulation of the operation of AE P networks (mesh and/or branched). See Figure 01.
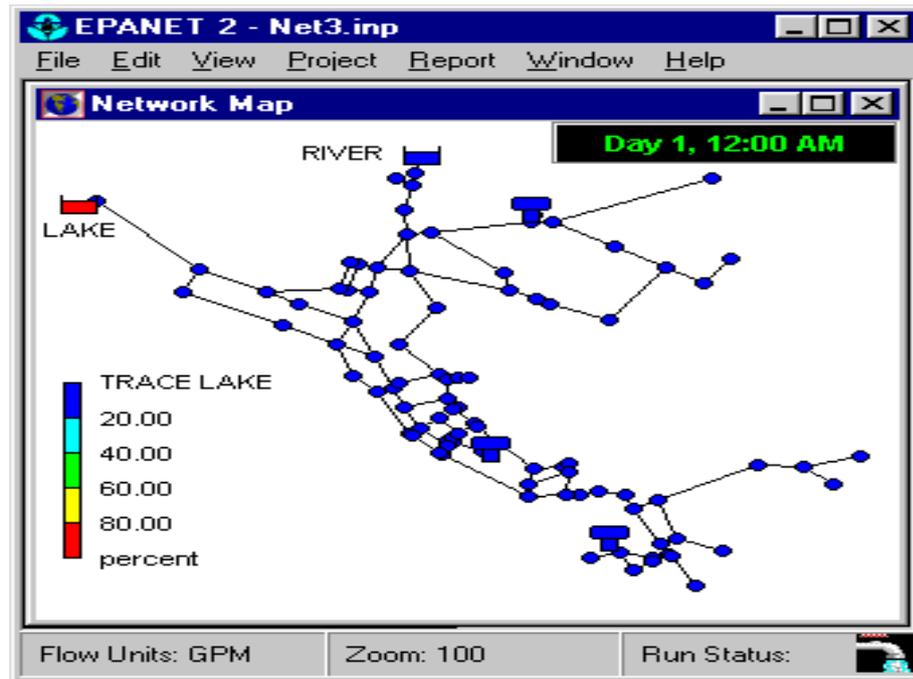
Figure 01. Map of the hydraulic network simulated with EPANET showing the traceability of water coming from the lake.

5. Gate

Porteau is a tool for modeling the behavior of a meshed or branched water supply network under load. It provides decision-making support for the sizing and management of a drinking water distribution or supply network. See Figure 02.

The software's graphical interface is easy to use and allows you to diagram the network being studied using sections for pipes and nodes for intersections. These elements are documented so that all the infrastructure present on the network and all the conditions of use can be represented in order to reflect reality as faithfully as possible.
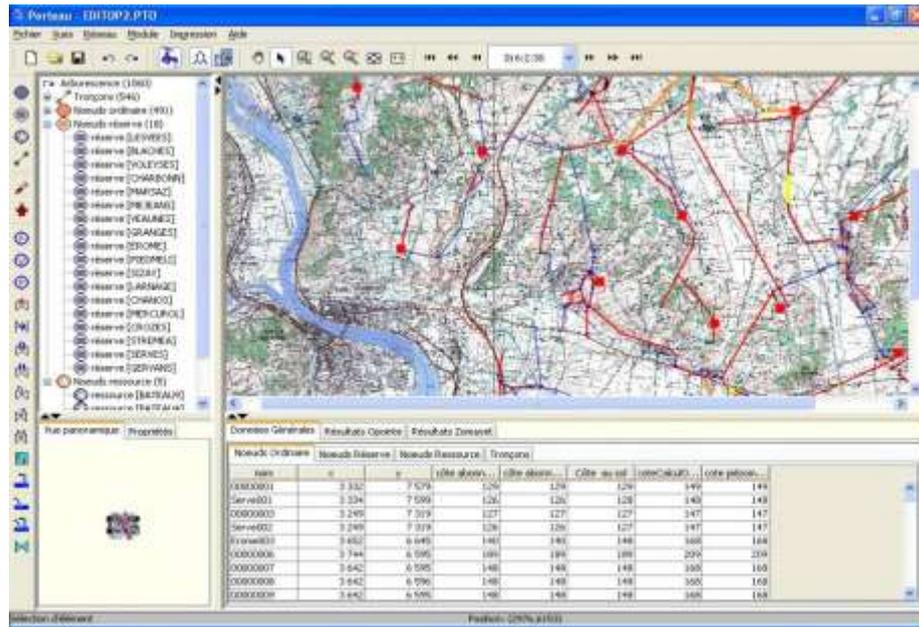
Figure 02. Geographic visualization of a drinking water network under the Porteau interface – Hydraulic and topographic simulation.

6.WaterCAD (Paid Software)

WaterCAD software , which, in my opinion, remains the best software for modeling hydraulic behavior and water quality in distribution networks (AEP and Irrigation). See Figure 0 3.

The software was developed by the American company BENTLEY SYSTEMS (developer of several solutions in the field of water and engineering in general). The price of a WaterCAD license depends on its simulation capacity (depending on the number of pipes that the version can simulate).
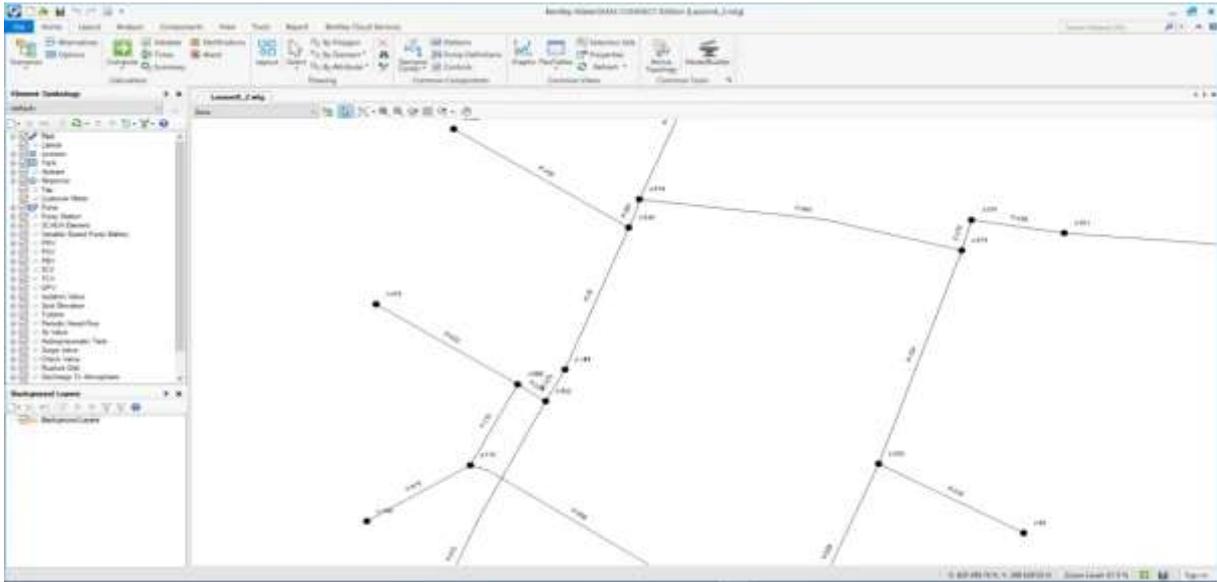
Figure 03. Diagram of a hydraulic network modeled in Bentley Water GEMS CONNECT Edition.

A) - Network modeling on Epanet software

a.1) - The Epanet software : Operation and specificities

Epanet software was born following an initiative of the United States Congress aimed at protecting the country's natural resources.

The EPA (US Environmental Protection Agency) was tasked with developing techniques to better understand water flows and transformations in a drinking water supply network.

Since 1993, the software has been available free of charge to all design offices and leasing companies that wish to use it.

In order to increase the user-friendliness of the software for French-speaking companies, the Générale des Eaux company financed the French version.

Finally, the software has undergone improvements since its creation. The latest version dates back to 2001.

The figure below shows the connections between the different objects forming the network. See Figure 04.
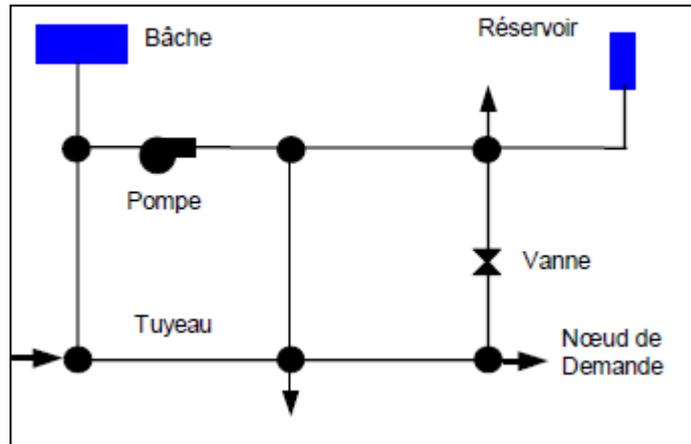
Figure 04. Physical Components of a Water Distribution System.

a.2)- Software potential

Epanet software is a software for simulating the hydraulic and qualitative behavior of water in drinking water networks. A drinking water network on software is defined by pipes (sections on the software), nodes (intersection of two pipes and end of an antenna) but also other organs (reservoirs, pumps, flaps, different types of valves, etc.).

The software allows you to calculate the flow rate through each pipe, the pressure at each node, and also the water level at any time of day and whatever the time of year.

In summary, the software presents all the tools to fulfill the following objectives:

-Regulation of pressures in the network;

- Detection of areas of deficient functioning;

- Network sizing;

-Improvement of water equipment management;

The software also features a quality module that allows for calculating chemical concentrations and water residence times in different parts of the network. It also allows for tracking the origin of the water.
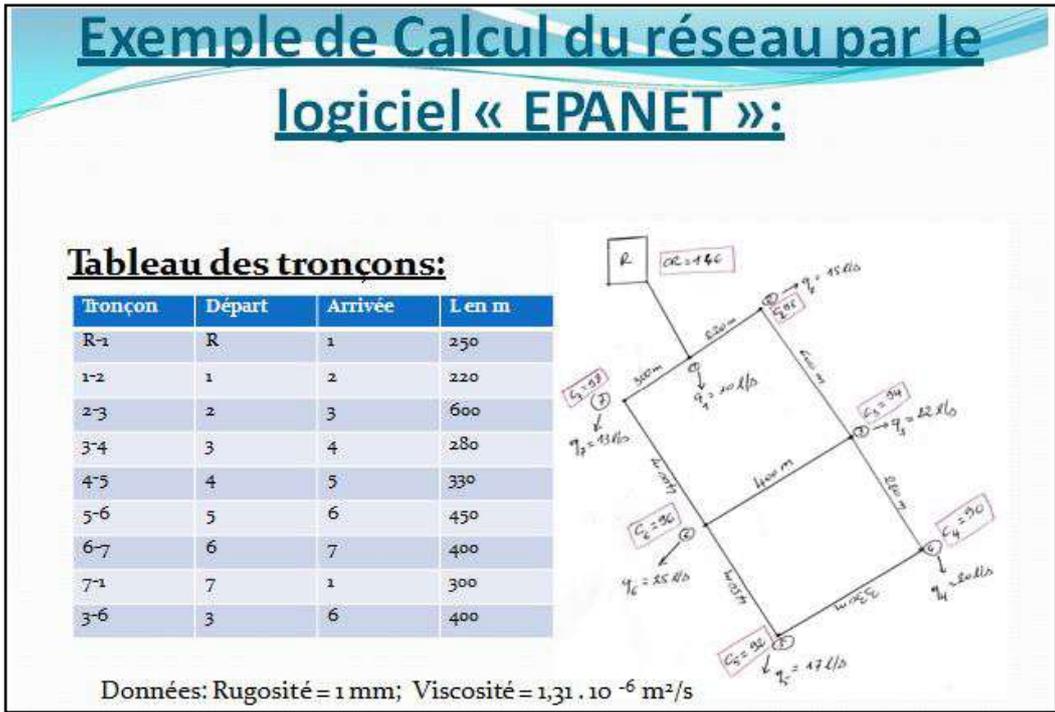
Figure 05. Example of modeling and calculation of a water distribution network with EPANET – Section data and hydraulic diagram.
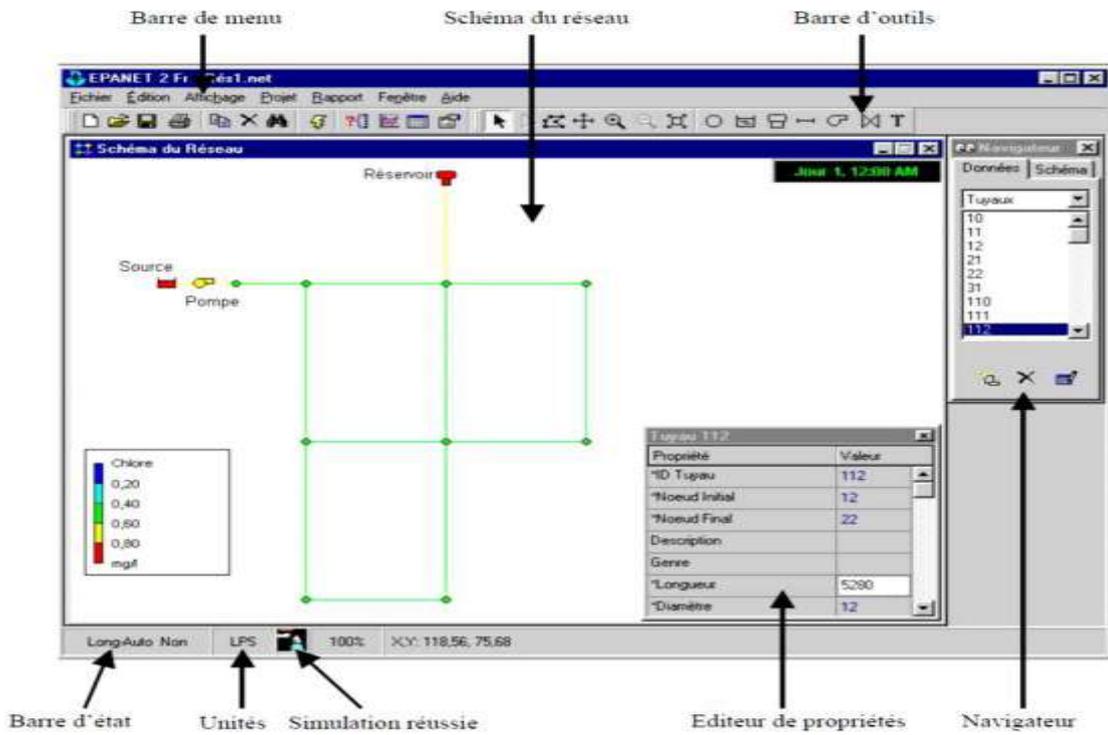

Figure 06. Physical components of a water distribution system.

a.3) - Software specificities

Epanet software has a user-friendly interface, which makes it quite easily accessible.

You can also work on a network entered on Autocad with the Epanet software thanks to a gateway allowing the transfer of files (EPACAD).

EPACAD is a free software that easily converts an AUTOCAD file into an EPANET.

b) - The data necessary for network modeling

The first step in entering the network is to divide the locality into various districts and assign a code to the different nodes (mesh nodes or antenna end nodes) and different sections. This would make it easier to find your way around the network.

b.1) - Characteristics of the sections

- **The linear pipes**

Network construction is facilitated by the fact that it is possible to import a file representing the network and acting as a wallpaper. Then, the length of each section is obtained from the GIS file or the AutoCAD file already operational at this stage of the study.

- **Pipe diameters**

The nominal diameter of cast iron pipes can be considered to be equal to the internal diameter, while for PVC pipes; the nominal diameter is equal to the external diameter. However, the diameter used for the calculation is the internal diameter.

- **The roughness**

The last characteristic to enter to describe a section is the "roughness" parameter.

First, we assign an arbitrary roughness of 0.1mm to cast iron pipes and 0.05mm to PVC pipes.

Roughness reflects the internal condition of the pipe. This parameter, which varies depending on the age, nature of the pipe and the stresses to which the pipes are subjected, is one of the calibration parameters to which a definitive value cannot be assigned at the start of the project.

- **Pressure losses**

The head loss or hydraulic head lost due to friction of water with the pipe walls can be calculated using one of these three formulas:

Hazen -Williams formula .

. Darcy- Weisbach formula .

Chezy -Manning formula .

b.2)- Characteristics of special works

- Downstream pressure stabilizers

On Epanet , downstream stabilizers are considered as sections, so we must specify the upstream and downstream nodes of the stabilizer, as well as the set pressure of the stabilizer.

The set pressure is the pressure that is set so that whatever the upstream pressure, the pressure downstream of the stabilizer cannot exceed the set pressure. The set pressure was acquired by a measurement in the field using a pressure gauge.

- The reservoirs

Different altitudes must be known to define a reservoir: the overflow height, the invert, the minimum, maximum and initial water levels. The reservoir data will be transmitted by the network manager.

b.3) - Characteristics of demand nodes

- Ground dimensions

In order to know the pressure at any node, it is necessary to fill in the box indicating the altitude or ground level of the node.

- Requests to nodes

The second data inherent to a node is the demand or outgoing flow at this node. This data is influential in the hydraulic calculation.

It is expressed in liters per second. The difficulty lies in the fact that on the one hand, it is necessary to identify and locate the subscribers geographically in the municipality and then assign them a consumption and on the other hand, it is a question of distributing them adequately at the level of these nodes. It is therefore necessary to proceed to:

- Identification of subscribers;

- The distribution of these subscribers around the nodes;

B-Model calibration

b.1 Definition of model calibration

Calibrating a model means modifying some of its parameters, such as the initial distribution of consumption, the demand profiles of the different consumer categories, the roughness of the pipes, or even the specific resistances of certain sections, in order to obtain the best possible correlation between the values measured in the field and the values calculated by the software.

Calibration is the most important part of modeling. Its purpose is to adjust the model to the reality on the ground in order to ensure the best representation of the actual operation of the analyzed network.

Perfect knowledge of the network in collaboration with the manager, during the previous stages, is essential for the smooth running of the calibration.

B.2 . The methodology for calibrating drinking water supply network models

The calibration of a model is carried out in four successive stages

a) volume adjustment (consumption, transit, pumping flow rates, etc.);

b) level setting (tanks);

c) pressure setting;

d) quality adjustment (if applicable).

b. 3 The choice of the measurement period

The choice of a measurement period (1 day or more) and a calibration time step (1 hour for example) is made following a multi-criteria analysis justified by the availability and continuity of the measurements, the representativeness of the measurements.

The 24-hour cycle used to carry out the calibration will be chosen in such a way as to optimize the following two criteria:

- day with the most available and usable data;

- day of higher consumption (this day will allow roughness to be adjusted more precisely).

B.4 CALAGE VALIDATION RULES: DETAILS SOUGHT

The calibration of the different measurement points must achieve the accuracies listed below (the most common, due to the precision of the different measuring devices):

- For distribution flow rates: ±5% of the measured flow rate.

- For tank level: ±5% of the measured level.

- For pressures: ±5 mce of the measured pressure.

EXAMPLE :

1. **Counts and flow rates (m^3 / h)**

Reminder: the flow tolerance has been set at 5% in distribution.

Table No. 01. Flow rate adjustment 3 values.

	Average observed flow rate (m ^{3}/h)	Simulated average flow rate (m ^{3}/h)	Average error*	Validation
Q_R1	15.83	15.97	0.9%	Yes
Q_R2	15.11	14.94	1.1%	Yes
Q_R3	2.22	2.20	0.9%	Yes

*The average error corresponds, in absolute value, to (Average observed flow rate – Average simulated flow rate) / Average observed flow rate

The flow rate adjustment is satisfactory in view of the stated criteria.

1. The level (m)

Reminder: the tidal tolerance is set at 5% of the measured level.

Table No. 02. Level 3 calibration values

	Average observed water height (m)	Simulated average water height (m)	Average error*	Validation
Reservoir ….	1.90	1.88	1.00%	Yes

2. Pressures (mce)

Reminder : the pressure tolerance has been set at ±5 mce of the measured pressure.

Table No. 03. Pressure setting 3 values

	Average observed pressure (mce)	Simulated mean pressure (mce)	Average deviation *	Validation
P 15….	39.29	38.85	0.44	Yes
P 25….	58.38	57.28	1.10	Yes
P 35….	78.81	79.25	0.44	Yes

*The average deviation corresponds to (Mean observed pressure – Mean simulated pressure)

a) - Volume adjustment:

Flow calibration is carried out for the flow rates distributed to each of the identified hydraulic sectors. The flow rate at the outlet of a storage facility or distributed to a hydraulic sector is composed of two distinct components:

The average volume distributed by hydraulic sector: **VMD = V1 – V2**

The volume of losses (equated with the volume of leaks): **V4 = V1 – V2 – V3**

a.1) - The consumption flow rate:

To adjust the consumption flow rate over the selected period, it is necessary to develop a modulation curve. This modulation curve corresponds to the ratio: flow rate linked to consumption over average consumption in the sector concerned (basic flow rate, assigned to the nodes in the sector considered, taken from the billing file).

It is this curve that will allow the software to calculate for each time step the variation in consumption (and therefore the variations in flow in the network, speeds, pressures, etc.).

a.2) - The leakage flow rate:

The leakage rate can be considered constant during a simulation between T=0 and T=24h. (In the majority of models, variations in leak flow linked to changes in pressure in the network are ignored).

Consequently, the leak modulation curve will be constant throughout the simulation duration retained (multiplier coefficient C= 1).

a. 3)- Validation of the flow rate setting:

After running the simulation, use the value table for the tracking object (arc in the case of flow calibration, node in the case of pressure, etc.). Copy the data and paste it into a spreadsheet to overlay the data.

b) - Level adjustment:

The tank level is adjusted by:

- Information on the initial level value (at T=0);

- The equivalent diameter of the tank (volume curve if the tank has a particular shape);

- Establishment of controls (filling levels)

When the upstream and downstream flow rates (inlet/outlet) of the tank are set, and the operation linked to the controls is correct, the tank level is automatically set.

c)- Pressure setting:

This part of the calibration aims to match as closely as possible (be careful not to fall into absurdities) the simulation results returned by the modeling software with the pressure recordings made on the network. The calibration is carried out by intervening essentially on the roughness of the pipes, the introduction of singularities at certain points of the network (singular pressure loss possibly not recorded).

c) - Key data for building the model:

The model construction assumptions (immutable unless the initial information is erroneous and therefore needs to be corrected) influencing the pressure results are:

*Altimetry of the network nodes: altimetry from the DTM (digital terrain model), IGN curves (National Geographic Institute) ;

* The diameter of the pipes (from GIS, paper plans or field investigations): **the diameters to be modeled are the internal diameters** (even for PVC!);

* Regulation values at the level of specific organs: stabilizers, flow regulators, pressure reducers;

*The status of the valves on the network: open / closed;

* Operating instructions for storage and transfer facilities (use the active instructions during the measurement campaign).

In the case of pressure recording with a "flat" profile (few pressure variations), to define the roughness in the pipes two strategies can be used:

- By symmetry with another sector for which the pressure amplitudes have made it possible to best calibrate the roughness (at the same installation date, same material and same diameter), the roughness will be transferred from one pipe of a calibrated sector to another;

d)- Other special cases:

For specific cases such as modeling:

- a float valve (valves with variable pressure losses, etc.);

- suppressor, servo systems, etc .;

- fire protection (post by post or using fireflow2 – software available) ...

This will involve checking and proposing the methods available to the various referents….

E)- simulation results

The scenarios studied and the shortcomings identified will be presented and commented on as follows:

- Scenarios concerning current needs will be simulated taking into account the upcoming commissioning of new hydraulic infrastructures;

- Scenarios concerning the future evolution of needs (horizon 2035 or more) will take into account the existence of a possible additional resource;

They will focus on:

- Network in its current state:
- Current average day
- Current peak day
- Peak day on the horizon studies.

Simulations taking into account development projection paths (PDAU, POS, etc.).

Calibration is the process that allows the quantities simulated by the established model to be verified and adjusted to the data from the measurement campaign.

The model therefore becomes an image of the functioning of the network over the duration of the measurement campaign.

Conclusion

Hydraulic modeling is an essential tool for analyzing, simulating, and optimizing the operation of drinking water supply networks. By calibrating models to real-world data (pressures, flow rates, consumption), it is possible to obtain a faithful representation of the network's behavior. This makes it possible to anticipate malfunctions, improve resource management, and facilitate decision-making. Thus, rigorous model calibration is an essential step in ensuring the reliability and performance of hydraulic simulations.

Useful links

- https://youtu.be/aGaMvvlDSms
- https://youtu.be/8mh_seF3iKA
- https://youtu.be/ID4WTZV3XXw
- https://youtu.be/JF94j_OMXsM
- https://youtu.be/TaFN-SZe35M

References

- FG Brière "Distribution and collection of water", Editions de l' Ecole Polytechnique de Montreal , 1994, 365 p.
- F. Valiron , "Lyonnaise des Eaux. Handbook for the Water Supply and Sanitation Manager. Volume I Water in the City Water Supply". Paris, Technique et documentation Lavoisier, 1994.
- François G. Brière, Water distribution and collection, Edition Presses inter Polytechnique
- Dupon A., urban hydraulics, Volumes 1, 2 and 3;
- Bonnin J., aide-mémoire of urban hydraulics applied to small and medium-sized towns.
- Varilon F., water and sanitation operator's guide
- Marc SATIN, Béchir SELMI "Technical guide to sanitation", Le Moniteur edition, Paris 1995.
- François VALIRON "Memento for the manager of drinking water supply and sanitation", Lavoisier TEC & DOC edition, volumes 1, 2 and 3, Paris 1994.
- Mackenzie L. DAVIS, David A. CORNWELL "Introduction to Environmental Engineering" Third Edition, USA 1998.

  Bernard CHOCAT "Encyclopedia of urban hydrology and sanitation" Lavoisier TEC & DOC edition, Paris 1997.