# Epanet and Development

## How to calculate water networks by computer

Santiago Arnalich

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First English Edition
October 2011

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# arnalich
water and habitat

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# 1

# Getting Started

> ➢ *Eyeballing a network is leaving a community's health, well-being and economic development to chance.*

# Some important points before you get started

● This manual is based on a personal view. Things are not absolute. Many decisions during the design process are debatable. Please, keep a critical mind and remember that what I present here is not "the way to design a network", but just one of them.

● Practice is important therefore we recommend the exercise manual *Epanet and Development: A progressive 44 exercise workbook* available at:
www.arnalich.com/en/books.html.

● This manual has been created for use in development projects and therefore some procedures will not be suitable for use in developed countries.

● This manual is limited to the design of a network. Analysis of existing networks needs a more complicated approach and more elaborate techniques.

● There are not many people who work in development full-time for a long period, and as such this is not intended to be a cutting edge manual, but one that you can return to when you need it.

.● Simultaneity cannot be directly used with Epanet because mass balance is not conserved (but don't worry if you don't understand this).

● If you find any errors, please let us know at: publicaciones@arnalich.com

## What to expect from this manual

With practice you will:

1. Be familiar with basic aspects of Epanet.
2. Be able to compile the information you need to get started.
3. Be able to design new networks.
4. Be introduced to techniques of repair, extension and optimization of existing networks.

# New design vs. existing networks

This manual covers the design of new, isolated networks and is the first step to the analysis of existing networks which is more complex. Design may seem more intimidating at first but networks that are already built add the following difficulties:

1.  Problems with **data reliability** in development work are very common. Plans, calculations and up to date information are often missing. In new networks, the data is 100% reliable.

2.  The **location and size of each one of the leaks** are unknown. New networks are tested under pressure when they are half buried so leaks can be detected

3.  The **diameter and roughness of the pipes have been modified** due to scaling and oxide deposits, increasing the flow resistance greatly.

4.  Normally **people do not know how the condition of the network**, which valves are not working or which ones are blocked in intermediate positions.

The process of upgrading an existing network using Epanet is complicated and expensive. It requires field measurements, and frequently, expensive and specialized equipment; due to lack of resources, the calibration is rarely done. Maybe the practical approach is to locate and uncover the most common problems, such as blocked valves and disconnected pipes.

This may be the topic of a future manual.

# Why do water projects?

The answer is pretty obvious: **to improve people's quality of life.**

Disappointed? Maybe you were expecting an answer such as "in order to reduce by 68.34% the prevalence of *Vibrio cholerae* in children under 5 years old" or "in order to get a peak flow of 0.28 m$^3$/s at a height of 37.22 m"…



**Stagnant waters from a leaking tap in Kabul, Afghanistan.**

0.28m$^3$/s may be a very noble objective however it could flood areas that cannot drain water with sufficient speed. The result is detrimental to the community to the point that, as illustrated, even children put their hands on their heads in disbelief and ask themselves what on earth is happening!

In the effort to justify activity, deadlines or loss of funding, sometimes the real objective is missed: quality of life. We must not forget that whilst people's quality of life can be improved substantially, water projects **can end up being harmful for communities therefore** they should not be carried out carelessly or in a hurry.

# Consequences of a poor access to water

The idea is not new. Back in 1875 Joseph Chamberlain, the mayor of Birmingham, stated that the loss of working days, health and lives was costing the city £54,000 per year.

Some organizations have tried to evaluate the consequences of lack of access to water and sanitation. The figures are debatable, but the tendencies are clear. Some of them are shown below:

● **HEALTH** "Water related diseases are the cause of 80% of the deaths and illnesses in developing countries."[1]

● **ECONOMIC** "Benefits from Water and Sanitation programs refund between $3 and $34 per dollar invested."[2]

● **LABOUR** "Time saved in Tanzania meant a 10% increase in crop production."[3]

This last reference, "Everyone's a winner? Economic evaluations of water projects", from WaterAid, is very interesting and can be downloaded from:
www.wateraid.org/documents/plugin_documents/everyonesawinnerindia.pdf

## Health

One of the greatest impacts is on people's health, which is very easy to measure because almost all medical installations keep statistics regardless of how basic they are.

Some statistics to reflect on:

● "The main cause of child mortality is diarrhea"[4].

● "Of the 37 main diseases in developing countries, 21 are water and sanitation related ones"[5].

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[1] *Secretary-General of United Nations Kofi Annan for the World Environment Day, 5th June 2003*
[2] *Hutton G. & Haller L. The Costs and Benefits of Water and Sanitation Improvements at the Global Level (OMS 2004).*
[3] *WaterAid (2004) 'Everyone's a Winner? Economic valuation of water projects' WaterAid, London.*
[4] *World Health Organization and Harvard University, 1996. "Global Burden of Disease."*
[5] *Water and Sanitation for Health Project, sponsored by the US Agency for International Development, 1993.*

● According to the WHO, **80% of illness in the world are related to access to water and sanitation** [1].

● "There are 200 million people in the world suffering from Schistosomiasis (Bilharzia), of which 20 million suffer severe consequences. This disease can be decreased 77% with well designed water and sanitation systems" [2].

● According to the OMS, **there is no other measure with a greater impact on national development and public health as those related to water and sanitation** [3].

---

[1] *"Battling Waterborne Ills in a Sea of 950 Million", The Washington Post, 17 February 1997.*
[2] *Esrey et al 1991. "Effects of improved water supply and sanitation on ascariasis, diarrhea, dracunculiasis, hookworm infection, schistosomiasis, and trachoma." WHO 69(5), pp. 609-621.*
[3] *OMS, factsheet 112 Water and sanitation.*

# From infrastructure to service

The concrete objective of any water project is to provide a service using certain infrastructures. But too often, infrastructures end up getting all the attention.

The challenge is to change from a mindset **of installing infrastructure to one of providing services.**

If high chlorine concentrations, long distances to water points or excessive soap requirements due to water hardness make people prefer consuming polluted stagnant water, the system has failed to improve people's health, no matter how well its hydraulics work.



From infraestructure...

....to service.

## Criteria for success

We can summarize criteria for a successful system into these three points:

1. The system is sustainable technically and institutionally over time.
2. It guarantees equal access for everybody.
3. It's adaptable and can be altered.

The following three principles are the foundation we have to work on in order to maintain the probability of success. Once your design is done, check it against them:

**A.** <u>Technically and institutionally sustainable</u> over time:

- Operational costs…are they related to the ability to pay?
- Spare parts…are they available locally? Are they well-known?

**B.** Guarantees <u>equal access for everybody:</u>

- Connection and maintenance costs, etc…are they affordable for all families?
- Is there anybody discriminated in the access (minorities, the disabled, the sick, the elderly…)?
- Does the system tolerate illegal connections?[1]

**C.** It is <u>adaptable and can be changed:</u>

- The exploitation of the network…is it adaptable to future needs?
- The design…is it easy to extend?

These are some of the questions that our water system designs should be able to answer, and will be covered in different chapters.

---

[1] *An illegal connection is the last recourse for the poorest. One of the most criticized aspects in privatization politics is that in order to manage more efficient networks, they disconnect people that cannot afford the tariffs, leaving the most vulnerable without access to the most basic right.*

# When should I build a network?

Networks are expensive and need considerable organizational capacity. The basic infrastructure needs very expensive components and once they are neglected it is very difficult to repair them back into shape. However, under certain common conditions, there are no alternatives that will supply such a great amount of water at such a low cost. The network is then the best option. These conditions are the following:

1.  **The population is concentrated** or has the potential to increase in existing occupied areas. Less piping is needed to cover more people, making it more cost-effective.

2.  **The population has social cohesion** with institutions capable of dealing with management of the network and proper structure which guarantees responsibility will be taken. Nomadic populations are not good candidates as frequently, there is no ownership of the systems which ends up being a "source of income" to be exploited. On the other hand, refugee camps, which have strong international support and designated people responsible for the water systems are, generally, ideal candidates for installing a network.

3.  **The water source can be exploited in a sustainable way.** The creation of a network encourages water consumption because it reduces one of the limiting factors for consumption which is water transport. The water source should be able to handle this increase in demand. An area served by a spring or an aquifer which shows clear signs of overexploitation is a bad candidate for a network.

4.  **It should not create environmental problems,** especially stagnant water. The water that is obtained and transported by a network has to go somewhere, therefore requires drainage. If the land is very flat, soil impermeable or there is no sewage system, the network will create more problems than solutions.

5.  **Topography**. Without excluding them as an option, networks on flat very flat and horizontal surfaces are more complicated and costly, more prone to Stagnant water problems, and continual pumping through lack of adequately sized elevated tanks. There are also problems with pipes which suffer from water hammer due to air that cannot escape from high points. A network should be considered as the first option in areas where gravity systems can be installed over relatively short distances, where there is a high water source or there is a good site to build a tank.

# Why should we calculate networks?

Although humanity had to wait until the year 1936 for a mathematic tool to be developed that could calculate grid networks[1], and that my 2011 computer needs a few tenths of a second to calculate a simplified network of the Lugufu refugee camp, it is widely believed that networks will work almost by themselves or that they can be designed by eye with a couple of obsolete guidelines.

The proliferation of people who assure you they can calculate networks in their heads is really exasperating. It is not surprising that many of those networks never work after endless rotations of "experts" and years of active involvement from donors.

**Eyeballing a network is leaving a community's health, well-being and economic development to chance.** Let me insist here: if you guess a network, it will be chance that determines the health, well being and economic development of the community. Here you have more reasons to calculate networks:

1. Networks that aren't designed properly devalue the work and effort of communities that are asked to collaborate.

2. They are dangerous. The emptying and filling of pipes due to the lack of pressure sucks pathogens into the interior of the pipes, facilitating disease proliferation.

3. They are fragile. Depressurized networks get full of air. When they are filled by water, the air needs to be evacuated. This bleeding has to be extremely careful in order to avoid water hammer which destroys pipes and creates leaks. Some studies in developing countries where there are frequent water cuts show that pipes that are constantly filled and emptied get broken 10 times more than should be expected[2].

4. They are rarely extendable. Due to lack of clear objectives in the design and improvisations it is difficult to expand networks as they are built with no criteria.

5. They are uneconomic. They do not use the available resources rationally, either because they are oversized or because they are expensive to operate. For example, a common measure to "solve" networks which have points

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[1] Cross, Hardy. *Analysis of flow in networks of conduits or conductors.* University of Illinois Bulletin No. 286. November 1936.
[2] Lambert, A., Myers, S. and Trow, S. (1998) *Managing Water Leakage: Economic and technical issues.* Financial Times Energy.

lacking in pressure is to further elevate the tank from which they are fed. This results in enormously increased energy consumption due to thousands of tons of water being elevated for the sake of a few points.

# Adapting to the context

There are many network manuals, and there is no need to make any more. So then, why another manual? **Because international aid projects are not like projects in developed countries.**

Let's look at two examples:

Networks in developed countries are designed with three objectives in mind. The first objective is that the hydraulics work meaning that they are capable of meeting the water demand. Secondly, that the water delivered to the user is of a very high quality. And thirdly, that it is resilient to breakdowns, electrical failure, etc. This last objective requires considerable investment including spare equipment and lots of additional pipes, among other expenses. When other needs such as vaccination, education or lack of work are threatening a population, does it really make sense to build elaborate electrical failure-proof networks? If you are still not sure, consider the consequences of an interruption in water supply during a power cut and compare that with the consequences of not having vaccinated the children against polio.

Another interesting issue is the demand for fire protection meaning the amount of discharge and storage required to fight a fire. In developed countries the network allows a discharge much larger than citizen's consumption and therefore the pipes and tanks that are installed are much bigger than the ones required to cover normal demand. Many poor countries have adopted some Western regulations but, does it make sense to over-engineer a network to provide a discharge of 32 l/s at a certain point and have tanks of 230 m$^3$ when the resources for fire protection are limited to the buckets that the villagers have? Would it not be more sensible to use, let's say 100,000 extra euro to subsidize the creation of 1,000 micro-companies?

All these circumstances make decisions very difficult and delicate. For these decisions, the rigor of Western manuals does not help.

# Introduction to network design

A network is designed by making calculations that guarantees it is going to work correctly. There are four main functioning parameters for development projects:

- **Pressure**, which will ensure that the beneficiaries will receive water at every point considered.

- **Velocity** in the pipe, which determines if the proposed network is too big and expensive to build (low velocities) or too small and too expensive to operate (high velocities).

- **Age,** which is the time water spends in the network meaning the quality deteriorates as the residence time increases.

- **Chlorine concentration,** which will ensure that the water is drinkable, and will determine whether taste causes water users to reject it or not.

There are infinite solutions to supply water under different given circumstances, and many of them are viable and reasonable according to the criteria we have just mentioned. Consider, for example, the two ways of connecting water points, to the tank:
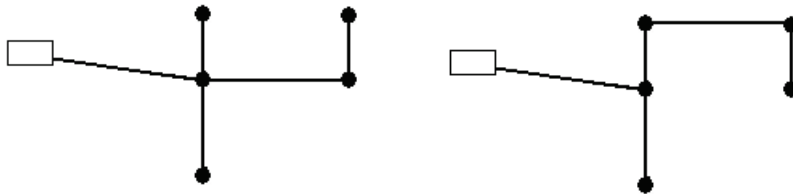


In order to choose one of them, we need to find another parameter, usually economic. Basically, it is a matter of finding the cheapest way not only for the construction of the network but also its operation costs. The method of comparing cost recovery of the initial investment against the operation of the network will be covered in chapter 7.

However, the economic criteria are not the only ones. There are other concerns that result from the overall shape of the network, one of the most important is the branched vs. grid networks.

In a **branched** design, pipes get branched off in a similar way to tree branches. Water can only get to each point through a certain route therefore there are two drawbacks, lack of reliability and quality problems due to the stagnation of water within the network. In order to solve them, networks are built with a grid layout (or a honeycomb) which although are more reliable and hygienic are also more expensive. In the image below, you can see the transformation of a branched network into a grid through the installation of pipe *t* to close the loop.
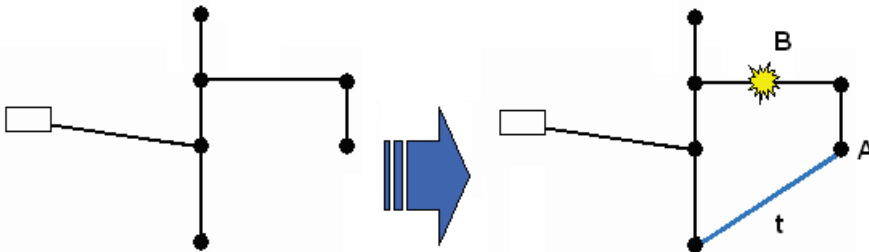


By adding pipe *t*, the water point A can receive water from both the north and from the south, so that if B breaks, the water supply in A will not be interrupted. Furthermore, water is not blocked anywhere. If not consumed in A it will circulate to somewhere else.

Returning to the issue of trying to find the cheapest network, it is clear that we always would end up building the branched design however, the tendency is to build grids!
In a development context, there are some other reasons for grids:

- **Robustness**, especially when the material is expensive, not easily available, and the inexperienced beneficiaries are dealing for the first time with a new water network and new staff.

- **Adaptability**, branched networks do not allow big modifications or extensions; it is more difficult to adapt them to keep up with the increase of population.

- **Scarcity and reliability of data** recommends grids because the branched designs need more precise knowledge of water consumption which is rarely available or reliable.

The design process has two well defined phases:

1. **Net tracing.** The plan of the water network is drawn on a map. There are practical limitations to the possible traces therefore normally pipes and other

elements are placed on streets, along roads, etc. so they are more accessible and to avoid problems of property.

2. **Dimensioning the elements**, this is determining its size and properties. Pipe 32 will be 200 mm, Valve 3 will be a gate valve, the tank on the hill will be 40 $m^3$…In order to do this, it is worked out for the worst of the foreseeable cases, with the hypothesis that if it works in the most adverse case, it will work with no problem in the rest of the cases. In other words, if the pipe is 200 mm it can transport a discharge of 30 l/s of water, it will also be able to discharge 5 l/s.

Here is where Epanet comes in. By using this program you will be able to determine which designs will behave adequately in the worst cases without needing very complicated calculations. Your task will be reduced to finding out which is the cheapest and most sensible among them.

# 2

# Epanet and network models

➢     *Computers are useless. They can only give you answers.*

*(Pablo Picasso)*

# Introduction

A model is a construction that allows you to reproduce the behavior of a network in order to carry out tests and find solutions. In the case of Epanet, such construction is not a mock-up, but a mathematical representation of the relationships among its components. It is practical because it allows you run trials on "what would happen if…" saving lots of time, frustrations and money.

Other important advantages are:

- It prevents beneficiaries from having to cope with our trial and error tests.

- It avoids social conflicts and getting into trouble with authorities.

- It improves the strength of the network because it avoids unnecessary installing and dismantling.

So, what is the reason for so few network models being built? The complexity of their calculations is overwhelming. Fortunately, it can be overcome easily by learning how to use the program which does all the calculations for you and allows you to concentrate on decision-making. Later on, I will explain why Epanet is used as a calculation program.

One of the biggest contributions of Epanet to development is making it possible for people with little knowledge of fluid mechanics to make decisions regarding any given network. At first, this may not seem very attractive, however, it is often difficult to find people in development work who are capable of making network calculations. The networks end up being taken on by people qualified in unrelated areas and locally, by people who have never had access to a solid technical training. Often, local people who have the technical skills to make such calculations don't have the motivation to live in remote places. They prioritize the education of their children, more challenging jobs, better living conditions, etc and in any case, they aren't available in sufficient numbers.

The result is that interventions are undertaken anyway without a solid base and with questionable reasoning ending up with fairly bad results. In cases where networks are already built in populations with little resources, cannibalism starts. Parts of the network are dismantled in order to install them again in some other parts based on impulses and hunches with little basis.

In my opinion, a more pragmatic approach should take priority. Often Development Agencies believe that NGO's will have the ability to calculate networks. NGO's then assume that such ability can be found locally, which is not the case, especially in the bush. The result is that nobody has the capacity and the network goes undesigned…do you not think it would be more appropriate to supply people who are directly in charge of the networks with the necessary tools to do so?

That is the main objective of this manual.

# Introducing Epanet

Epanet is an easy calculation program distributed by the U.S. Environmental Protection Agency (EPA), which has a very visual interface and intuitive operation. It can be downloaded for free from the US Environmental Protection Agency website. As you can see in the image below, it is not that intimidating:
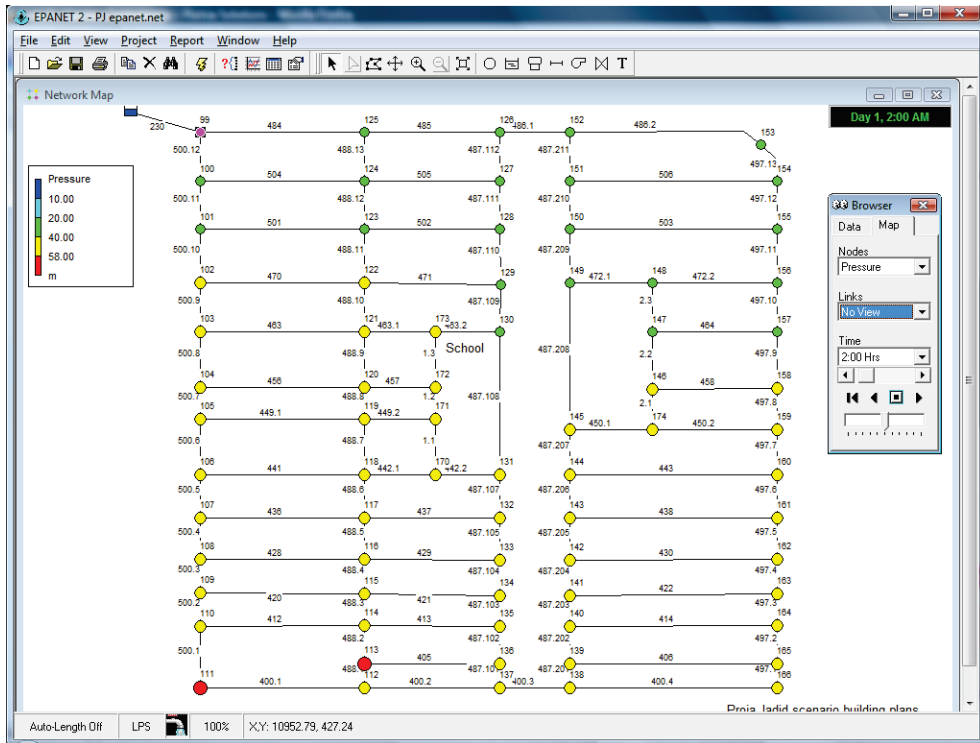


In fact, it is very easy to use, which has contributed to its popularity. I have learnt from experience that people without a lot of knowledge of Epanet can learn its basic aspects in about 8 hours and can learn how to use it in about 30 hours.

# Some Practical Information

## Downloads

You can download the program at the following URL:

- USEPA (English): U.S Environmental Protection Agency
  www.epa.gov/nrmrl/wswrd/epanet.html

You can also download the Epanet Users Manual at the URLs below:

- USEPA (English): U.S Environmental Protection Agency
  www.epa.gov/nrmrl/wswrd/epanet.html

## Other languages

To complete the International Aid languages, the program and user manual also are available in Spanish, French and in Portuguese at www.epanet.es.

## Exercises

To our knowledge and at the time of writing there is only one manual with exercises which we also prepared, *Epanet and Development: A progressive 44 exercise workbook* available at: www.arnalich.com/en/books.html:

## Mailing lists

Epanet and Development, a discussion group to promote the use of Epanet in development contexts:

 www.epanet.org

There is a well established distribution list for Epanet users of a very high level, unfortunately it is not very prone to answer novice questions:

www.lsoft.com/scripts/wl.exe?SL1=EPANET-USERS&H=LISTSERV.UOGUELPH.CA

### Add-ons

Because of the limitations imposed by the courts, it is unlikely that new applications will be added to this program. This fact has not stopped the creation of new add-ons that compensate for some of its weaknesses or deficiencies. One of the best web pages for these applications is www.zonums.com/sp/home.html from Armando Barreto.

AutoCAD importing Add-on:  www.epacad.com/caracteristicas-en.php

## Developments on the program

The development of Epanet has been halted by the courts because its commercial competitor (who curiously uses its calculation base) claimed unfair competition by a public organization. The outcome will determine future versions. You'll see that in some aspects the program seems frozen in time (no undo button, integration with AutoCAD, etc).

## Help files disappeared from Vista and later

The Help files are not visible in Windows Vista and above systems because the help program *winhlp32.exe* that came with them was deprecated. This may be solved in the future, meanwhile to access the help files, you can try to download the winhlp32.exe program from the Microsoft website or install (at your own risk) the update for your system from this download:  www.arnalich.com/dwnl/ayudaVista.zip

# What Epanet can and cannot do

Good news! Epanet can do most of the calculations you may need for your project, and those that Epanet cannot do are actually pretty easy to do on a piece of paper. You will use Epanet mainly for:

- Determining what pipes with which diameters should be used.
- Determining what improvements and /or extensions the network needs.
- Determining where to install the tanks, valves and pumps.
- Studying chlorine's behavior and the necessity to establish secondary chlorination points.

Although you can also use Epanet to make the following calculations, in my opinion, it is safer and much quicker and less prone to error to make them by hand:

- Dimensioning tanks.
- Pump selection for simple pumping systems (it cannot calculate complicated ones).
- Estimation of energy consumption.
- Simulation of the behavior of different elements, such as pressure reducing valves or pressure sustaining valves. Even though these valves are quite useful, they are difficult to find in many contexts.

Epanet's benefits are described in detail in the Epanet Users Manual.

## What Epanet CANNOT do

Epanet assumes the quasi-equilibrium condition, that is, it assumes there are no abrupt changes in the network. This is true up to a certain point. Long pipes (many kilometers long), are very resistant to change, and beneficiaries do not behave like a sardine shoal, opening and closing taps in unison. However, it leaves out some real and quick phenomena such as pipe bursting, water hammer (which is caused by a mass of water which weighs several tones and is stopped in just a few seconds after closing a valve), sudden shutting of non-return valves, starting a pump or stopping it, etc.

Some of the things Epanet CANNOT do:

1.  Calculate water hammer.

2. Simulate pipe bursting.
3. Model the real behavior of non-return valves.
4. Evaluate the consequences of the presence of air inside the network.

To sum up, it does not allow you to model abrupt changes that do happen in real life and some of which can be destructive.

# Epanet´s main objects

Epanet recognizes 6 types of objects that are found in networks and it is vital to know them as the network is modeled on them.

They are shown and explained in the following paragraphs:



○ **Junctions**. A junction is a point at a certain height, where water can leave the network. This outlet is created by assigning it a demand. When a negative demand is assigned, it is automatically turned into an inlet. A borehole can also be shown as a junction where the height represents the water level inside. In junctions, demand is known and pressure is unknown.

**Reservoirs**. The reservoir works as a drain or as a water source. It is a good idea to use one when working with Epanet, to avoid error warnings. The volume remains constant regardless of water input or output because of its huge size in comparison to the system. In order to picture what they could be like, think of rivers, lakes, aquifers…

**Tanks** have a limited capacity to store water and the water level increases or decreases as they fill or empty.

**Pipes** convey the water from one part of the system to another. Epanet assumes that pipes are always full. Furthermore, it assumes that by using their properties they are capable of being opened or closed, and limiting the flow to one direction therefore it is not necessary to add check-valves to the model. As water travels through pipes, part of its energy is dissipated by friction.

**Pumps**. If there is one thing we should be scared of when working with Epanet, it's the pumps. It is wise to avoid them as much as possible (by creating equivalent gravity-flow systems), as they cause too many unexpected headaches that may end up testing your nerves. Pumps impart energy to the water, in other words, they lift it.

**Valves** as understood by Epanet are elements best avoided in developing contexts due to their high cost and difficulty in obtaining spares. Remember that

non-return valves (to prevent backflow) and shut off valves are already included in the model as a property of the pipe. There are several types of valves:

- Pressure reducing valve (PRV). Limits the pressure to a value.
- Pressure sustaining valve (PSV). Maintains the pressure upstream to a given value.
- Pressure breaker valve (PBV). Forces a pressure loss across the valve.
- Flow control valve (FCV). Limits the flow to a maximum value.
- Throttle control valve (TCV). Simulates a partially closed valve.
- General purpose valve (GPV): the user designs its behavior.

# Avoiding wasting time with Epanet

Epanet is used to save time and effort. Try to avoid:

1.  **Drawing networks too precisely**. When you work with the automatic length option switched off you are drawing a sketch of the network to which you will introduce lengths separately. Epanet does not care if your drawing is accurate or not and will give you the same results for these two networks providing you have given the same length for each pipe:
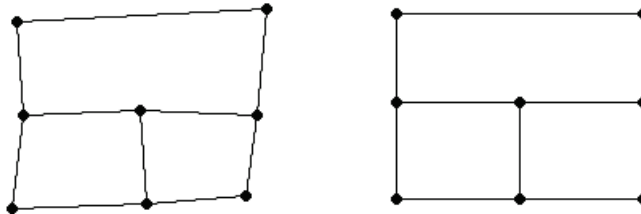


2.  **Labeling pipes and junctions** with logical names. During the process, Epanet assigns one number to each object: pipe 1, junction 63 and so on. To attempt to make these numbers follow certain logic is not a good idea as during the design process you will erase and add lots of pipes. Updating the labels would be a very time-consuming task.

3.  **Destroying the template model**. Once you have introduced all the topographic data, pumps, etc., save it and work on a copy, especially for existing networks as after hours of fruitless work on a model it is difficult and time consuming to revert back to the original.

4.  **Making changes to the model of an existing system without writing them down.** Congratulations! You have managed to get an optimized design, with an adjusted budget, buuut….what did you change on the 267 pipes and 198 junctions?! Write down any change. Write something like this:

    *Pipe 58, changed from 75 to 125mm*
    *Pipe 63 new*
    *Pipe 113 deleted…*

    For example:
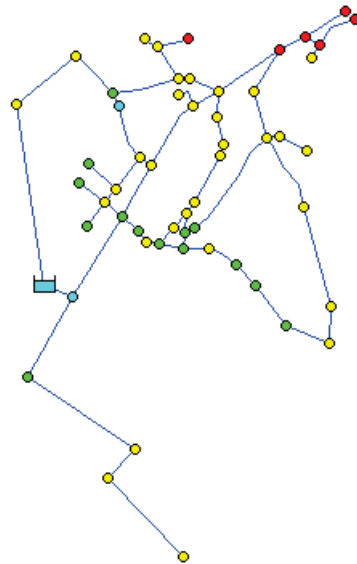
MODIFICATIONS

Pipe 19: 50mm --> 90mm
Pipe 27 removed
Pipe 45 new
Pipe 34, 150mm --> 110mm

**Last modified: 11/04/09**

**You should:**

1. **Use default options** for the lengths, diameters, demands, etc. that are most common in your system. Later on you will see how to do it.

2. **Save versions of the file** as you complete the steps. Epanet does not allow you to undo changes automatically. The possibility of going back to the starting point after trying to model something which has failed will save you a lot of time. Saving the networks as "Network v1.2 stable.net", "Network v1.3 pumping station.net", etc. allows you to go back to the previous point quickly.

3. **Model simultaneously in single-period and extender period** by using the option starting time of the analysis. This will be covered in the section "One way of working" in Chapter 6.

If you feel like you are full of energy at the beginning of your project and you want to be so meticulous that you decide to ignore some of the recommendations above, you should read the section "Overcoming the Post-Assembly Laziness Syndrome" in Chapter 6. After reading it, you may reconsider saving some energy for later on.

# Avoiding False Starts

On September 23, 1999, 125 million dollars burnt away in Mars' atmosphere. After some investigations, it was found that the two teams that collaborated on the Mars Orbiter project had been working in two different unit systems. To avoid similar embarrassments, the first thing you must do when you start the program is to configure Epanet to make sure it will work with the right units.

In order to do this, click on Project and, in the drop-down menu, select Defaults. The rest of these instructions are given in the manual by means of routes. The route for this action would be:  > Project / Defaults.
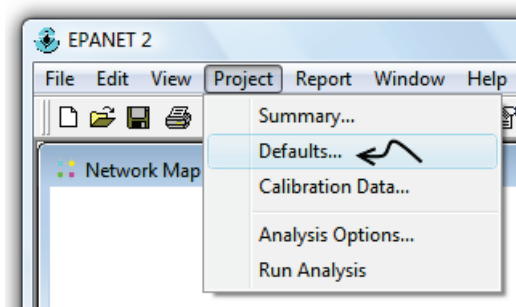


In the menu that appears, click on the Hydraulics tab and make sure that you put LPS. Choosing this option implies that the following units are used:

- Flow Units: liters/second
- Pressure: MWC [1]
- Diameter: millimeters
- Length: meters
- Height: meters
- Dimensions: meters



---
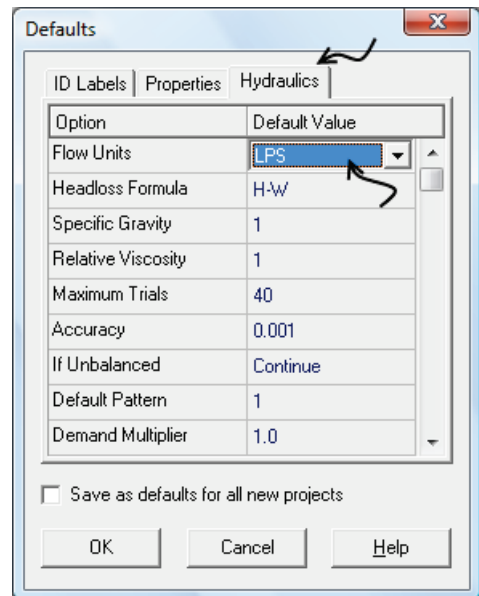
[1] *Meter Water Column, is a convenient way to measure water pressure and relate it to the topography. 10 meters of water column is a bar, another frequently used pressure unit.*

# Basic Tools

The object of this section is to highlight some important tools and how to make the most of them.

➢ **Editing by Regions**. If you repeatedly have to change the pipes roughness from 140 to 120, it is not necessary to do it pipe by pipe:

    **1.** Follow the route: >Edit/ Select Region. You will see that the cursor becomes a cross.

    **2.** Select the objects you want to change. Surround the selection area by clicking around it. To close the selection polygon, click the right button of the Mouse. To start again click Esc.

    **3.** Once it is closed, click >Edit/Group Edit and have a look at the menu that shows up. Now, the only thing you need to do is to construct a sentence by ticking and selecting options in the dialogue box until you come up with a sentence such as "For all pipes within the outlined area with roughness equal to 140 replace roughness 120" like the image below:
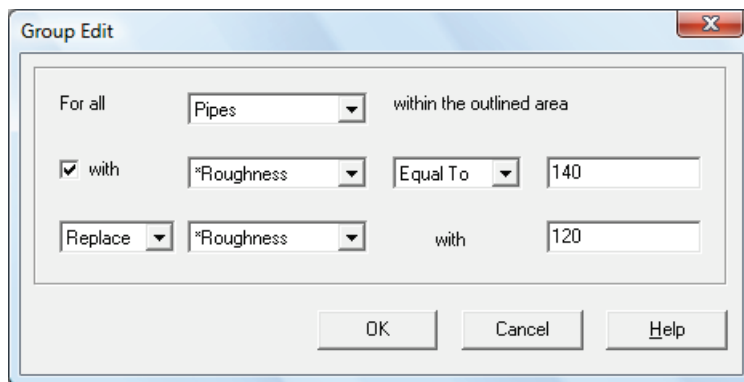


➢ **Make the legend´s scale consistent with design criteria**. If you have decided that pressure must be between 1 and 3 bars (10 to 30 meters), you can modify the legend so that the first color shows negative pressures, the second one shows the bottom limit, the third one an intermediate level, and the fourth one the maximum pressure level. This way you can detect values that are out of order with just a quick look.

In the image bellow, there are zones with negative pressure (dark blue), insufficient pressure (sky-blue) and excessive pressure (red); apologies if you are reading the printed B/W copy.
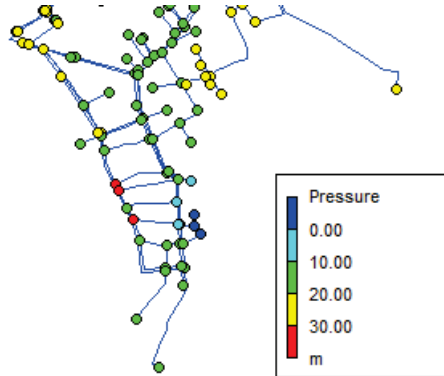


The procedure is:

1.  Click the right button on the legend. If you click it with the right button, it disappears. To display the legend again, go to View in the toolbar, click on >Legends/Junctions (or Legend/Pipe depending on the parameter you are referring to).

2.  Write the values of your choice in the textboxes and click OK.
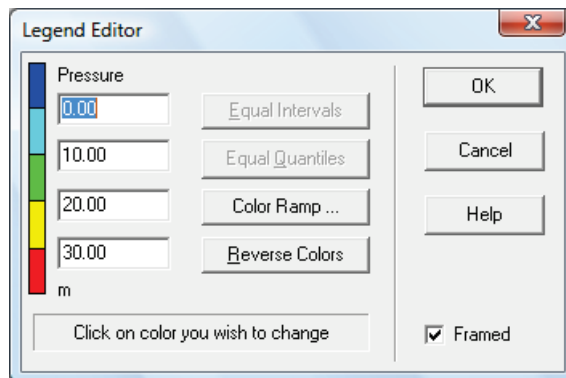


➢ **Use the Help**. Epanet's Help is surprisingly good and contains a lot of useful, quickly accessible information.

An example of Epanet´s Help for setting up a pump´s curve is shown below:

# 3

# Assembling the model

> ➢ *A model can only be as good as the data which it is based on.*

# Introduction

In this chapter we will build a model. We start by drawing, and then add the data. The estimation and allocation of the demand is covered in the next chapter, "loading the model."

Before you start, please take an hour to follow the tutorial which comes with the program to familiarize yourself with the program. By following this tutorial you will be ready to continue with the rest of the manual. It can be found in: >help/tutorial

If you are using Windows Vista or later, read the section 'Lost help files in windows in Windows Vista and later' in chapter 2. The tutorial is also in the manual.
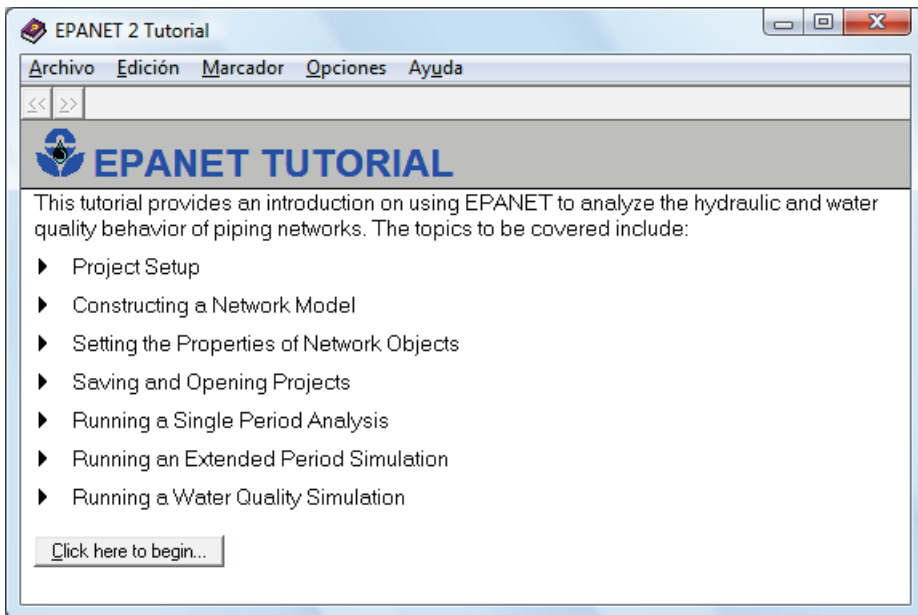


Finally, **make sure that you have configured Epanet´s default values and units**, as seen in the previous chapter.

## Sticking to units and avoiding errors

To work with Epanet you need to do some very simple calculations by hand. These although very simple can prove tricky, like double negatives or finding out the number of days between 2 dates.

If you are disciplined and carry the units, you will be able to detect many of these mistakes before they affect your emotional stability. Take a look, for example, at these two calculations for the same unit conversion:

**A.**  $14 \text{ m}^3/\text{h} = 14 \dfrac{m^3}{h} * \dfrac{m^3}{1000l} * \dfrac{3600s}{1h} = \dfrac{14*3600}{1000} * m^3 * m^3 * \dfrac{1}{h*h} * \dfrac{l}{s}$

$= 50.4 \text{ l*m}^6/ \text{h}^2\text{*s}$

**l*m$^6$/ h$^2$*s?!**  If, like me, you don't know this unit for flow, something was wrong.

**B.**  $14 \text{ m}^3/\text{h} = 14 \dfrac{m^3}{h} * \dfrac{1000l}{m^3} * \dfrac{1h}{3600s} = \dfrac{14*1000}{3600} * \dfrac{m^3}{m^3} * \dfrac{h}{h} * \dfrac{l}{s} = 3.88 \text{ l/s}$

Multiplying by 1h/3600s is the same as multiplying 1/1, because 1 hour and 3600 seconds is the same thing. To make it easier, you can think "there is one hour every 3600 seconds". The result is a unit conversion.

# Adding cartography

There are 2 ways of working with Epanet. In the fist, you would draw a sketch of the net and introducing the data. This requires a topographic survey to determine the distances and elevations. In a word it's laborious.

The second way which is the main focus of this section is easier and more accurate. Basically, you download a map or satellite image and set it up as backdrop in the program. Then you specify the real life dimensions corner to corner and once you are have finished, Epanet will calculate the lengths of the pipes you draw on top.
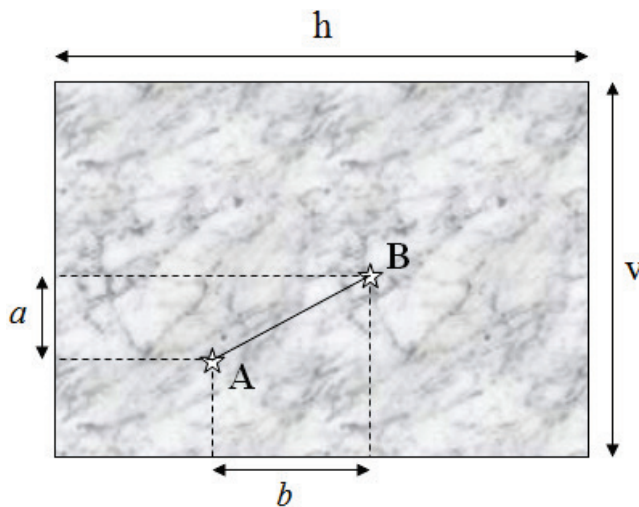


Using h and v, Epanet will determine how many pixels in the image are equivalent to a certain amount of meters in real life. Then, by counting the pixels in the image between A and B (distances a and b) it can calculate the real life distance from A to B.

Next, we will see the method for calculating the horizontal and vertical distances of an image.

## Finding out map dimensions

Maps usually have this distance already measured in the form of coordinates.

    **a)**   Recent maps will use UTM and its margins read something similar to this:
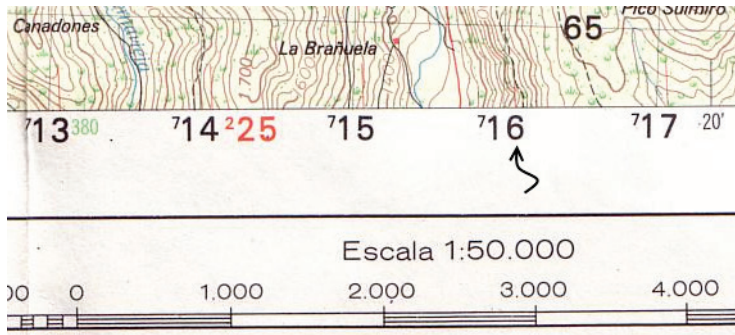
Because the scale is given, it is very easy to deduce the dimensions. If this was not the case, look at the numbers $^713$, $^714$, etc. These represent the horizontal UTM coordinate. In a GPS, $^7$**13** will appear like this:

32S **713**000 8033400

You can ignore the first group, 32S. The second group is the horizontal coordinate measured in meters from a point, and the last one is the vertical. In order to work out the distance between $^713$ and $^714$, you can subtract using this following method: point $^713$ is 713,000 meters from the reference point (which we are not interested in) and $^714$ is 714,000 meters away. Therefore, the distance between them is 714,000 - 713,000 = 1000 m.

Let's look at an example. The framed area of the map on the following page is where we plan to do a project and we need to calculate the dimensions.
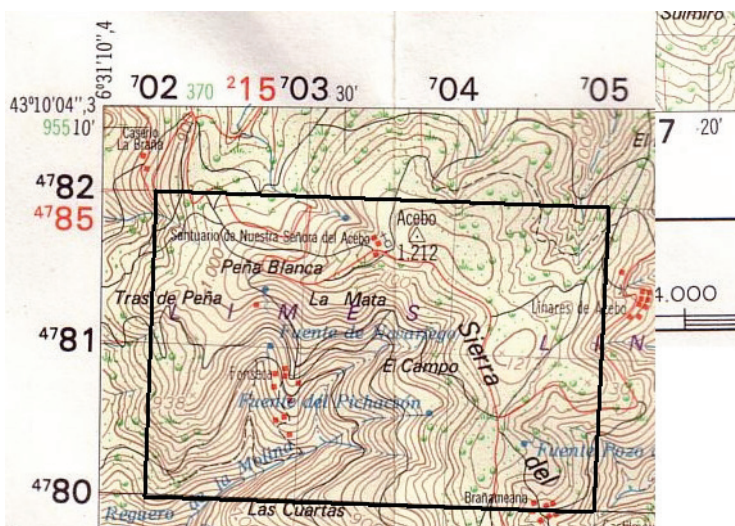
Horizontal dimension 705,000 - 702,000 = 3000 meters

Vertical dimension 4,782,000 - 4,780,000 = 2000 meters

One big limitation of Epanet is that it only accepts border dimensions therefore the map needs to be trimmed to show only the black rectangle of the area to be worked on.

**b)** If the map is given in longitude/latitude degrees, you can use a coordinate converter which can be found on the internet, and proceed the same way, for example: www.csgnetwork.com/gpsdistcalc.html

## Establishing dimensions of images and maps with no references

You need a GPS set for UTM coordinates or use a satellite image software like Google Earth to find out the coordinates. Do not use latitude and longitude, as they are only practical in open areas such as sea or air navigation. As seen before, your UTM coordinates will be something like this: 32 S 486000 8033400. The first coordinate, 486000, is the horizontal in meters, the second one, 8033400, is the vertical also in meters and the group 32 S has no use at this scale.

If for example you need to calibrate the following image simply locate 2 points which are easily identifiable on the map and in reality. In this instance the gas station and mosque are ideal as they are located at each corner of the map and therefore will cover the complete area.

Once the points are chosen go and take their UTM coordinates. The subtraction between the two coordinates is the dimension of your future image:

| | |
|---|---|
| Gas station (upper right corner) | 32 S  486000 8033400 |
| Mosque (lower left corner) | 32 S  484000 8032000 |

--------------------------------

2000      1400 meters

Remember, it is important when using Epanet that the points are in the corners of the rectangle as the image will be cut to coincide with these points.
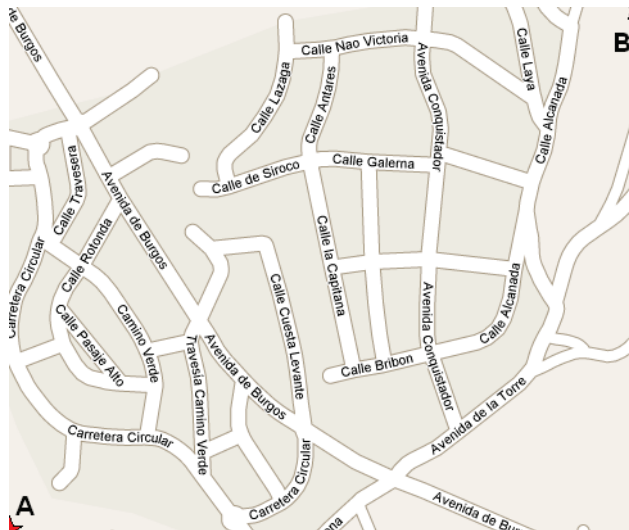


In order to load your image to Epanet go to View/Backdrop /Load and search until you find it. Epanet works only with .bmp and some less common format. To change the image to .bmp use the option 'Save as' (as in all image programs, including Paint). Once you have the backdrop image, set its dimensions. Click View/ Dimensions and fill in the dimension dialog box like this:
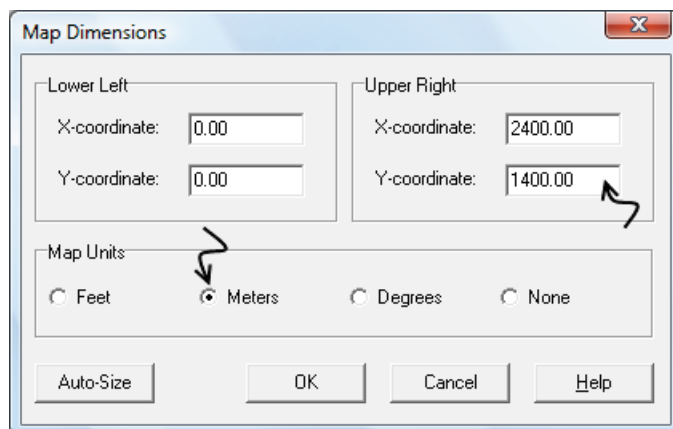
Alternatively, you can insert the whole coordinates (i.e. 486000 for X coordinate) and let Epanet take care of the subtraction. Coordinates will appear on the lower right corner of the program when you move the pointer.
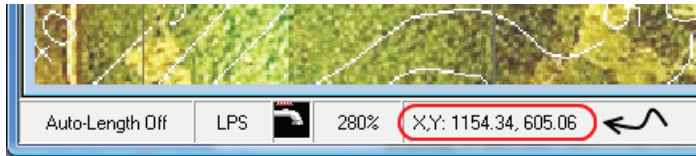


To confirm that you have entered it correctly, place the pointer on the upper right corner of the image. Allowing for a few meters it should coincide with its dimensions.

## Some practical matters

a) You already have your image referenced and ready for you to draw the network…oops! You cannot see anything there! This happens very often when working with images of vegetation. There is an easy solution. You can edit the initial image (for example backdrop.bmp) in order to increase the brightness and diminish the contrast then save under a new name (for example backdropclear.bmp). Providing you do not alter the dimensions or cut the new image it will remain referenced. The original (left) can be used for detail and the modified image (right) for drawing loading them alternatively.
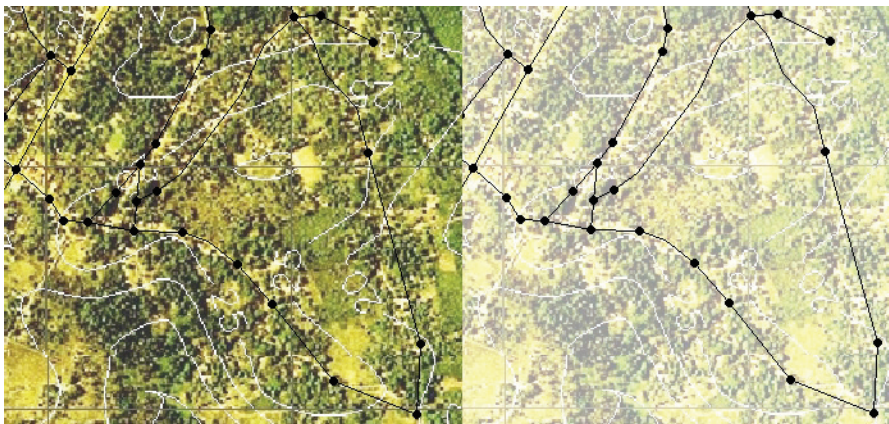


b) Because the format you need to use is generally .bmp, the images will have a large file size. Use your preferred image size bearing in mind that the larger the size, the slower the operation. Personally, I think 2 or 3 Mb images (or even 10 Mb depending on the area to be covered), are a fair compromise between detail and agility.

**c)** In order to use this process trouble free do not use distorted images. Use images in which vertical and horizontal scales are the same.

# Drawing the network

## Over a calibrated backdrop

When you have loaded a backdrop and set its dimensions you can draw directly on top of it. Check frequently that the auto-length mode is activated when you draw. It has an insistent tendency to become inactivated. In order to activate it, click the right button on Auto-length Off:



It is inevitable however that at some stage you will find yourself drawing with the mode inactivated. To detect recently added pipes where auto-length was not used, check with the default pipe length you have, normally 1000m. You find this value in >Project/defaults, in the properties tab. Then, make a 'query' with the icon:



Once you have filled in the fields "find links with", "length", "equal to" and the value, click submit. The items that meet the conditions will appear in red as shown in the image. The arrows have been added in order to highlight the links, but they will not be shown in Epanet. It would be very unlikely that the pipe you have drawn on auto-length is exactly 1000m therefore you can conclude that these pipes have not received the real value and they are inheriting the value by default.
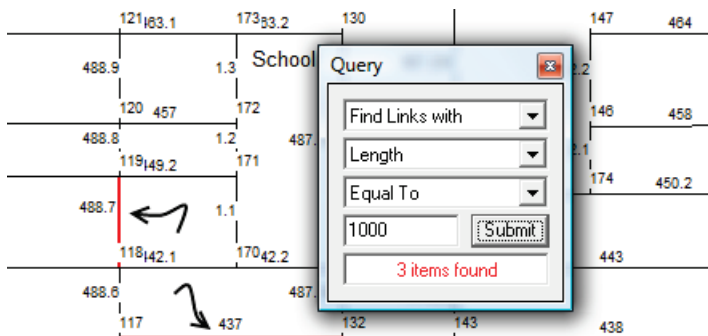
An important point to remember when calculating distances is that Epanet will not take into account the altitude of junctions but treats it as a flat surface. In the image below Epanet would calculate the length of the pipes A, B and C as 500 m, although more pipe would be needed to reach the point 100 m higher than the horizontal. The overall pipe requirement will not change dramatically but remember to order an additional 10% (see Chapter 7). This way, you will not find yourself needing 25 extra meters and having to wait 6 months for the next order to arrive.
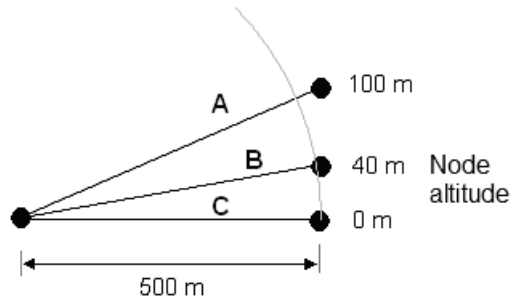


## With a topographic survey

Unless your network is located in a very flat area, you will need to measure the relative height of the junctions. Even when you have cartography, it is convenient to predict which high points in the pipeline will need air released and which low points will need sediment removed. A topographic survey looks like this:



| Distance | 60 | 47,5 | 93 | 74,5 | 80 | |
|---|---|---|---|---|---|---|
| Chainage | 60 | 107,5 | 210,5 | 285 | 365 | |
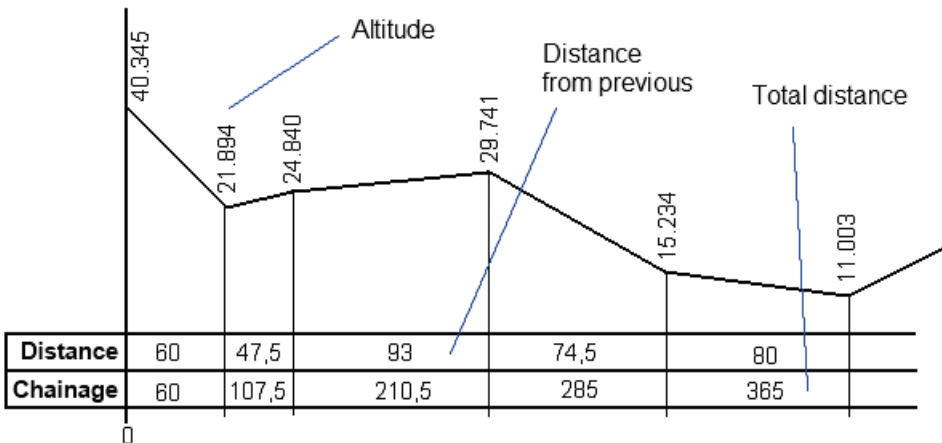
It basically shows the height of a point and the length of the pipe between two points. For example, from the first point to the last one, there would be a pipe of 365m (365 - 0) and the height difference is 29.342 meters (40.345 -11.003m).

Some people suggest (I did myself at the beginning of this book) that you can save a lot of time by introducing the most common length of the pipe by default in repetitive networks (remember: >Project/Defaults).
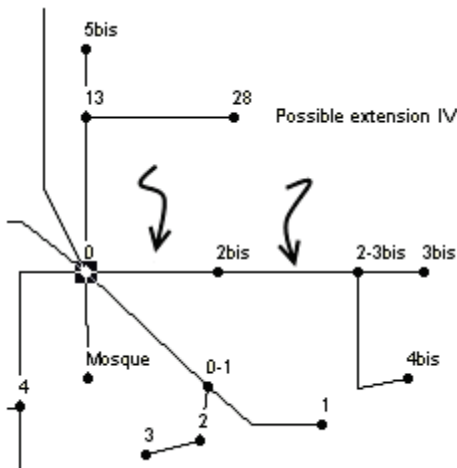
If you do it this way, be careful because when you draw a sketch that does not follow a scale, it will be difficult to trace pipes with unrecorded data. (see previous chapter). For example, in the image below, the two pipes indicated by arrows seem to be similar lengths; however, the first was 90m whilst the second was only 40m. Once you have put in an existing default length how can you check to see if you have forgotten to input any data?

## Bread crumbs and GPS points

This method is useful, quick and effective when you do not have other data. It consists of creating your own backdrop starting with "bread crumbs" that your GPS registers while you cover your future network on foot (also called tracks). Once you have created this image, you only need to dimension it in the same way as described in the previous sections and you can draw over it. On the following page you have two images that will help you to understand this explanation.

You need a GPS, a clear idea of the future network's layout and internet connection in order to find the approximate heights in Google Earth or similar (see 'Introducing heights').

1.   Cover the routes on which you want to lay the pipe with the GPS, recording with the GPS points that are likely to be junctions. Take care not to fill up your GPS memory, because besides these points, it needs to record a large number of other points on the way (tracks). If you use all the memory, the GPS will write the new data on top of the data that has been previously saved.

2.  Download the points and tracks to the program on your GPS. These could be the evaluation versions Ozi explorer, CompeGPS, etc. Some of them, like CompeGPS, have an option "create map using tracks". Others may have similar options, but if they don't, you can make a screen print using the 'Prnt Scrn' key (which is normally situated in the upper right corner of the keyboard), together with the key Fn, capital letter…depending on the computer, so that you paste it into an image program.

3.  Then, in the program, add two new GPS points (waypoints), one in the lower left (calib a) and one in the upper right, which will frame the network. This will help to determine the dimension of the image. They are the equivalent to the points for the Mosque and Gas Station of the example we saw earlier.



| 001 | 30S x=380483 y=4085505 |
| 002 | 30S x=380440 y=4085497 |
| 003 | 30S x=380396 y=4085491 |
| 004 | 30S x=380418 y=4085348 |
| 005 | 30S x=380460 y=4085351 |
| 006 | 30S x=380522 y=4085369 |
| 007 | 30S x=380423 y=4085634 |
| 008 | 30S x=380620 y=4085214 |
| Calib a | 30S x=380250 y=4085200 |
| Calib b | 30S x=380650 y=4085650 |
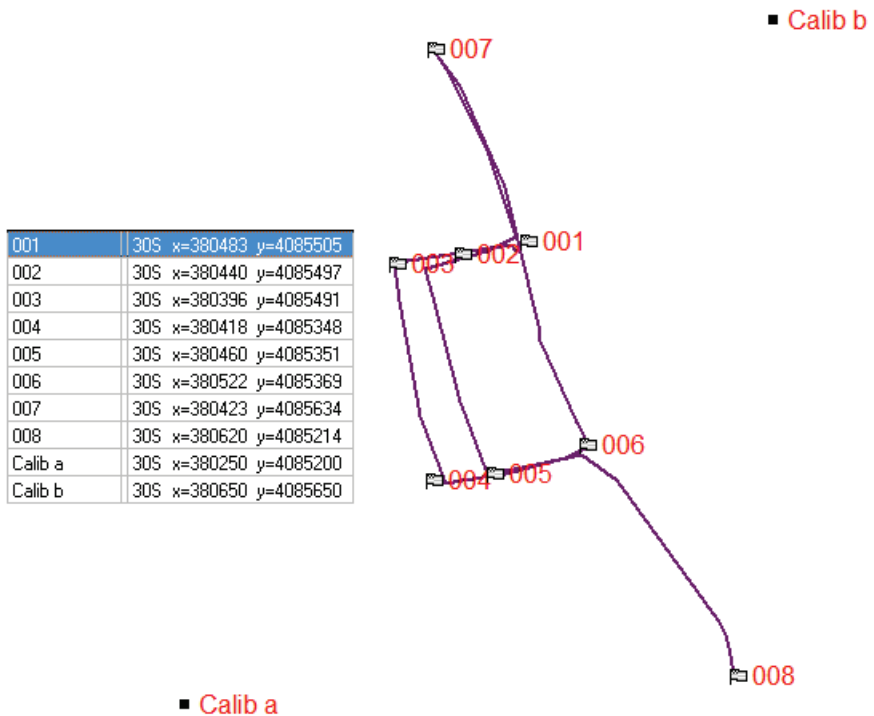
4.  Cut the image to the two initial calibration points, and subtracting its coordinates as we have seen, determine its dimensions. From now on you can draw the pipes on the corresponding tracks and you will get the junction positions from the GPS.

Below, you can see the result of drawing on the top of a backdrop created by the GPS. The pipes have been placed so they match with the "tracks". Remember you should not use the GPS, even if it has a barometer, to determine heights.
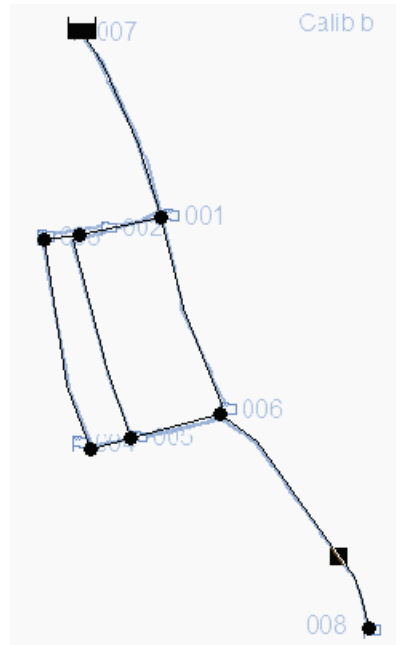


## Net2epa

This online tool enables you to draw a map of junctions directly over satellite images or Google Earth Maps. You can access it using the address:
www.zonums.com/gmaps/net2epa.html

The image shows an area of Mogadishu city in Somalia. The yellow points are the junctions that will be transferred to Epanet through an INP file, a text file Epanet uses to save information.
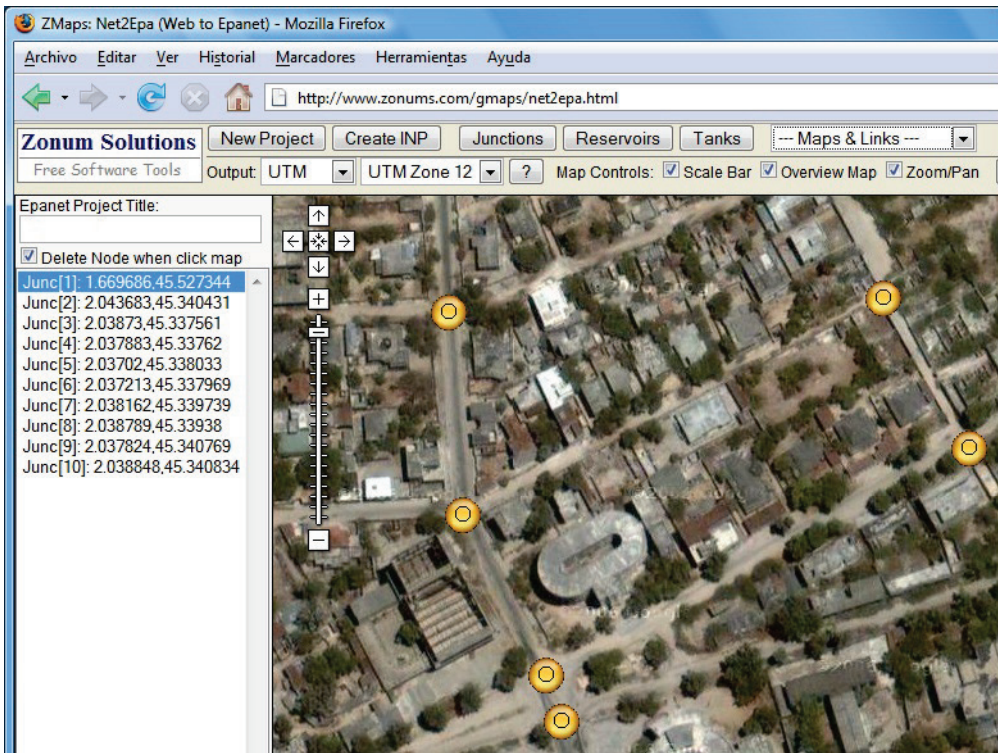
Once you have finished, save the info by pressing "create INP" and receive it by e-mail or paste it into a text editor. The dialog box, that shows the INP file, is shown below:
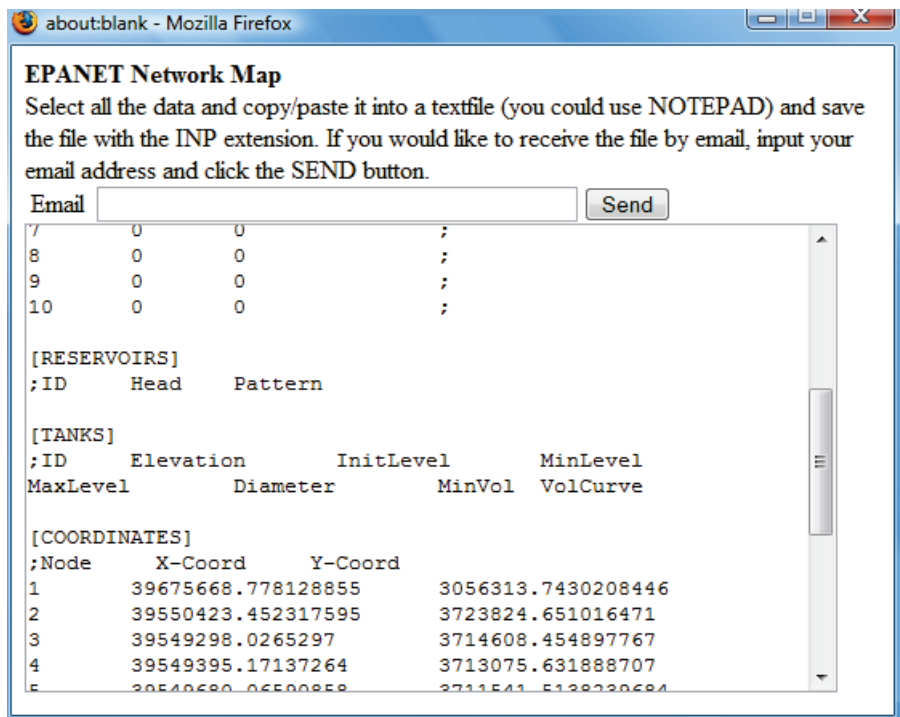
The problem with this method is that in many areas there is insufficient coverage for the scale. Cities, as seen with Mogadishu, do have a very good resolution and they are the images most commonly used today. However, thanks to the improvement of coverage with high resolution from Google cartography, it's becoming a tool with a great future.

These tools are basically beta versions, which is to say they are used in testing but the results are not guaranteed. If you use them, pay close attention to the results.

## Importing maps from AutoCAD

In some cases, the network may be digitalized in AutoCAD. There are some programs that interpret the information contained in AutoCAD and transform it so that it can be understood by Epanet. One of them is dxf2epa, developed by Lewis Rossman, creator of Epanet.

It is important to pay attention to these two things:

1.  If you have not used accurate tools with AutoCAD (such as Snap) lines which appear to be connected but in reality are not will be disconnected in Epanet.



2.  Crossed lines are interpreted automatically as a junction. If we have crossed pipes which are not connected, we need to disconnect them by representing them as it shown on the right.
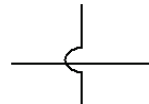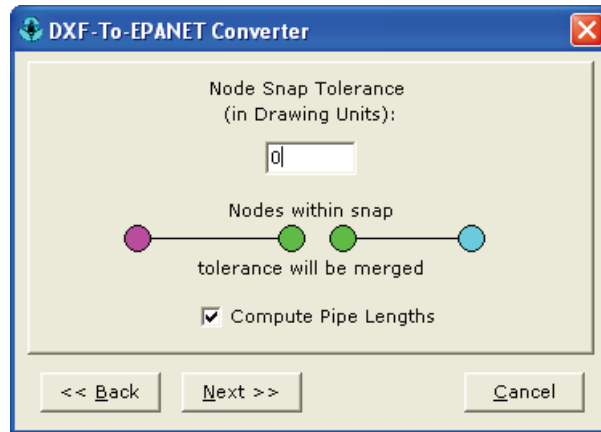
A newer software and probably a better choice is EpaCad, available at:
www.epacad.com/caracteristicas-en.php

**Downloading maps from Google Earth**

With a pro version of Google Earth, which is free for nonprofits, you can obtain satellite images by following Archive/ Save/ Save image. Ask a search engine for other alternatives, if you cannot get the PRO version. Frequently a simple screen capture will do the job.

**Including details**

Keeping the scale within the picture can cause congestion as with the pumping station shown in the image below. The same applies if you create a small system in the same network such as schools, hospitals etc.
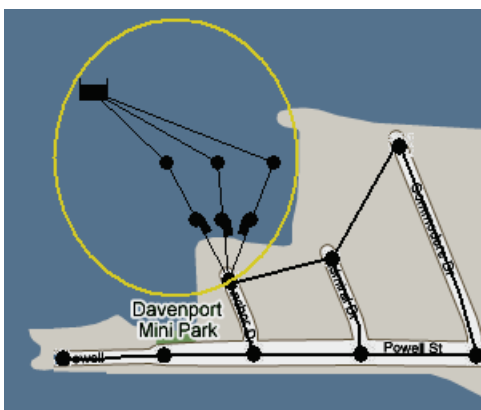


The easiest way to deal with this is to deactivate the automatic length, draw this part of the network enlarged then assign the real lengths afterwards. In the image, the area inside the circle corresponds to a pumping station and although in reality it should only occupy a few meters, to legibly model all its components, it has been enlarged to avoid having an unintelligible cluster of points and pumps.

# Entering data for junctions

Now we have drawn the network, it is time to go over the data we will need. As you will know from the tutorial, when double-clicking on an object a dialog box opens and shows its properties. In this box, you can read some things and modify others but cannot modify all of them.

| Junction 130 | |
|---|---|
| Property | Value |
| *Junction ID | 130 |
| X-Coordinate | 4262.01 |
| Y-Coordinate | 6115.29 |
| Description | |
| Tag | |
| *Elevation | 20.31 |
| Base Demand | 0.08 |
| Demand Pattern | 1 |
| Demand Categories | 1 |
| Emitter Coeff. | |
| Initial Quality | |
| Source Quality | |
| Actual Demand | 0.03 |
| Total Head | 59.72 |
| Pressure | 39.41 |
| Quality | 0.00 |

This is the complete dialog box for a junction, with all its properties.

Those which are shown inside the red square (above), with the exception of description or tag, can be modified, but will acquire an automatic value when the object is drawn. These properties are self explanatory and the tag has little use

In black (underneath), is calculated data which is read-only. Any required data comes with an asterisk which in the case of a junction would be elevation and name.

Focus on the parameters in the centre:

1. Elevation
2. Base demand
3. Demand Pattern
4. Demand Categories
5. Emitter coefficient
6. Initial quality
7. Source quality

These parameters will be covered in the following sections. The main part, the demand (points 2, 3 and 4), are covered in the following chapter.

Please, do not be intimidated. It is actually very simple.

**Elevation**

The elevation is simply the height of a given point. Because we work with relative height, it makes no difference if the heights refer to sea level or to a stone where you may have forgotten your hat. The reference point which is used to compare elevation points is called the datum. Normally, for example with topographic surveys, this will be the base of a tank or a borehole. You can use any datum but it must remain fixed and visible. The datum determines the height and elevation for subsequent points.

Imagine you do not know the height above sea level for the following three points in a network (they have been put in a column as a reference). If you decide that the datum is going to be the borehole and you assign it an elevation of 0 meters, you will have:

| Object | Relative height | (Height above sea level) |
|---|---|---|
| Datum  Borehole | 0 meters | 500 m |
| Tank | 67 meters | 567m |
| Spring 1 | 22 meters | 522m |

If you used the tank as the datum, you would have:

| Object | Relative height | (Height above sea level) |
|---|---|---|
| Datum  Tank | 0 meters | 567 m |
| Borehole | - 67 meters | 500m |
| Spring 1 | - 45 meters | 522m |

The most accurate way to determine heights is by doing a topographic survey. **Never use a barometer or a conventional GPS in order to determine heights**. These devices have an error of ± 10m at best, which is the whole pressure range of a well balanced system.

Another alternative is to use a contour map if available.

In some places, you can work with free digital elevation models with a reasonable precision. For example, with the free program Google Earth (http://earth.google.com), navigate until you can match the UTM coordinate of a certain point in the navigator and read its height.
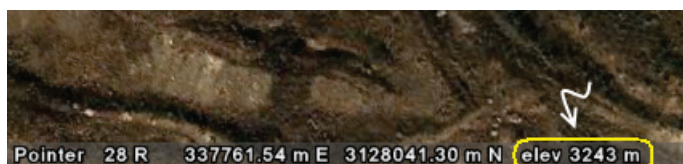
If you need the elevation of numerous points, you may require a program to digitalize them. Click in the Google Earth Map and it will write down the coordinate of the points and their heights in a file. You can find one at www.zonums.com/zge_toolbox.html and see how it works as in the image below:
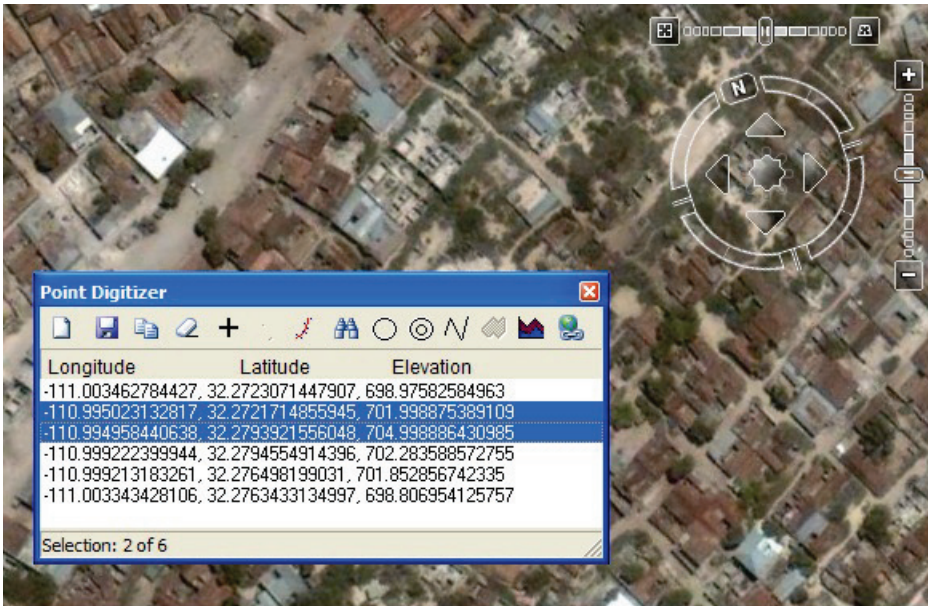


If you use these, be cautious and check the accuracy in your area. In some places and moments, you may get surprises, like the sea level is at 17m:
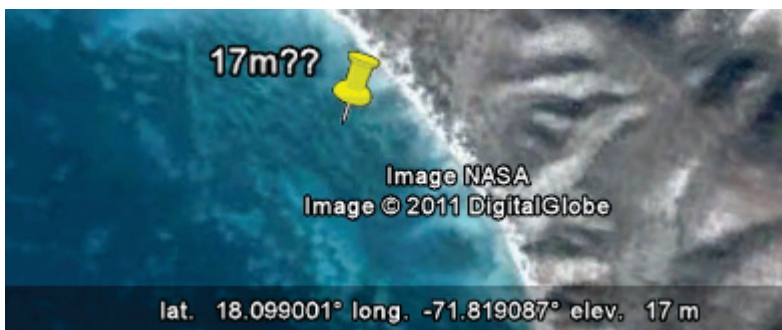


It is human nature to forget one or more of the points. Oversights will have a value of 0. Repeat the search in 'query':
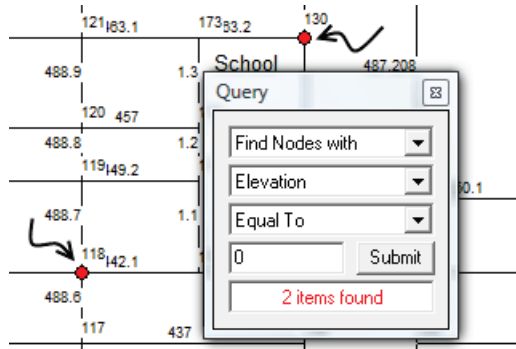
## Watch out with "tricky" elevations

Determining which elevation you should use may be tricky. Read the following paragraph carefully, because sometimes it is not just as simple as determining the height of a certain point.

Within a model, not all house connections are represented. For example, 25 houses between junctions A and B are omitted in the sketch, and their demand is distributed between points A and B. One of those houses, C, is located much higher than either of the end junctions. Because the height has been introduced in points A and B, there is a risk that problems with lack of pressure in point C remain hidden due to its greater height. The model will only provide pressure values for A and B.
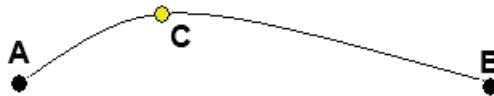


The picture below shows a group of houses positioned on the top of a hill. These houses are supplied from a main along the road. Although the model gives a pressure of 1 bar, o 10 meters, because the house is located 15 m above the road, its real pressure is 10m-15m= -5 m.

What should we do then?

> ➢ If there are just a few connections in this situation, draw a junction for each of them

> ➢ If there are many, put some sample junctions at greater heights to warn of pressure problems occurring in connections located at higher points.

When determining heights, it is not necessary to determine the exact height of a pipe. Use ground level as an approximation, the only error being the pipe's depth which is less than a meter.

The opposite problem, a connection in a low point, is less common. The sections on demand allocation and skeletization explain this further.

**Be careful with high pipe points**

Following the same reasoning, if the pipe has a point, A, which is higher than the water pressure line, it will not be able to reach point B.
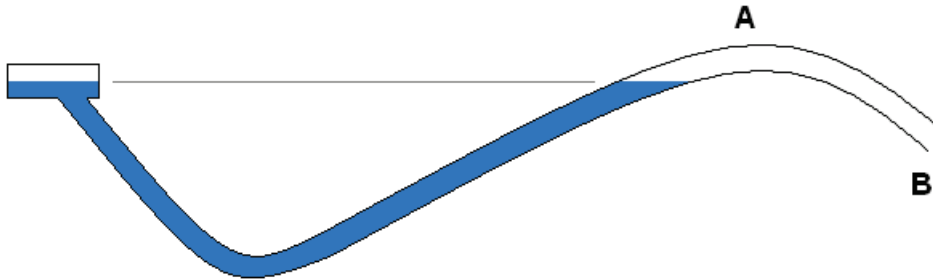


In order to prevent this happening, although problematic, place a junction with no demand in the highest point of the pipe. Once the water starts moving, the hydraulic gradient will not be horizontal any more. It is more difficult to evaluate the pressure in point A if there is no junction. Except for some particular and exceptional cases, the minimum pressure of these points must be 10 meters in order to avoid pressure problems.
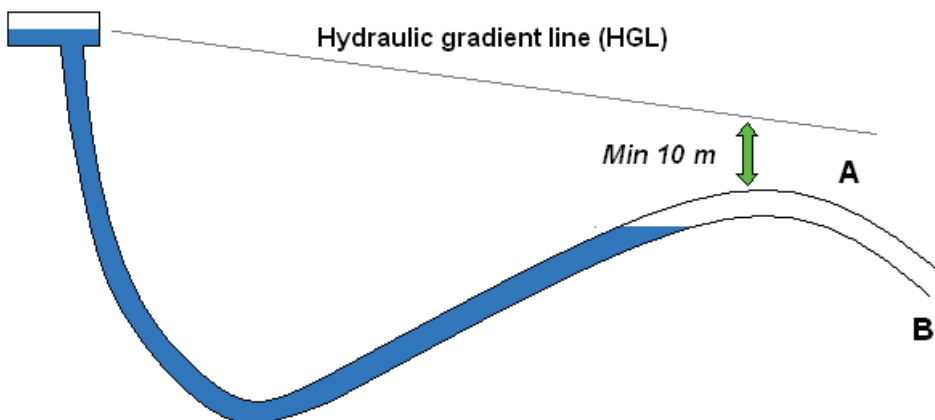


What are these exceptional cases?

In cases where the pipe cannot be re-routed and would need pumps or elevated tanks in order to meet the requirement. In these circumstances, if the pressure in point A is a least 5 meters, it is not worth adding complexity to the network by adding a pumping station or an elevated tank.

## Emitter Coefficient

This application is to model leaks and pressure-dependant demands… but it is unlikely that you will simulate those for new networks.

## Initial Quality

This is usually left blank. It would be used when modeling if you were required to start with a value for water quality, for example, 0.6 ppm of chlorine. Its main purpose is to avoid long waits before the chlorine of the source spreads into the system.

## Source Quality

In junctions where water enters the network, this parameter is used to describe its chlorine concentration. For example, you can model a drop chlorine injector with a discharge of 0.001 l/s and a source quality of 100 ppm. In Chapter 5 chlorination will be described in detail.

# Entering data for pipes

We are not going to talk here about the pros and cons of each type of pipe. When modeling in a development context you need to consider mainly two groups of pipes:

a) **Metal pipes.** They have greater friction, they absorb chlorine, their diameter is decreased by build-up and scaling on the inside of the pipes and they are more expensive. They include galvanized iron and cast-iron.

b) **Plastic pipes**, are smoother, don't absorb chlorine, and they accumulate less build-up and are cheaper. They include PVC and polyethylene (PEAD).

The introduction of data for pipes is much easier. The 3 first parameters are given by Epanet automatically. Although you can change the ID of a pipe, this is a big waste of time. If you still really feel you want them to follow a certain logic wait until the network is working properly so you don't have to keep modifying the pipes in the model. When you make modifications, the junctions' IDs keep changing.

The last 7 are read once the model has been analyzed. Until then, they will show up "#N/A".

## Length

With a calibrated image, the length will be determined by Epanet in the auto-length mode. If you do not have a background image, you will have to enter the lengths pipe by pipe from the topographic survey.

## Diameter

Metal pipes are specified by the internal diameter. A 25 mm pipe has 25 mm of inside diameter, and this is the diameter that is entered when modeling them. In contrast, plastic pipes (PVC and PEAD) are classified by their outside diameter.
The inside diameter is calculated by taking the outside diameter less the thickness of the wall. ***When modeling DO use the inside diameter***. To make things more

complicated, the specifications vary from one manufacturer to another however in practice, it is acceptable to use an approximated integer, as it causes little errors, simplifies the task enormously and avoids errors. Use this table of approximated relationship between commercial or nominal diameters (DN) and inside diameters (ID):

| DN | 25 | 32 | 40 | 50 | 63 | 75 | 90 | 110 | 125 | 140 | 160 | 180 | 200 | 250 | 315 | 400 | 450 | 500 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID PEAD | 20 | 26 | 35 | 44 | 55 | 66 | 79 | 97 | 110 | 123 | 141 | 159 | 176 | 220 | 277 | 353 | 397 | 462 |
| ID PVC | 21 | 29 | 36 | 45 | 57 | 68 | 81 | 102 | 115 | 129 | 148 | 159 | 185 | 231 | 291 | 369 | -- | 462 |

## Roughness

The roughness coefficient depends on the formula that is used to calculate the system hydraulically. The two main options are as follows:

a) If you use the **Darcy-Weisbach equation**, which is largely used in Europe, this coefficient is f and it takes values with decimals.

b) If you use the **Hazen-Williams**, as used in America, this coefficient is called C and it takes values like 100, 120, etc. The bigger the coefficient, the smaller the friction of the pipe.

I would recommend you to always use Hazen-Williams, because it is more intuitive. The coefficient has no decimals, and moreover, this coefficient does not depend so much on the diameter or velocity. Its detractors state that it is an experimental equation (Darcy-Weisbach is theoretical) and that it only works for water at room temperature, but…isn't that just what we want to calculate?!

If my argument has convinced you, and you are not modeling the hydraulic behavior of fish soap at 90ºC, you must make sure that you have the Hazen-Williams equation selected (represented by H-W in Epanet). In order to do that go to >Project/Analysis options, and select H-W. [1]
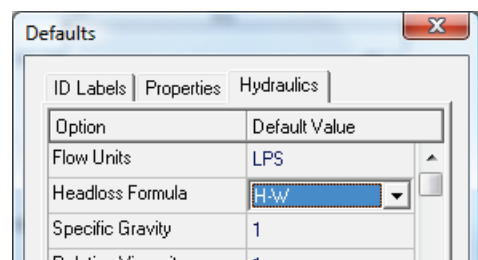


The value of C depends on material and state (and slightly the diameter), being bigger for plastic and new pipes. Basically for pipes of:

---

[1] *Don't worry, in the United States they have been calculating networks like that for 100 years.*

|            |         |
|------------|---------|
| Plastic    | 140-150 |
| Galvanized iron | 120-133 |
| Cast-iron ducts | 100 |

For an exhaustive list, consult table 2.3 in Advanced Water Distribution Modeling and Management, Haestad, 1st edition, or search the internet.

## Minor Loss Coefficient

Minor losses account for the energy losses produced by the turbulence in the flow as it goes through anything that is not straight pipe: elbows, valves, reducers, tees, etc. In the image, the half closed valve creates a conical turbulence on the outlet of the tap which is clearly shown on the wall reflection and against the blue cloth. Producing this whirl consumes part of the energy available in water. The turbulence created when changing the velocity and direction of the water flowing in the pipe as it is forced through a fitting produces the friction that uses up pressure.

In most cases, the losses are so small that they are not included in the models. Cases in which they should be included are:

- Pumping stations
- Internal building installations and diameters smaller than 1".
- Places where water flows at high speed.

One way of presenting minor losses is by adding an equivalent length to the pipe, that is to say, X extra meters produce the same friction as the accessories added. Even if this may seem quite practical at first, it presents two main disadvantages:

- Because Epanet would not be representing real pipe lengths, you could not take data directly from the program in order to determine the materials required. Mixing real and fictional lengths can generate a very confusing database.

- Water quality analysis is affected. When you add a pipe length, you affect travel times making them longer, however the reaction does not have in reality this extra time which produces false results.

To avoid these problems we use the loss coefficient. This coefficient (K) is characteristic of each accessory and it is related to energy loss in water head meters (H) with the formula:

$$H = K * v^2/2g \qquad\qquad v: \text{velocity and } g = 9.81 \text{ m/s}^2.$$

The coefficients given with Epanet´s help are faulty at the time of writing. Please use Table 2.6 of *Advanced Water Distribution Modeling and Management* or other source.

Be careful when you draw a pipe with an angle of 90º, for example, and want to take into account the losses as you need to include its value for loss coefficient. With Epanet, no matter how you draw the pipes, they are all straight and with no accessories. To illustrate this, you can see that the pressure is the same in both pipes with identical section and length, even though one of them is not straight. Epanet has not taken into account the great number of elbows and the losses needed in order to build pipe B.



Pipe A, 100 m          Pipe B, 100 m
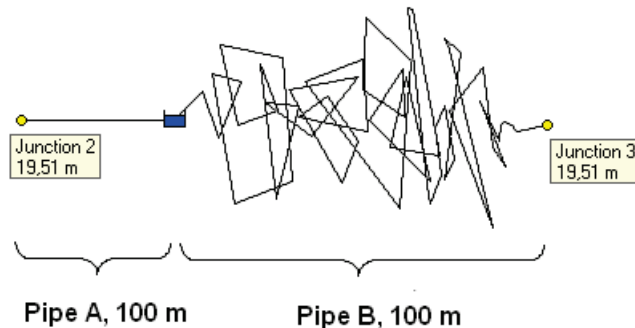
### Initial State

Refer to valves further in this section. It basically describes if they are open, shut, or only allow flow in one direction. This is the way to incorporate shut-off and non-return valves.

For **Bulk and Wall Coefficients** see Chapter 5.

## Entering data for a reservoir

| Property | Value |
|---|---|
| *Reservoir ID | 1 |
| X-Coordinate | -1341.10 |
| Y-Coordinate | 9448.42 |
| Description | |
| Tag | |
| *Total Head | 60.40 |
| Head Pattern | |
| Initial Quality | |
| Source Quality | |
| Net Inflow | #N/A |
| Elevation | #N/A |
| Pressure | #N/A |
| Quality | #N/A |

Reservoir 1

Here you have the most common parameters used in a development context. For others, please refer to the Epanet Users Manual.

### Elevation/ Total Head

This is the height of the water level. In some cases it can be tricky to determine.

Besides a river or lake, the most frequent case in development is a **borehole**. As you pump from an aquifer, the water level goes from rest (static level) to a much lower one (dynamic level) as is shown in the image. Broadly, a depression cone is formed, similar to the one that is created when pulling the plug out from the sink. The bigger the discharge, the greater the depression cone is. This cone makes the water level much lower inside the borehole and this is the level that needs to be entered. For example, if the borehole cap is at 30m height, and static water level is 10m under the ground, and when the pump is activated the equilibrium is reached at 50m from the cap, the level of this "reservoir" will be 30m - 50m, and so -20 meters.

Another common error occurs when entering pumping head of the pump. If the dynamic level is 20 m above the pump, the pump does not do any work to move a fluid inside another fluid of the same density, that is to say, it does not matter what depth the pump is installed below the dynamic water level. Only when raising water over air is an effort made. To visualize this concept, put a bag of water into water and see that it only requires effort to move it when trying to take it out of the water.

Static Water Level (SWL)

Dynamic Water Level (DWL)
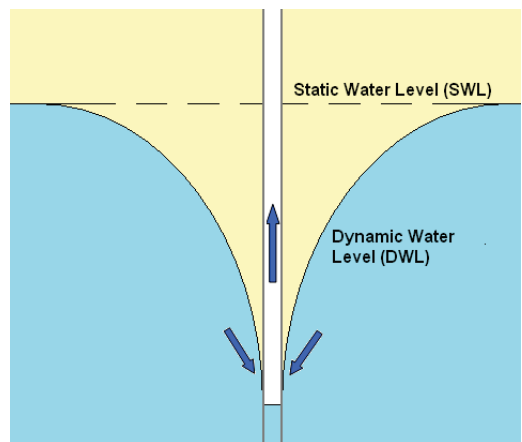
For **Initial Quality** and **Source Quality** see chapter 5.

# Entering data for a tank

We are going to enter one of the most common tanks in emergencies, an Oxfam T95. It is a corrugated tank, which is 3 m high and has a diameter of 6.4m. The outlet is 20cm above the floor and the overflow outlet is at 2.8 m.

| Property | Value |
|---|---|
| *Tank ID | 2 |
| X-Coordinate | 1653.48 |
| Y-Coordinate | 5680.38 |
| Description | |
| Tag | |
| *Elevation | 123 |
| *Initial Level | 1.4 |
| *Minimum Level | 0.2 |
| *Maximum Level | 2.8 |
| *Diameter | 6.4 |
| Minimum Volume | |
| Volume Curve | |
| Mixing Model | Mixed |
| Mixing Fraction | |
| Reaction Coeff. | |
| Initial Quality | |
| Source Quality | |
| Net Inflow | #N/A |
| Elevation | #N/A |
| Pressure | #N/A |
| Quality | #N/A |

### Elevation

This is the height of the tank base, for example, 123m above sea level. It is used as a reference for the data that follows.

### Initial level

This is the initial water level in the tank. If it is half full: 1.4m.

### Minimum level

This is the relative height of the water outlet for distribution. Do not mistake it for the drainage level or the fire reserve outlet. On the T95, it is 0.2m.

### Maximum level

This is the relative height of the overflow. In our case this is 2.8m

### Diameter and "rounding" of rectangular tanks

Epanet assumes that all deposits have a circular section. Although tanks are modeled as if they were cylindrical, in reality most tanks are rectangular…argh! In order to overcome this difficulty, convert to the "equivalent diameter", which is as simple as finding the diameter of the circle that has the same area as your tank.

It's best to explain it with an example:

An 8m x 12m tank has an area of 96 m$^2$. What we need to do is to find the diameter of a 96 m$^2$ circle. The equation that we get is:

   96 m$^2$ = π (D/2)$^2$       The diameter to be introduced is then 11.05 m.

The generic formula is, with A and B being the width and the length:       $D = 2\sqrt{\dfrac{A*B}{\pi}}$

## Minimum volume

Ignore this. This is to help calculate mixing with the residual volume when the tank has uncommon shapes.

## Volume curve

This is used for tanks with a variable diameter, in order to relate volume with height. Tanks with variable diameters are conical ,spherical, etc. To start defining the shape of the tank click on "Curves" on the data tab of the viewer, and click the "add" button in the bottom left corner. The menu that comes up is used to determine different curves, and among them is the Volume curve. Select Volume in the Curve Type dropdown menu of the curve editor dialogue box.
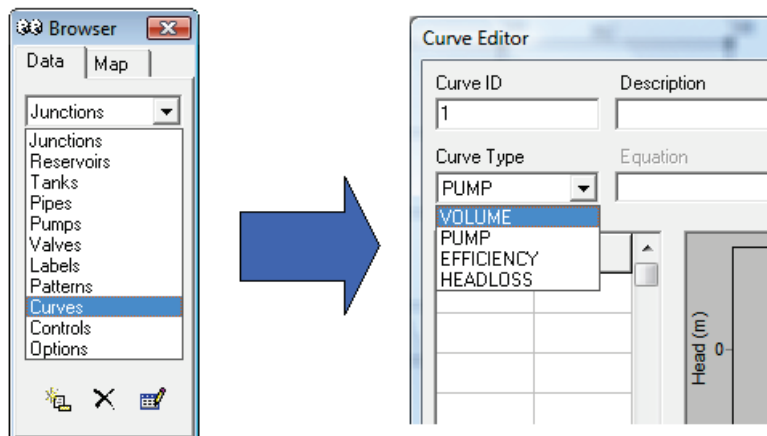


The level points (height) and volume are calculated easily by the volume formulas of the different shapes.

For example, the formula that defines the volume of a partially filled sphere of radius r which depends on its height h is:

$$V = \pi h^2 (r - 0{,}333h)$$

Assuming that this spherical tank has a radius of 2 meters, the points to be entered are shown on the table on the right. When introducing them in Epanet you get the typical S shape of spheres:

| Height | Volume |
|--------|--------|
| 0 | 0 |
| 0.5 | 1.44 |
| 1 | 5.23 |
| 1.5 | 10.6 |
| 2 | 16.76 |
| 2.5 | 22.91 |
| 3 | 28.29 |
| 3.5 | 32.1 |
| 4 | 33.56 |
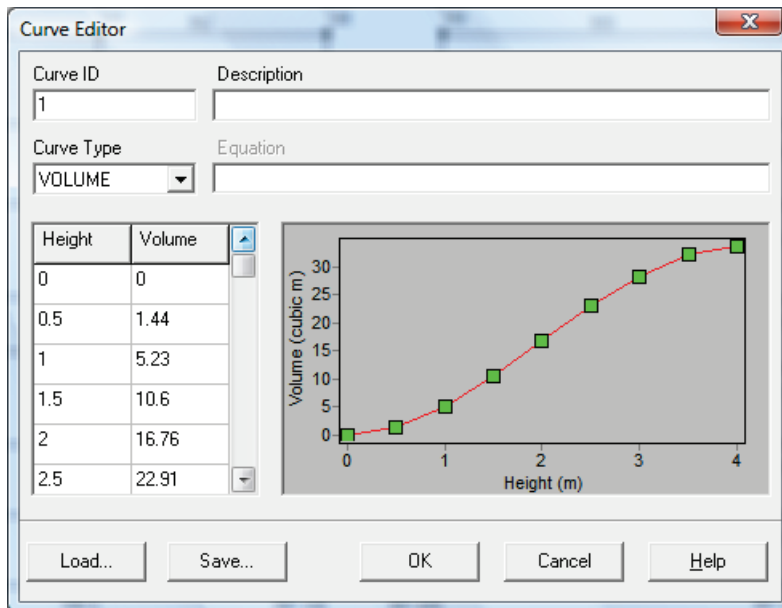


## Mixing model

There are four mixing models of which the first one is the most common:

1. **Complete.** Mixing is complete and instantaneous. It is ideal for systems that fill a tank completely and empty them afterwards. This frequently happens in a developing context because the easiest way of chlorinating the water is to fill the tank completely, dose the chlorine and wait for it to act before it is opened for consumption.

2.  **Two compartments.** This is uncommon. Refer to the Epanet Users Manual for further details.

3.  **LIFO.** This stands for Last in First Out and assumes that water is not mixing. The last water to enter the tanks is the first to leave. It can be used to model treatment tanks.

4.  **FIFO.** This stands for First in First Out. Refer to the Epanet Users Manual.

**Mixing fraction**

This is only needed for the 2 compartment mixing model. Refer to the Epanet Users Manual.

For **Reaction coefficient, Initial quality** and **Source quality,** see chapter 5.

# Valves

As we stated earlier, shut-off and non-return valves are modeled as a property of the pipe. They are not represented as an object, but as a property within the pipe. In order to close a pipe or install a check valve you need to change the property "initial state": open, close or check valve, which only allows flow in one direction.

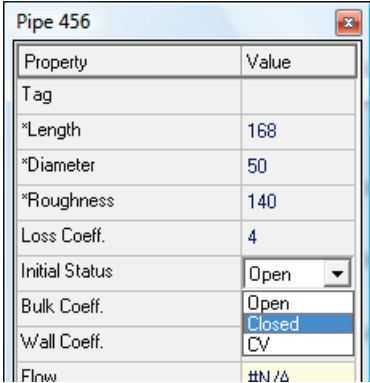| Pipe 456 | |
|---|---|
| Property | Value |
| Tag | |
| *Length | 168 |
| *Diameter | 50 |
| *Roughness | 140 |
| Loss Coeff. | 4 |
| Initial Status | Open |
| Bulk Coeff. | Open / Closed / CV |
| Wall Coeff. | CV |
| Flow | #N/A |

Other valves, and this is my personal opinion, should be avoided in most cases in a development context. The reason is that these valves are delicate and expensive. A 200mm pressure sustaining valve costs over 3,500 €. This high cost and lack of local experience in using these valves plus lack of availability in local markets makes replacement very unlikely. I know that you will agree that water pumps are easily available and widely known…however, I have seen many abandoned water systems because the local community could not afford the cost of a new pump!?!

So avoid the following valves:

- PSV (pressure sustaining valves). Prevent pressure upstream from going under a certain value.
- PRV (pressure reducing valve). Reduce pressure downstream to below a certain value.
- FCV (flow control valve).
- Throttle valves. Valves that are partially open, i.e. butterfly valves.
- PBV (pressure breaker valve). Force a pressure drop.

If after all you decide that you need one of these valves, simulating them is easy and you can handle it by using the Epanet Users Manual.

In hilly areas, dissipating high pressure caused by the height may be necessary. In these cases, the PBV or the PRV can be replaced by a break-pressure tank which is more sturdy and economic. These tanks (see the image below), are modeled in the same way as other tanks.
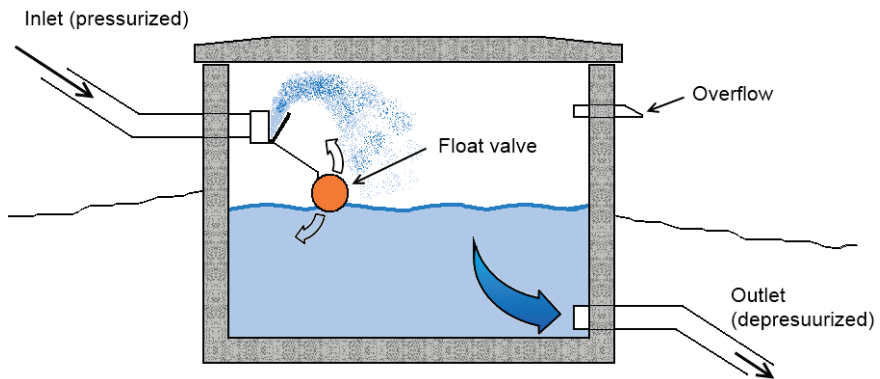
# Modeling a pumping station

Don't add pumps at this stage even if they are included in the network. This is because the pipes are dimensioned first and the network stabilized. Once this is done the suitable pumps are added so they work for that specific network. Wherever the pump goes put instead an imaginary reservoir at a certain height and proceed as if it was a gravity system. Work with the pipes until you can lower the tank as far down the hill as possible. The height of the hill will be the water pumping head (the height the pump should be able to lift), at it will be more economical to pump to lower altitudes. Look at the image of the section Skeletonization further ahead, and this is exactly what has been done, and why there are so many reservoirs.

Here is an example highlighting some points:

- The type of pump (centrifuge, horizontal, submersible) does not affect the simulation if the intake of the pump has enough water pressure so that the pump does not suck in air or produce it (google NPSH for more info).

- If there are big demand variations, several pumps of different sizes are used instead of a bigger one so that they can be turned on and off depending on the required discharge of the moment.

## Modeling a submersible pump for a borehole

Let's design a very simple network in a flat area, let's say in Eritrea. The water is taken from a borehole and is directly distributed to four points.

1. Start drawing this network without connecting the borehole (it will be modeled as a reservoir).

2. Enter the following data: 0m for elevations, 100m for pipe lengths and, to start, 200 mm for pipe diameters.

3. Assign the maximum pressure you want for the system to the reservoir, above the height of the lowest point. Let's say that I want 3 bars, equivalent to 30m of head. Because the lowest height is 0, the reservoir elevation is 0 m + 30 m = 30 m.
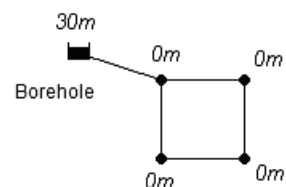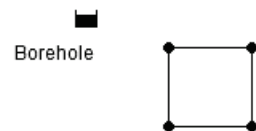
4. Join the reservoir with a pipe.

5. Now we need to follow a process that will not be explained here but will be covered in future chapters. Basically you would start changing pipe lengths and diameters until getting the optimal solution for the network, which will have allowed us to lower the reservoir to 25 meters. This is the result of the process:
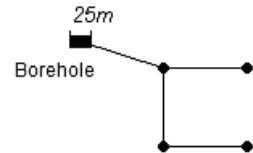


If the borehole is not drilled or the pumping test has not been done, you cannot know how deep the water will go when pumping (**dynamic level**), or what discharge the well will provide. Because you do not have enough data yet, you need to leave the model like this for now.

6. Now we make changes to accommodate the pump. Remember that it is a borehole; when we start pumping the water level goes down. Place the reservoir that you are simulating at a height that equals the height of the borehole top minus the dynamic level. This means that if you had the cap of a borehole at an elevation of 5 m, and when you pump the water, the water level goes 35 m below that point, the height you need to introduce for the reservoir is 5 m – 35 m = -30 m.
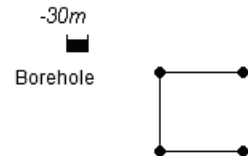


Watch out, remember that 35 m is not the depth at which you need to install the pump, but the depth the water table reaches in the drilling test. Now delete the pipe that connects the borehole to the junction on the network.

7. Select a pump that provides the suitable discharge as you will see in the following chapters. The pumping head or pumping height is the sum of:



25 m   (A, calculated in point 4)
30 m   (B, from the dynamic water level to the top borehole, as calculated in point 6)

The pumping height would be 55 meters, which is the total height from the dynamic level up to the hypothetical
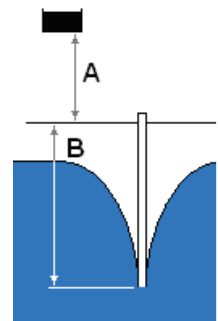
reservoir that we had placed in point 4. This hypothetical elevation simulates the resistance of the network to receive the water plus the residual pressure.

**8.** Draw the pump remembering that the pumping direction is the same as shooting from an imaginary cannon. You will learn how to add the pump properties in the following section.



Borehole
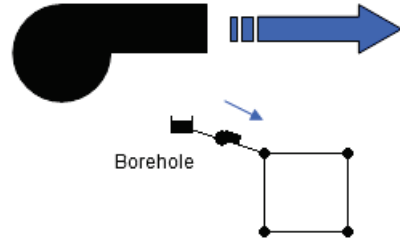
**9.** There is no need to put a pipe as the pump assumes it automatically, however, it does not include the parameters of that pipe. If you think that can affect the systems behavior, for example because there is a great distance, add an intermediate junction and assign the properties of that pumping main.



Borehole
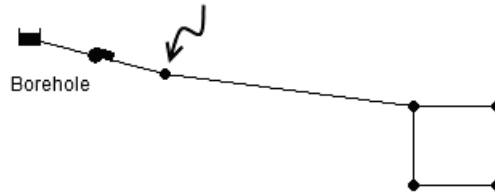
# Adding a pump

| Property | Value |
|---|---|
| *Pump ID | 1 |
| *Start Node | 2 |
| *End Node | 157 |
| Description | |
| Tag | |
| Pump Curve | |
| Power | |
| Speed | |
| Pattern | |
| Initial Status | Open |
| Effic. Curve | |
| Energy Price | |
| Price Pattern | |
| Flow | #N/A |
| Headloss | #N/A |
| Quality | #N/A |
| Status | #N/A |

**Start Node**

This is the junction from which the pump takes water.

**End node**

This is where the water is taken. Remember:



**Pump curve**

This is a curve that represents the pumping head pump.

If you are not familiar with this, or you're not entirely sure what it is, this is a good chance for you to look up a pump book or google for it. On the right you can see the three curves that define a pump's behavior: the pump curve, the performance curve and the suction curve for non-submersible pumps.

In this parameter you enter the name of the curve that you have constructed using the manufacturer's manual. In order to make the pump curve follow the instructions that were given to make the tank volume curve making sure that you choose "Pump" as the curve type and that the pairs of numbers are the height with respect to the discharge.
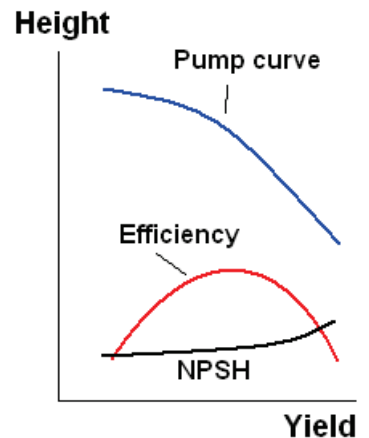


A really good place to look for information on the Internet is the program Webcaps from the manufacturer Grundfos, which also helps you to select a pump (if you are going to buy it from them). On the next page you will find a screen-shot of this easy program in action.

The link is:  http://net.grundfos.com/Appl/WebCAPS/
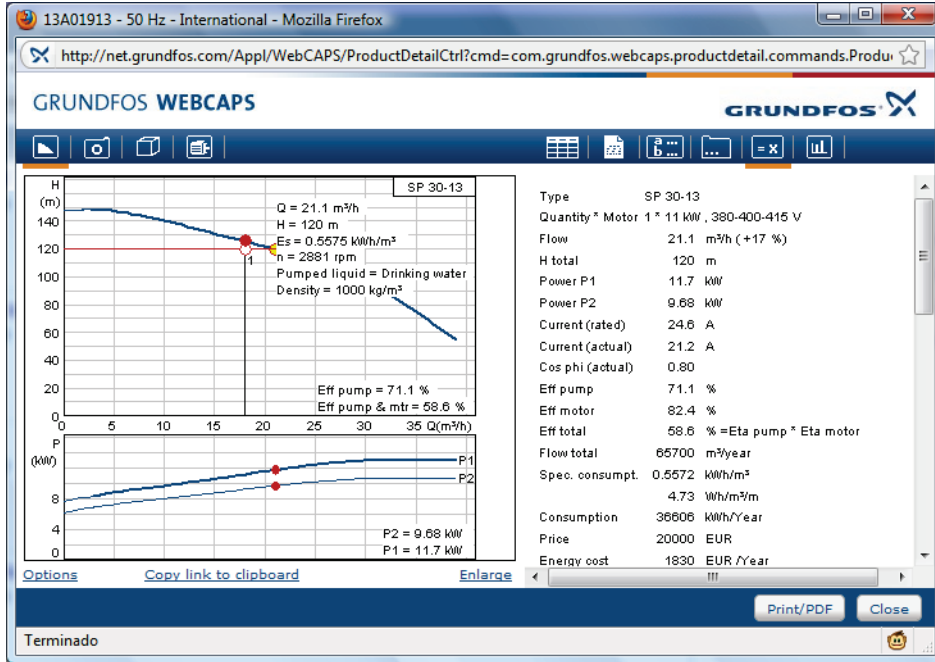


## Power (kW)

This is used when the pump curve of the pump is unknown, and for other cases is left blank. In the design phase this is not going to be needed because you are going to choose the pump yourself, but it is very useful for boreholes that already exist, when you do not know which pump is inside.

## Speed and pattern

These are not common in development. Refer to the Epanet Users Manual if necessary.

For **Efficiency curve, Energy price** and **price pattern** see Chapter 7.

# Skeletonization

If a model considered absolutely every component it would be very laborious and expensive to build, impossible to maintain and difficult to interpret. Skeletonization is a process which eliminates the pipes that have little effect on the network's behavior. Both images below are the same network, one with all the data, and the other one simplified to analyze the loop behavior. In this extreme simplification it has been considered that all the deleted elements do not contribute much to the loop's analysis.
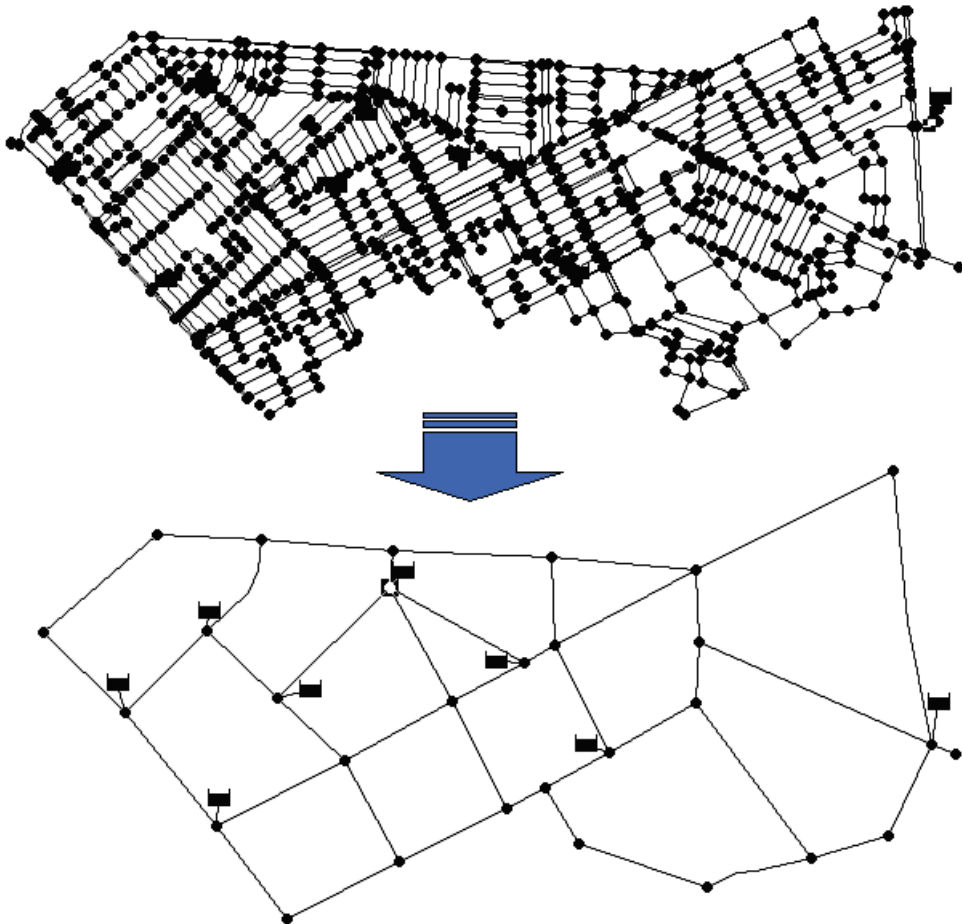


In development, models are relatively simple and only the really unnecessary details are eliminated. For example, these three things don't need to be modeled in detail:

- House connections. As you will see in the section on Demand allocation, the total demand of all houses in a reach of pipe is concentrated in one or two nodes on each end.

- Interior installations of each user are replaced by a node.
- Detailed connections of fittings are ignored, as in the image below.

Only with these principles, the network is simplified considerably and I believe all the necessities of common systems are covered without risks. If you need to simplify your network any further, check out some books, adapt the model to the changes and see what happens. Alternatively you can use specific expensive software like Skelebrator, or a free beta program, like optiSkeleton.

In many cases, skeletonization does not mean information loss as existing parts will include that information. For example, the group of accessories in the image below will be simply transformed into three pipes with minor losses included.
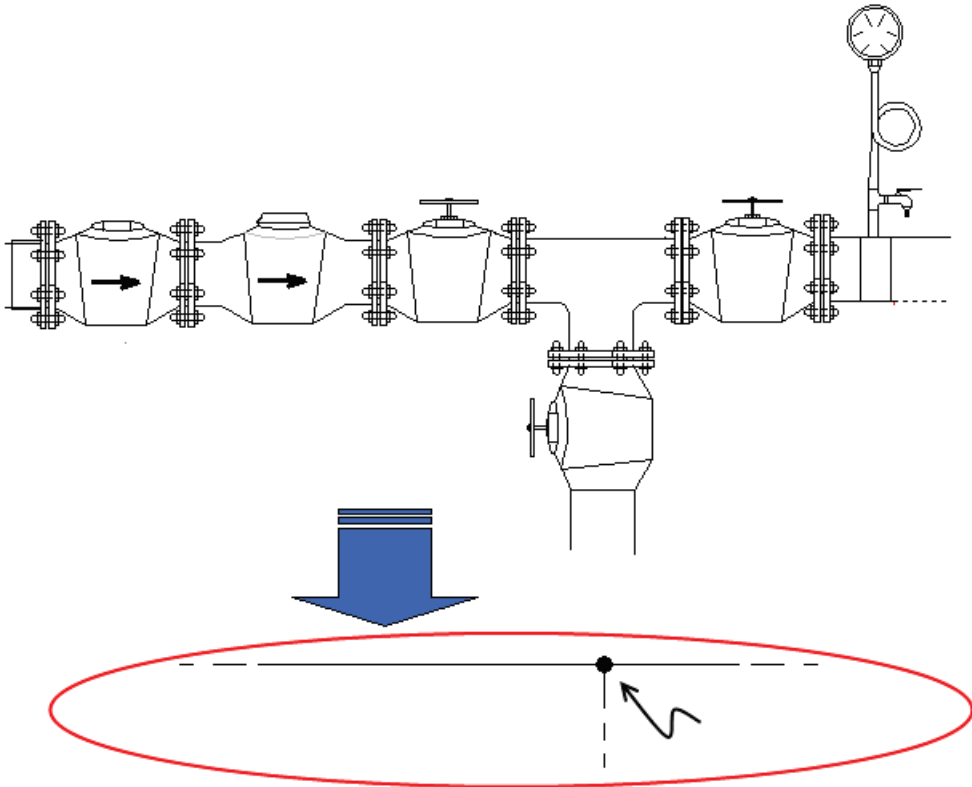
# 4

# Loading the model

> ➤ *The demand is a self-fulfilling prophecy.*

# Introduction

**Loading** a model is applying the "load" of the consumers on the network. It is a fundamental step but comes with less solid information. Avoid taking an overly cautious approach, pay attention and calmly accept that not everything is going to be based on solid data. This is the territory of assumptions and it is important to work with the correct ones.

The model is loaded to work adequately at the hour of the day, of the day of the week, of the month of the year when the future population will consume the most, that it to say, it's **designed for the peak consumption point.** This way, the networks are slightly over-designed, but the advantages definitely deserve a slightly larger investment. The philosophy behind this is that if the system works in the worst case scenario, it will work in the others. Emergency and small systems are calculated with other approaches explained later.

**Demand** is consumption of an individual, business, factory, etc. To make data comparable and easy to modify, the demand is divided up half-hourly. Multipliers and coefficients will be applied to take into account the hourly, weekly, monthly variations, etc.

Besides the value itself, **the spatial distribution of the demand is vital**. At the end of the chapter, techniques to assign demands to each junction are described.

Two aspects with strong social implications are fire demand and long design periods. Both require big financial investments which could perhaps be better used in other community issues, such as vaccination or lighting. It's about finding a compromise that avoids blindly following Western design standards.

We started the chapter with the statement "the demand is a self-fulfilling prophecy". If you have designed a network correctly, you have planned it for the community that is going to receive it. Make sure that the quantity per person is adjusted to the population.

# Current population vs. Future population… ¡ouch!

When a network is planned, it takes into account the population after a certain number of years, usually 30. To estimate the future population, formulas are used to project it over time according to its growth rate to give a graph as shown in the image. If in 2001 the population is 90,000, in 2036 according to the geometric formula it will be 230,000:
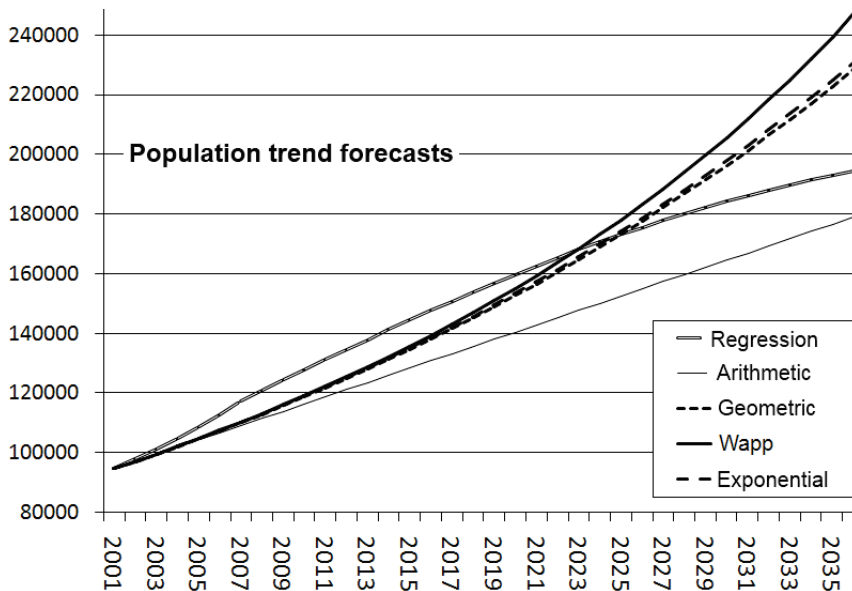


But things are not so simple, and here we begin to have difficult questions, for example:

- Is it right to pay attention to the need of the population in 30 years time if it means neglecting some of the needs of the current population?

- If the network is built without taking into account the future population it will be obsolete before it is paid back, but if it is built too big… will it not run the risk of the community not being able to maintain it?

There is not a clear answer to these questions, but there are ways to deal with these matters. Some ideas are below:

1. **Design easily enlargeable networks.** This generally involves making big loops rather than branch layouts and not installing pipes less than 100 mm. As you see in the graph, the installation expenses are proportionately very big for

small diameters therefore inevitably it ends up being preferable to install bigger pipes at very little additional cost.

## Pipe cost vs installation expenditure
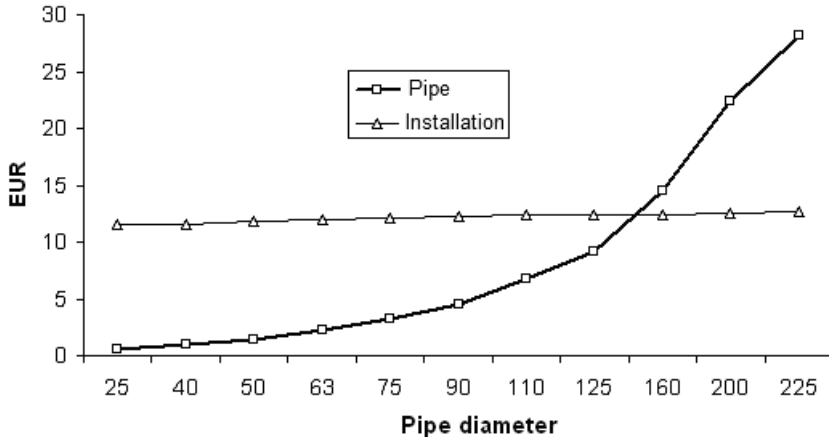


**HDPE pipe cost vs., excavation, sand bed and installation cost, Afghanistan 2002**

2.  **Use plastic materials** in networks with a high possibility of growth. The price per increase in diameter is negligible compared to metallic ones. Once you have assumed the cost of excavating trenches and filling material, to install bigger pipes is not too expensive (see Chapter 7).

3.  For urban settlements you can use **density limits** in place of projections. If the population in the surrounding areas cannot tolerate more than a certain number of people per $km^2$, the population served will be the result of multiplying the working area by the density, for example:

$$8 \text{ km}^2 \times 1650 \text{ people} / \text{km}^2 = 13,200 \text{ people.}$$

4.  **Plan the construction in two phases.** Using billing, you can determine how many years the system needs to save the necessary money to be able to finance a later enlargement (second phase). A very simplified example: if the net income of a water company is 10,000 €/year and it takes an investment of an additional 120,000€ to adapt the network for the needs of 30 year growth, design for at least twelve years, but better with a cushion of a few years.

**Projection formulas**

Arithmetic:     $P_f = P_o \left(1 + \dfrac{i * t}{100}\right)$

Geometric:     $P_f = P_o \left(1 + \dfrac{i}{100}\right)^t$

Exponential:   $P_f = P_o * e^{\left(\frac{i * t}{100}\right)}$

$P_f$ , Future population

$P_0$ , Current population

$i$ , growth rate in %

$t$ , time in years

$e$ , Euler's number ($\approx$2,718)

This table, taken from the Bolivian Standard NB689, contains recommendations for the application of each method:

| Method | Population (people) | | | |
|---|---|---|---|---|
| | Up to 5,000 | 5,000-20,000 | 20,000-100,000 | > 100,000 |
| Arithmetic | X | X | | |
| Geometric | X | X | X | X |
| Exponential | X [2] | X [2] | X [1] | X |
| Log curve | | | | X |

[1] Optional, recommended
[2] Subject to justification

# Determination of the total daily demand

Next, and during a few sections we will see how to construct the demand that Epanet will utilize. You will only be able to enter values for demand when you arrive at the end of the section "global coefficient". Once you have arrived there you will be able to enter the parameters:

1. Base demand.
2. Modulation curve.
3. Demand type.

There is no quick recipe for determining the demand of any population. It varies a lot from one population to another and from certain conditions to others and you will need, above all, common sense to distribute it spatially. If there is another system close by you can get an idea, but watch out, the existing data doesn't tend to be correct. In emergencies, for example, the data is open to manipulation in order to sweet-talk the donors. In normal conditions it is extremely unknown and generally based on how much is produced, not how much is consumed. By way of orientation these are the **minimum standards** with which to work. I stress that they represent what arrives at the people, not what is produced in the boreholes, well, etc.:

| Minimum consumptions (l/u*day) | |
|---|---|
| Urban inhabitant | 50 |
| Rural inhabitant | 30 |
| School | 5 |
| Outpatient | 5 |
| Hospitalized patient | 60 |
| Ablution | 2 |
| Camel (once a week) | 250 |
| Goat and sheep | 5 |
| Cow | 20 |
| Horses, mules and donkeys | 20 |

What, you want to know how much an office of lawyers consumes? Not very likely, but you can see the demands of the most unusual suspects in table 4.1 of "Advanced Water Distribution Modeling and Management" Haestad 1° ed. taking into account that they are consumptions for the United States.

One area of consumption to investigate and avoid nasty surprises is small kitchen gardens. A typical garden consumes nearly 5 mm/m$^2$. Remember that 1 mm/m$^2$ is the same as 1 l/m$^2$, and a small kitchen garden of only 20 m$^2$ consumes 100 liters per day. If the custom of having kitchen gardens is widespread it can represent a considerable proportion of the total consumption.

In practice, the highest quantity of water will be set so that:

- It doesn't produce environmental problems (flooding, overexploitation, etc.).
- The people are willing to pay and at a cost that is adapted to the local economy.

**Note that this is not the value that should be put as the base demand**, it is only the starting point for calculating it.

So summarize, if I have 2 goats, 3 rural people and a donkey, the total daily demand is:

```
2 goats  x  5 l/goat            =  10 l
3 people  x 30 l/ person        =  90 l
1 donkey  x  20 l/donkey        =  20 l
                          ---------------------------
                           120 liters per day
```

# Multipliers

Consumption is not constant. People get up, go to bed, and are going to work at their individual whims and conveniences. To be able to represent the daily, weekly and monthly variations in an easy way we turn to the concept of multipliers.

A multiplier is a number that multiplies the average consumption of a population to give a real consumption in the timeframe considered (i.e. an hour). This way, if the average consumption is 100 liters per hour and the consumption is 50 between 12:00 and 13:00, the multiplier is 0.5 so that

| 100 liters | x | 0.5 | = | 50 liters |
|---|---|---|---|---|
| **Average demand** | **x** | **multiplier** | **=** | **Real demand** |

The use of multipliers allows calculations to be simplified and automated. Imagine that you want to see what happens with a model projected every five years in the future. Without a multiplier you have to adjust the consumption for each of the 24 hours of the day for each calculation. That is to say, if the consumption increases by 38.5% you will have to multiply the consumption of each hour of the day by 1.385. If you have used multipliers, you leave the 24 multipliers as they are and simply adjust the average consumption by multiplying it by 1.385, saving 23 multiplications.

I have been talking about using the average consumption. In reality you can use multipliers with respect to any number. If you were using multipliers to define a pump pumping at different hours of the day, then it would be simpler to use the pumping flow (for example 8 l/s) when it is in use instead of average flow for the day. If it was running the first eight hours of the day, multipliers and flows would be:

| Multipliers | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flow in l/s | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

This is a lot more visual as binary, 1 is "on" and 0 is "off".

# The daily consumption pattern

You have calculated what the beneficiaries consume in a whole day but the way the water is consumed in that day is as important as the total quantity. The figure below shows the variation of consumption according to the hour of the day for twenty urban beneficiaries in Bolivia. Although each one consumes in a different way, tendencies can be observed. For example, the consumption at night, from 0:00 to 6:00 is very low.
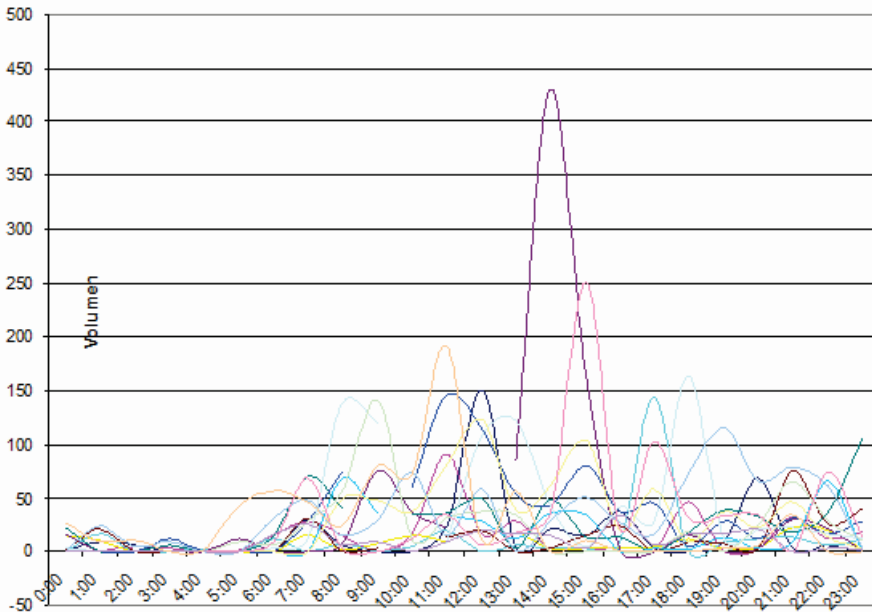


These tendencies can be summarized in the **consumption pattern** that you will find on the next page. The method of construction is relatively simple:

1.  Take the measurement during 24 hours in certain points. In order to have statistical validity there have to be at least 30 points.

2.  Find the average for each hourly frame, this sometimes requires the decision to be taken as to whether an unusual consumption is deleted or not. It's possible, for example, that there is one in every 30 consumers that is a high user therefore gave a peak that is not due to an error (i.e. a tea shop or car wash). Before eliminating them you should think hard about the decision. If you want to split hairs, you can see what values are anomalous in a statistical test of out of range values (i.e. Grubbs).

**3.** These tendencies are now reflected in what Epanet calls "patterns" but we have been calling consumption pattern. The dotted line is the average consumption.
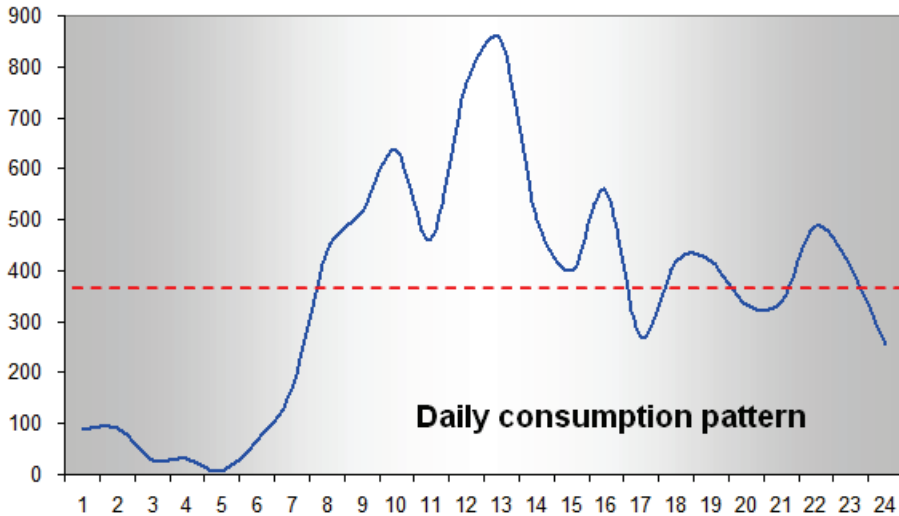


Note that if you measure patterns of networks that are not performing correctly you can end up with an undesirable pattern.

It is unlikely that the peak of consumption coincides exactly with one of the hours measured. The result is that there is always a peak that is overlooked. The way to take this peak into account is to estimate shape of the demand curve. Although there are programs that have the option to do this automatically, this is not the case with Epanet. If there is very rapid growth in the demand before and rapid decline after an hour, as in the graph, you can take this peak into account by drawing it on graph paper or making a graph with the "smoothed line" option in a spreadsheet.
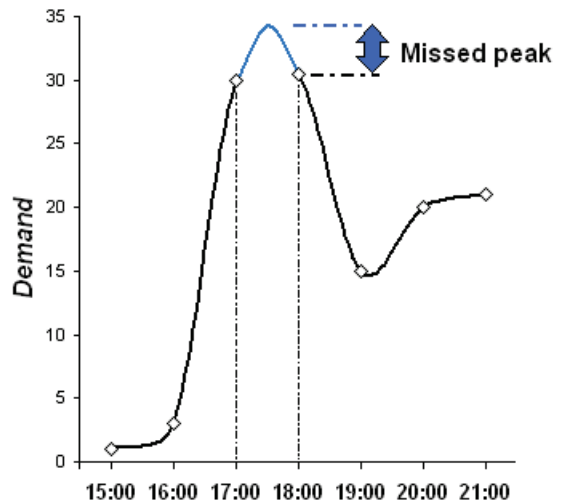


Assess yourself if it is worth the hassle to do in your network.
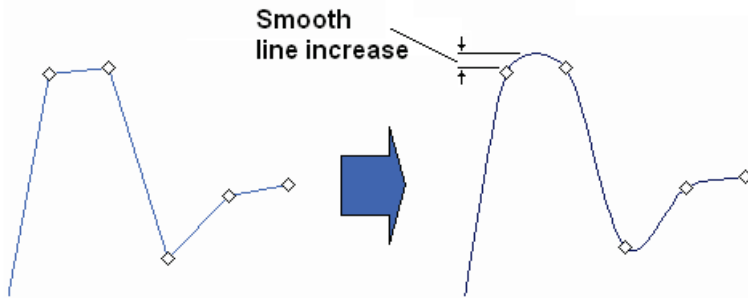
So that Epanet can understand the tendencies, they must be expressed in the form of multipliers, one every hour timeframe. In the following section you are going to see a step-by-step example.
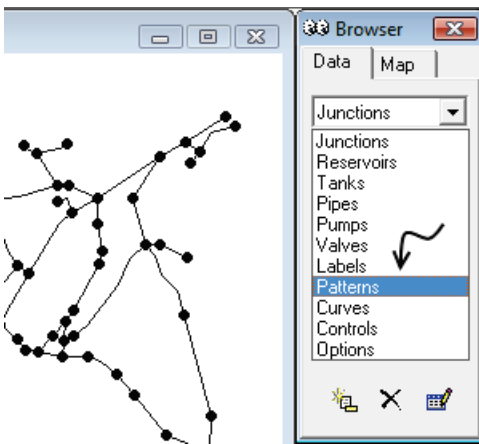


If the multipliers are done well, their average is 1 and their sum 24. Once ready, enter them in Epanet by going to the browser and selecting "patterns" in the data tab.

To open the dialog box, click the add button. By adding the multipliers for each hour, it is going to draw a bar chart that corresponds to the daily consumption pattern, as you can see below:
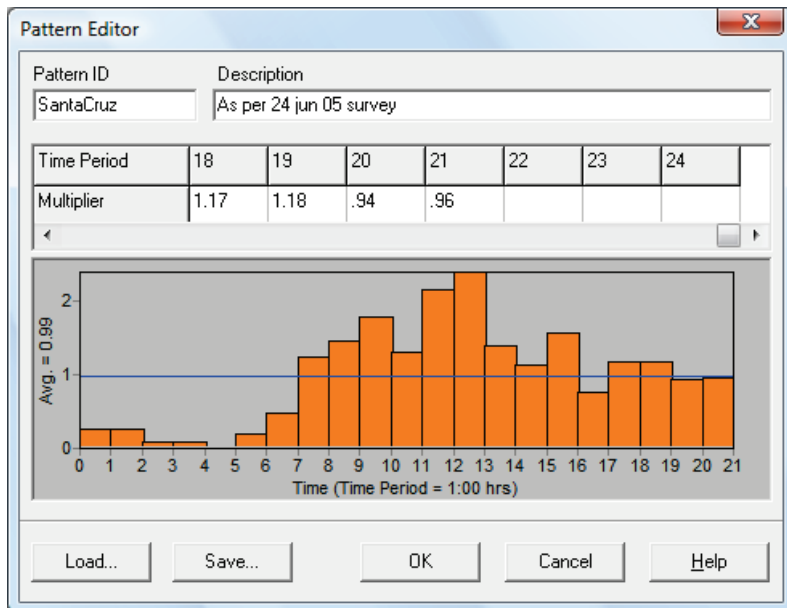
To name this modulation curve or pattern "1", enter "1" in the property **"Pattern ID"** for the junctions that have this consumption pattern. The highest multiplier is that **daily coefficient** and is of great importance in the calculation. In the example, although it is hidden it is 2.39.

## Example of the calculation of a daily consumption pattern

After having taken measurements in the field, the registered consumptions per hourly timeframe are shown in the first column. The next steps are:

| | Hourly consumpt. | Multiplier |
|---|---|---|
| 0:00 | 1800 | 0.20 |
| 1:00 | 700 | 0.08 |
| 2:00 | 200 | 0.02 |
| 3:00 | 300 | 0.03 |
| 4:00 | 500 | 0.06 |
| 5:00 | 1200 | 0.13 |
| 6:00 | 3000 | 0.34 |
| 7:00 | 8000 | 0.90 |
| 8:00 | 15000 | 1.68 |
| 9:00 | 12000 | 1.35 |
| 10:00 | 6000 | 0.67 |
| 11:00 | 5000 | 0.56 |
| 12:00 | 16000 | 1.80 |
| 13:00 | 23000 | 2.58 |
| 14:00 | 32000 | 3.59 |
| 15:00 | 25000 | 2.81 |
| 16:00 | 11000 | 1.24 |
| 17:00 | 7000 | 0.79 |
| 18:00 | 8000 | 0.90 |
| 19:00 | 9000 | 1.01 |
| 20:00 | 10000 | 1.12 |
| 21:00 | 9000 | 1.01 |
| 22:00 | 7000 | 0.79 |
| 23:00 | 3000 | 0.34 |
| TOTAL | 213700 | 24 |
| Average hourly consump. | | 8904 |

1. Work out the total consumption for the day adding up the consumptions for each hourly timeframe:

    1800 + 700 + 200 + …+3000 = 213,700 l

2. Work out the average hourly consumption, dividing the total by 24 hours:

    213,700 l / 24 hours = 8904 l/h

3. Finally work out the multiplier for each hour by dividing the consumption for the hour in question by the hourly consumption:

    0:00 → 1800 / 8904 = 0.20
    1:00 →  700 / 8904 = 0.08
    2:00 →  200 / 8904 = 0.02
    …..      …..      ……
    23:00 → 3000 / 8904 = 0.23

4. To finish, make sure there isn't a mistake by checking that the sum of the multipliers is 24:

    0.2 + 0.08 + … + 0.34 = 24

The daily coefficient is 3.59.



Daily Consumption Pattern
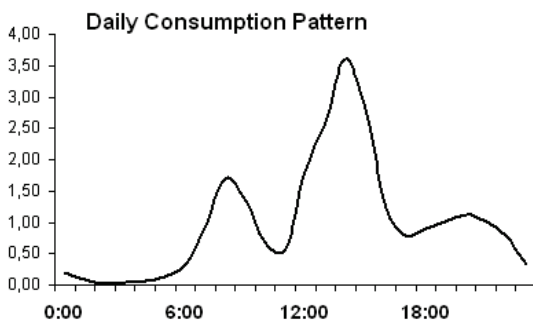
## When there is no data

Sometimes it's not possible to obtain data from the field, because there aren't counters or simply because there isn't a water system that allows the measurement of consumption. There are three ways to proceed:
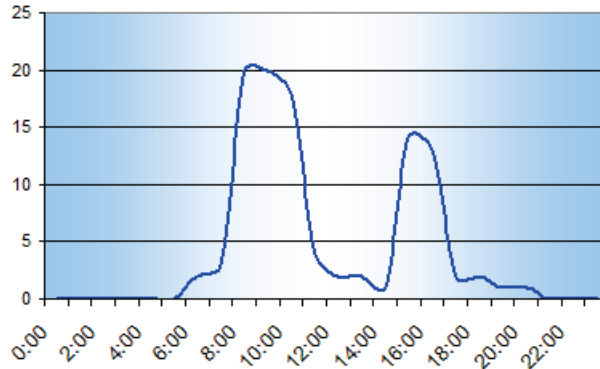


a. Assume the population adapts to a **general pattern**, in which there is a peak of consumption in the morning where approximately 60% of the water is consumed in 3 hours and a second peak in the afternoon with 25% in two hours. The remaining 15% is used in the rest of the hours. Then you would build a fictitious pattern that behaves like this.

b. Assume a **generic total multiplier** that summarizes the daily, weekly, monthly peaks, etc (we will see this further on) with a value around 3. In my experience in developing countries they take values higher than 2.5 for extended-period and 4.5 for static (see Global coefficient section).

c. **Survey the population.** A simple technique and very visual is for them to make piles with 100 grains of maize according to hours. If for the afternoon there are 40 grains, they consume 40% of the water. Unfortunately, people are not very conscious of how they use water.

# Entering different demands

Take into account that **there isn't just one consumption pattern.** Taken to the extreme, each beneficiary has their own pattern. In practice, with a few patterns all significant groups are incorporated.

For example, compare an office's consumption, mostly in office hours,
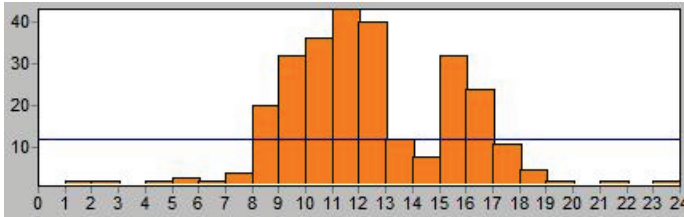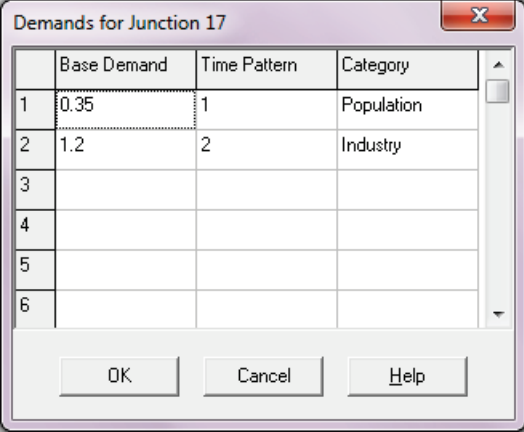


with that of a restaurant, that has peaks that coincide with mealtimes,
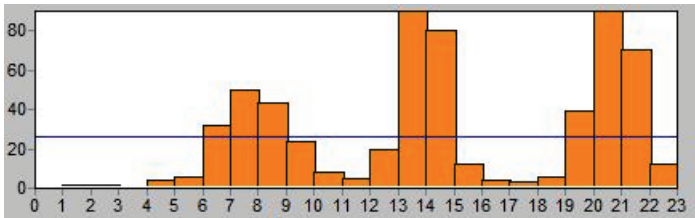


and to finish, with one from an industry that works at night because of excessive heat:
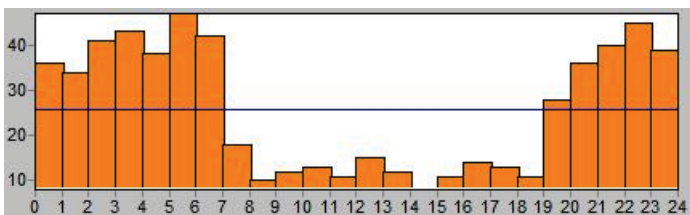


One junction can supply various families with a consumer demand category, and a workshop with an industrial demand category. This is done with the parameter "Demand Categories" in the properties of the junction, which opens the following dialog box:

| | Base Demand | Time Pattern | Category |
|---|---|---|---|
| 1 | 0.35 | 1 | Population |
| 2 | 1.2 | 2 | Industry |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |

**Demands for Junction 17**

OK    Cancel    Help

The demand for this junction is the sum in each hour of the consumer demand category of 0.35 that will be applied according to the pattern 1 and the industrial category, 1.2 l/s, which will be applied according to pattern 2.

# The weekly consumption pattern

This is similar to the daily consumption, but with the following exceptions:

- It is unnecessary to build the entire pattern but simply compare the pattern for the measured day against the day of highest consumption in the week. To transfer the information use a coefficient called the **weekly coefficient.** If a Saturday was measured, whose daily coefficient is 1.18 and the day of highest consumption is Wednesday (daily coefficient 1.35) the weekly coefficient will be worked out as follows:

$$Cw = \text{highest multiplier / multiplier of the day of the measurement}$$

For example:   Cw = 1.35 / 1.18 = **1.154**

- Taking measurements over the course of a week is exhausting and normally there are not very significant differences. Therefore unless the population have a pronounced pattern (i.e. a market day) it is fruitless to gather data and contributes little to the result.
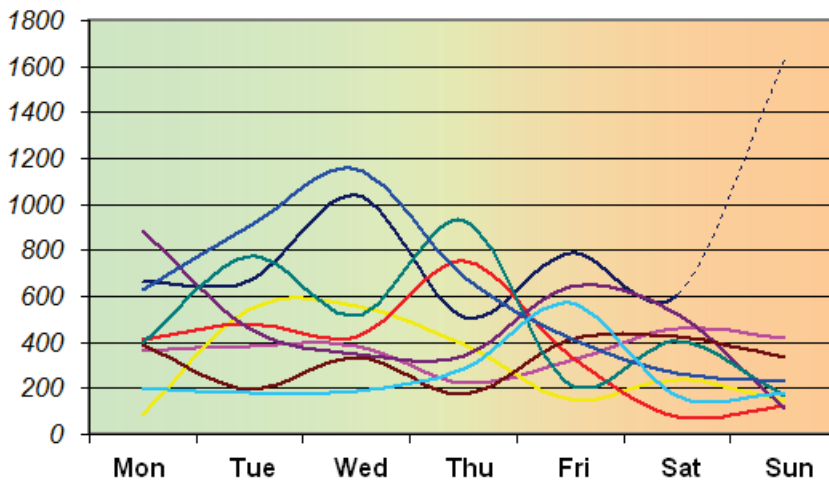


The value of the weekly multiplier is not entered into Epanet.

# The monthly consumption pattern

This pattern is very important and fortunately as billing is normally done monthly, there invariably will be networks to study. We will proceed the same way as for weekly using this example below which details three consecutive years of consumption with the average temperature and precipitation:
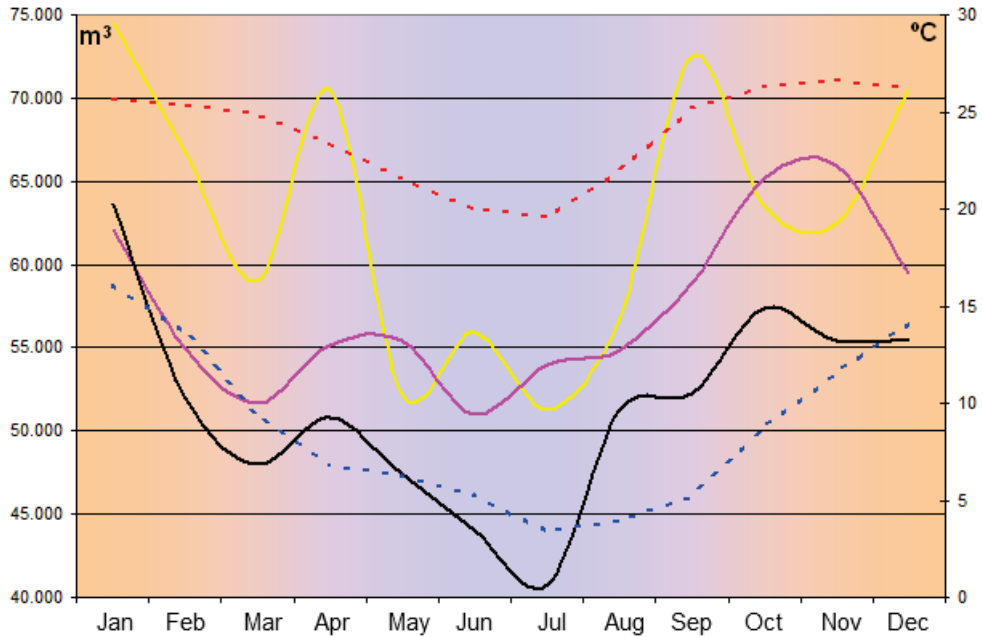


You can see clearly that the consumption falls during the "summer" months bearing in mind that this is the winter in the Southern Hemisphere. Water consumption and temperature are usually related. The coefficients for monthly averages are summarized in the table on the next page. The columns represent multipliers for the years 2002, 2003 and 2004 with different months and their averages in the box. The separate table below illustrates real consumption in $m^3$ for the same months and how it was calculated.

If the month measurement had been July with a multiplier of 0.85 and the maximum of 1.17 corresponded with January it leaves:

Cm= 1.17 / 0.85 = 1.376       Cm, monthly coefficient

| | 2002 | 2003 | 2004 | Multipliers |
|---|---|---|---|---|
| μ | 51.523 | 57.385 | 62.996 | 57.301 |
| JAN | 1,235677 | 1,081293021 | 1,18366715 | 1,17 |
| FEB | 1,008187 | 0,958246929 | 1,05957942 | 1,01 |
| MAR | 0,931426 | 0,90056635 | 0,93584091 | 0,92 |
| APR | 0,985246 | 0,961523046 | 1,11866277 | 1,02 |
| MAY | 0,92046 | 0,966454648 | 0,82884957 | 0,91 |
| JUN | 0,854742 | 0,888315762 | 0,8877583 | 0,88 |
| JUL | 0,791527 | 0,940280561 | 0,814801 | 0,85 |
| AGO | 0,994659 | 0,955371613 | 0,90141002 | 0,95 |
| SEP | 1,014476 | 1,02552932 | 1,1506808 | 1,06 |
| OCT | 1,112335 | 1,13574976 | 1,00794101 | 1,09 |
| NOV | 1,075206 | 1,149411867 | 0,99225741 | 1,07 |
| DEC | 1,07606 | 1,037257123 | 1,11855165 | 1,08 |

| | | | | |
|---|---|---|---|---|
| JAN | 63.666 | 62.050 | 74.566 | 66.761 |
| JUL | 40.782 | 53.958 | 51.329 | 48.690 |
| | 1,56 | 1,15 | 1,45 | 1,371 |

.
The value of the monthly coefficient should not be entered into Epanet.

# Unaccounted-for water

This refers to water lost by leaks, illegal connections, some public services, etc.



To make an approximation of this, compare the water that is produced against what is measured. The difference is the unaccounted-for water. For new networks it is estimated at 20%. Using this, the multiplier for a new network would be 1.2. So a network carrying 10 l/s would really have to carry 12 l/s, and would lose 2 l/s along the way:

$$10 * 1.2 = 12 \text{ *}$$

If the network is homogenous it is simple. Distribute the Unaccounted-for water between all of the junctions equally. When parts of the network are older than the rest, the unaccounted-for water should be increased for older pipes and when pressure is higher in a specific zone as it will lose more water. In both cases, a different multiplier can be established for each of the zones.

The value of the unaccounted-for water should not be entered into Epanet.

---

\* *Multiplying by 1.2 is the quick way of adding 20%: 10+0.2\*10 =10(1+0.2) =12*

# Global coefficient

To take the daily demand measured to the hour of the day, the day of the week, the month of the year with higher consumption, multiply together all the coefficients according to the type of analysis to be done:

a.  Steady-state analysis multiplies all the coefficients,

Global  = Daily x Weekly  x Monthly x Unaccounted-for water
Global  = 2.39 x 1.15 x 1.37 x 1.2 = **4.54**

If the average demand for the future population was 100 l / hour, the maximum the system would have to deal with is:     100 l  x 4.54  = **454 liters / hour = 0.126 l/s**

**This is the value that should be distributed between the junctions**, as you will see in the section "Demand allocation", to be able to enter the parameter base demand in each of them.

b.  Extended-period analysis multiplies all the coefficients except for the daily. That is because the multipliers for the daily pattern are going to be applied to each hour, and the multiplier for each hour doesn't have to be the maximum.

Global  = Weekly  x Monthly x Unaccounted-for water
Global  = 1.15 x 1.37 x 1.2 = **1.9**

If the average demand was 100 l / hour, the respective demands would be:

| | | | | |
|---|---|---|---|---|
| 0:00 | 100 l/hour * 0.2 * 1.9 | | = 38 l/hour | |
| 1:00 | 100 l/hour * 0.35 * 1.9 | | = 66.5 l/hour | |
| … | ... | … | … | …. |
| 12:00 | 100 l/hour * 2.39 * 1.9 | | = **454 l/hour** | Peak of consumption! |
| … | ... | … | … | …. |
| 23:00 | 100 l/hour * 0.4 * 1.9 | | = 76 l/hour | |

You may have noticed that in both cases the peak is the same, 454 l/hour.

Once the model is analyzed statically, get rid of the daily peak coefficient before analyzing it in extended-period as the daily coefficient must not be applied twice. In

practice, do both analyses at the same time as explained in Chapter 6, but here is an example to clarify the concept.

For this you would do a group edit:                    > Edit / Select all
                                                        > Edit / Edit group

You should substitute the original value for the result of the average demand times the new coefficient (1.9), that's to say:

       100 l/hour * 1.9  =  **190 l/hour = 0.053 l/s**

And the dialog box would be:
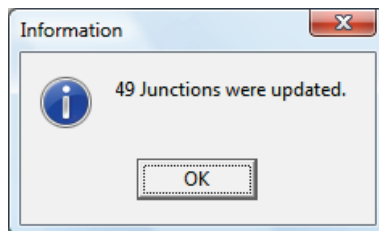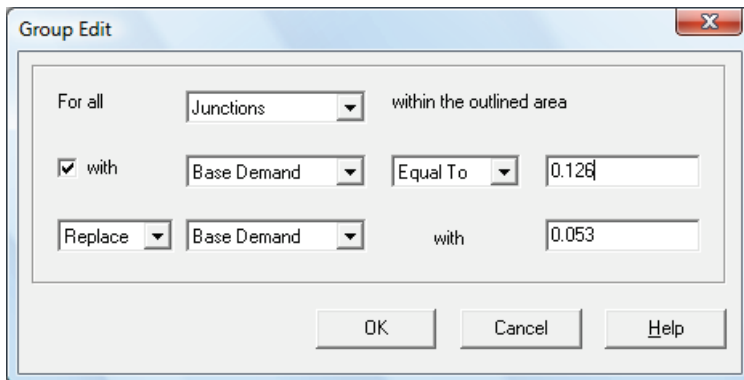




There is no need to add a safety factor since networks calculated this way are usually over-designed[1].

---

[1] *Cohen, J (1993). New trends in distribution research. Dynamic calculation and monitoring. Water Supply Systems. State of the art and future trends p213-250.. Computational Mechanics Publications. Southampton*

## Summarizing

Look at this very simple example to summarize what we have seen up to now:

1.  The population to be covered, all normal consumers, is 10,000 people.

2.  You have decided that it is reasonable to project the population over 15 years. Applying the formulas, the design population becomes 18,000 people.

3.  The total demand is 18,000 people x 50 liters per person = 900,000 liters

4.  The average demand expressed in liters per second is:

    900,000 liters * 1 day / 86,400 seconds = 10.4 liters/ second

5.  You have worked out the weekly coefficient to be 1.1, the monthly 1.4 and the corresponding unaccounted-for water 1.2. The adjusted demand is:

    10.4 liters/ second * 1.1 * 1.4 * 1.2 = 19.25 l/s

6.  If you have 10 junctions, and have opted to assign the demand homogenously (next section) it leaves:

    19.25 l/s / 10 junctions = 1.925 l/s*junction

7.  You have constructed your consumption pattern and the highest multiplier of the day is 2, that is to say, during that hour of the day the consumption is double the average.

8.  Now you can proceed in two different ways according to the type of analysis you want to run:

    8.1 If you want to run a steady-state of the rush hour, the demand to enter into the properties dialog box is the product of the adjusted average demand per junction and the highest multiplier of the day:



    1.925 l/s*junction * 2 = **3.85 l/s**

8.2 If you want to run an extended analysis, the succession of static analyses over 24 hours and not just of the peak hour, the demand to enter in the dialog box is exactly the one you have obtained in point 6, **1.925 l/s,** as well as adding the demand pattern calculated in 7, called "1" and shown by the arrow.



## Calculation of the demand from top-down

By now you have probably realized that calculating the demand requires a lot of field work. This way of calculating the demand is called "bottom-up", which is to say from consumer to source.

You may feel tempted to use the opposite approach, "Top-down" which basically consists of seeing how much is produced then distributing it between the consumers. This method employed frequently in developed countries, will produce the following problems:

1. **The networks are usually falling to pieces.** To take the production of a neighboring network to calculate the demand of a future network can lead big errors.

2. **The networks rarely provide service without cuts or restrictions.** To use a dysfunctional network as a base of calculation is to perpetuate the mistakes in all the following ones.

3. **The production data is not always reliable or thorough.** Frequently it contradicts other data. Regression is an interesting statistical technique for looking at the reliability of data.

   Imagine you have received some data from the operators about the running hours of the pump of Well 6. We need to be certain that the data is correct in order to estimate the quantity of water entering the network for people's consumption. The approach is very simple, if the pump pumps 10 $m^3$/h and has run for 5 hours, it has pumped out 50 $m^3$ or 50.000 liters into the network. With the running hours per month data vs. total cost, we drew the following graph of the group of points.

Working hours

Borehole 6

$y = 0{,}0032x + 646{,}9$
$R^2 = 0{,}003$

Bolivianos  (Local currency)
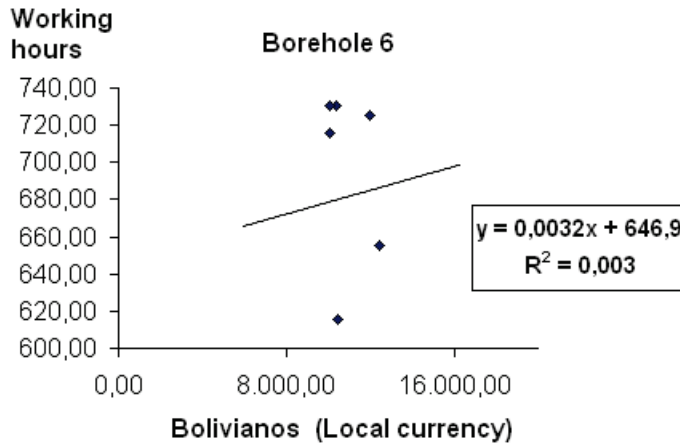
As the tariff is the same for all hours in the day, the two variables should be proportional. So many hours consume so many kWh costing the same unit price. The cost for ten hours of pumping is bound to be half the cost for 20 hours.

However, by using regression to compare the hours declared by the operators and the cost from electric company… they are independent variables[1]! Notice that in spite of their difference, 730, 715 y 610 hours of work generate all the costs around 10,000 Bolivianos. The two most probable reasons are that the company is charging randomly or that the operators are not overly disciplined in recording working hours. Whichever of the two cases, a design cannot be based on this uncertainty.

---

[1] *The closer the R coefficient is to 1 or -1 the strongest the dependence between variables. A coefficient close to 0 means that the variables don't depend on each other, they are independent. If the two variables directly depend on each other, as it should be, the points would line up in a straight line or in its vicinity. More explanation can be found in any statistics textbook or by searching the internet.*

# Small systems and other approaches to demand

*Pay close attention to this section, as it´s really important.* What we've seen up to now is the **time-varying demands method (TVD)** which is not suitable in all situations:

## All taps open method

The TVD method is irrelevant in some cases where users don't choose how they use the system but are forced to line up for what the system can deliver, for example, in an emergency system set up after a disaster. It is also common where the population chooses a smaller less costly system, for example, a set of public fountains each of a certain capacity.

A tap is assigned with a specific number of users, and the flow is designed to supply all taps simultaneously. For example, one tap is assigned 250 people with a flow of 0.2 l/s. Then if two tap tapstands are used, the overall demand is 0.4 l/s and that is what is introduced in a node representing the tapstand in Epanet. There is no pattern.

## The Simultaneity method

When a system is small using the average flow as in the TVD method will lead to installing pipes which are too small. To illustrate this, imagine for a second just one tap at the end of a pipe with a flow of 0.2 l/s. If at the end of the day the user has consumed 50 liters, the average flow is very small:

$$50l / 24h*3600 \text{ s/h} = 0.00058 \text{ l/s}$$

However, when the tap opens, the pipe has to carry 0.2 l/s...almost 350 times more!

This difference between the average flow and the instantaneous flow becomes smaller and smaller as the number of users increases. The fact that one user opens or shuts a tap becomes less and less important, and the average demand begins to stabilize. The point at which the simultaneity coefficient coincides with the TVD coefficient varies from one system to the other, but you can use the rule of thumb of 250 connections (not people).

This effect takes place in every pipe. Even if a system supplies a lot of people, if in one particular branch line there are only 35 connections, be careful not to install pipes which are too small.

The design flow of the pipe obtained by multiplying the average demand by a simultaneity coefficient you can get from this graph (Arizmendi 1991), that substitutes all the TVD coefficients:

**Multiplier**
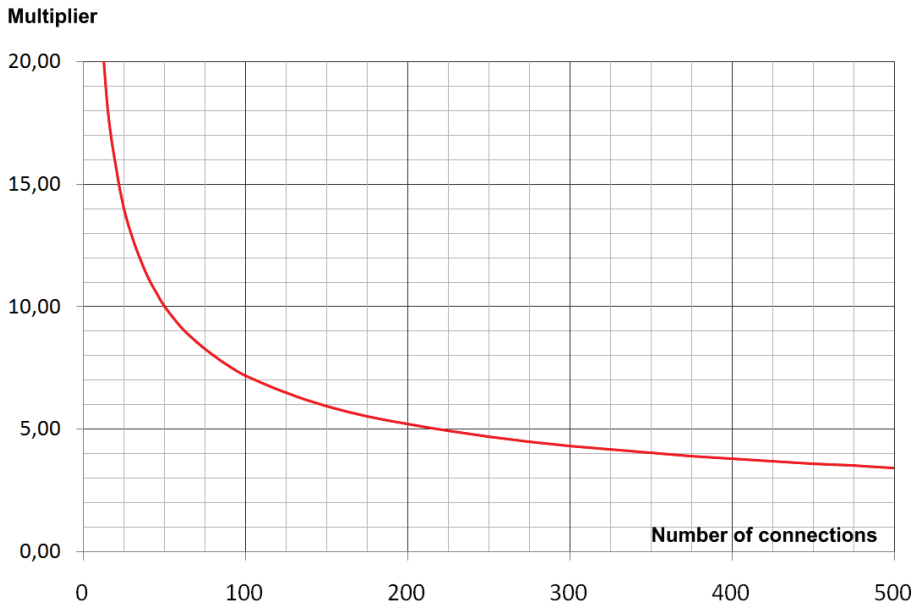


Now, there is an important catch, **you cannot use simultaneity with Epanet[1].**

The simplest way of avoiding problems is to establish a **minimum diameter** for the entire system. For demands of over 50 liters per person per day, use at least 3"; less than 2" won´t be enough. Using minimum diameters is also really useful for protection against fires.

For large systems, there shouldn't be excuse for using pipes smaller than the minimum diameter, as you´re working with a bigger budget and the added expense is minimal. The concentration of more people also demands greater protection from fires.

To sum up, choosing the method for calculating the design demand comes down to 3 basic questions, which you can see in the flow diagram below:

---

[1] *Since each pipe will have a different number of users and a different coefficient, the mass is not conserved, in other words, water is "created or destroyed" when using this method.*

Average demand

Are people going to queue
at distribution points?

YES

NO

All taps open

Has a minimum diameter been stablished?

NO

YES

Simultaneity

Temporal variations
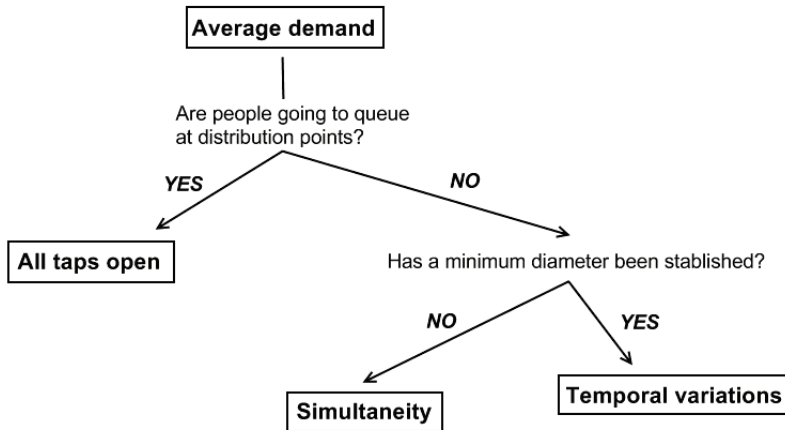
# Demand allocation

Previously we saw how to determine peak demand and how to apply it to projected population. Even more important is how to distribute this demand between different junctions, that is, to **allocate the demand.** I have a demand peak of 43 l/s, how do I distribute that demand between the 67 junctions that are on my drawing?

Compare these two methods of drawing the pipes horizontally:
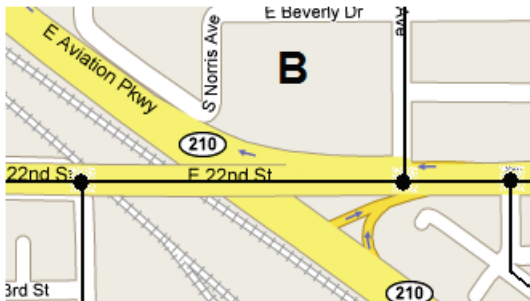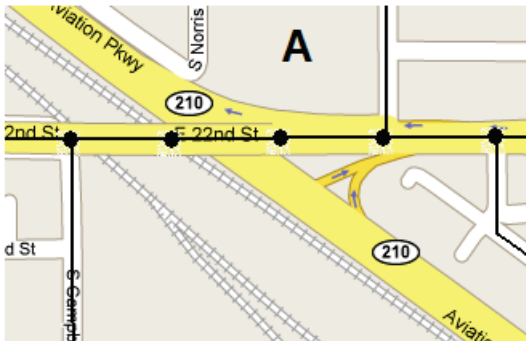


Example A has 5 junctions and Example B has 3 covering the same distance, so the demand per junction is dependent on the method of drawing.

In Example A you would divide the demand by 5 junctions and in Example B by 3 junctions so that the pipe is transporting the same flow.

**Allocating the demand correctly is one of the key steps in obtaining a precise model.**

You have two options and combinations:

## 1. Point by point assignment

Assign each beneficiary their consumption. This option is laborious but makes models precise and is suitable for small networks or building interiors. It is impossible to predict consumption for future beneficiaries therefore it is only suitable for networks with little potential for growth. Assigning point by point is especially recommended for large consumers, a hospital, a market, an industry…

To do this, distribute 50% of the total consumption between the ends of a pipe except in the case of a large consumer (the big yellow junction). Try to represent correctly the real distances to the end nodes in the model by precisely positioning the big consumer so that it divides the pipe into two, each with its corresponding distance to the end node.
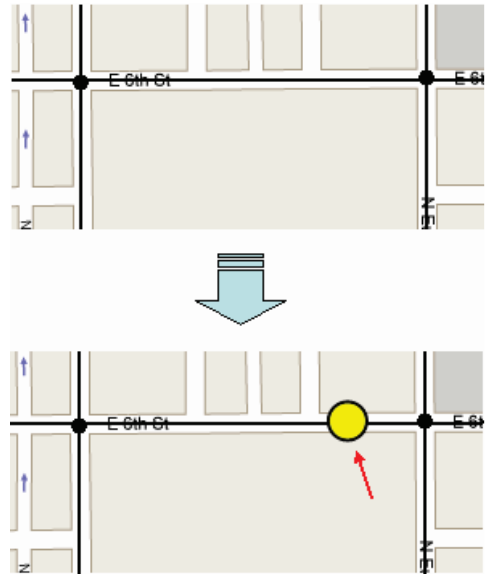


The idea is that, since water will find the easiest way to the consumer, the different travelling distances to reach it from either side are accounted for.
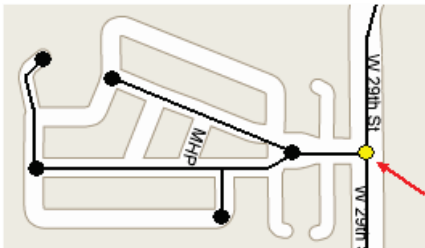


If there is a small branch coming off a junction, the total consumption of the branch is assigned to the junction (yellow).

## 2. Assignment by streets

The total beneficiaries for each street are distributed between the first and last junctions. This can be done by stretch, as in the image, or by meters of pipes. For example, Silverlake Rd is 1200m long, we are considering a stretch of 120m and the total average consumption of the street is 20 l/s. The stretch considered will have a consumption of (20 l/s / 1200m) * 120m = 2 l/s, to be distributed between the two junctions.
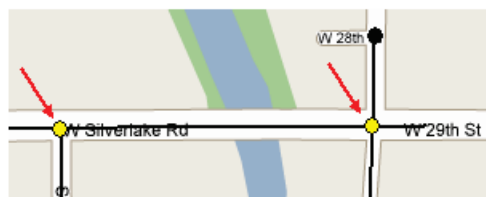
## 3. Assignment by grids
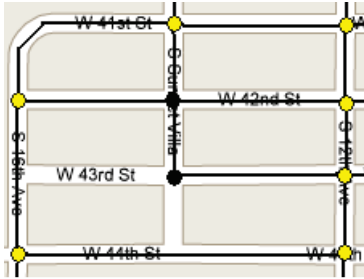
The consumption within a grid is distributed equally between the junctions surrounding it. This method of assigning is particularly useful if you use population densities as follows:

Maximum density: 500 per./km$^2$
Area enclosed by the grid: 2 km$^2$
Number of junctions: 10
Average consumption per person: 0.01 l/s

500 people/m$^2$  x  2 km$^2$  x  0.01 l/s  /  10 junctions  =  1 l/s in each junction.

## 4. Total assignment

Where consumers are evenly distributed in symmetrical networks the total demand can be divided equally between the junctions.
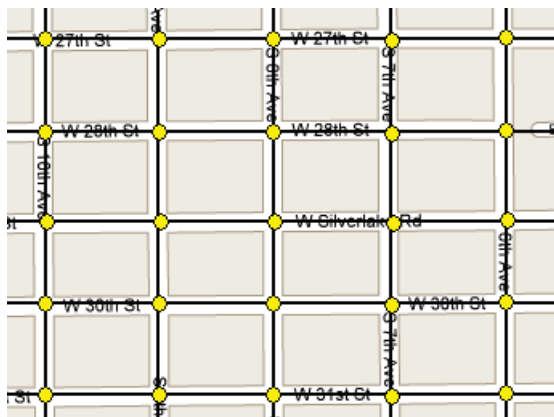
With a total consumption of 50 l/s between 25 junctions, the consumption per junction is:

50 l/s  / 25 junctions = 2 l/s*junction

# 5

# Modeling water quality

Introduction
What parameters of water quality to evaluate with Epanet?
Preparing the model for water quality
Ascertaining your chlorine decay coefficients
Defining the chlorine entry points

➢ **For chlorine to have an effect, people must <u>drink it</u>.**

# Introduction

The chapter started with the statement "For chlorine to have an effect, people must drink it".

Surprised? Of course chlorine doesn't work like a medicine, but…

a. **Often people prefer to drink water that isn't chlorinated.** To build an amazing water system where people won't drink the water because it tastes of chlorine is failing to achieve the objective. In some cases, the chlorination process is so bad that the users complain immediately that it is ruining their clothes. Often, communities unaccustomed to the flavor of chlorine, taste it and reject it even at low concentrations. A patient marketing campaign which introduces chlorine then gradually increases the dosage can deter people drinking from roadside puddles as illustrated.

 For safe water to have an effect, it has to be drunk.

**b. It's essential to protect water from recontamination when** in contact with dirty containers, dirty hands, animals, etc. A small quantity called **residual chlorine** is needed, usually between 0.2-0.6 ppm. You can see in the image below how the hands of the user are *washed* right into the jerry can in one of the several models of self-closing taps popular in cooperation:



## One last idea

Maybe hearing the word marketing applied to development has repulsed you. Don't underestimate the possibility of utilizing marketing to help introduce beneficial ideas, especially those that are culturally or religiously neutral. Examples and the philosophy behind the use of marketing are described briefly in "The Critical Villager" by Eric Dudley.

There are also interesting examples in developed countries. For example, to avoid saturating the environment with plastic bottles in Paris, the Water Authority launched the campaign "La carafe de Eau de Paris". It uses bottles like the one illustrated to promote the consumption of tap water in Paris, where 51% of the inhabitants say they drink bottled water.



Similar campaigns, adapted to the context, could promote the use of safe water instead of water from contaminated sources.

# What parameters of water quality to model with Epanet?

Mainly two:

## Water age

This is a measurement of how long the water stays inside the network. It has two main purposes:

1. **To ensure contact time with chlorine**. To ensure that water is drinkable it has to have had contact with chlorine for 30 minutes. Water must remain in the network for at least 30 minutes. In systems without tanks this is quite difficult to achieve.

2. **To avoid quality deterioration with time.** When water spends a long time in pipes, the quality deteriorates noticeably. It you have come back to a house unoccupied for some time, you have probably noticed how dirty water comes out from tap. As a general rule, plan for **water to spend no more than one day in the network.** Although three days is normally recommended, it is possible that the network has not been well maintained and under these circumstances the risk is increased. Longer times suggest that the network has been overdesigned, or that it has a tree-like structure allowing the accumulation of water at the end of pipes. The image on the following page shows water age at 12:00 PM. It can be clearly seen that water has aged more at the far edges of the system.

   From this we reach an important conclusion: **It is in the furthest and most isolated areas of a network where quality problems are greatest**, mainly because:

   - The journey time is longer. Chlorine concentration decreases through internal reactions with time, increasing the possibility of contamination.

   - Recirculation or dilution is not possible as the water only travels one way.
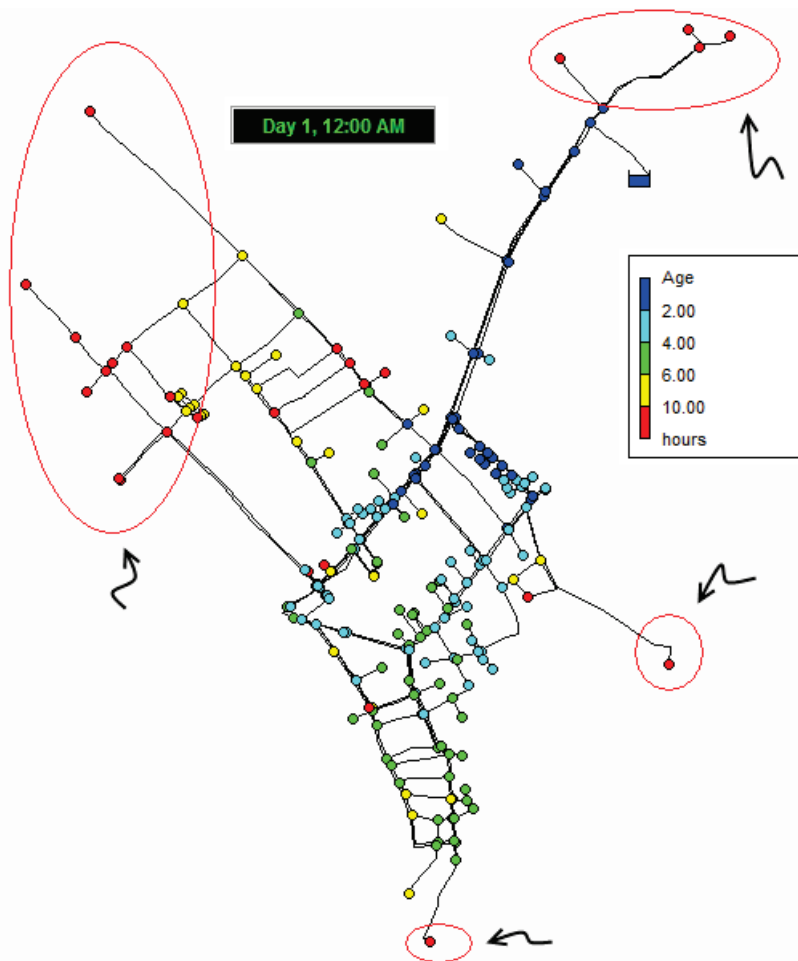
## Chlorine concentration

We have already seen that to prevent water being contaminated after chlorination, it is necessary to maintain at least **of 0.2 ppm** of residual chlorine. When the amount of chlorine is increased, it starts to flavor the water and people may reject it in favor of less secure water sources. This maximum value depends greatly on the population treating the water and whether they are accustomed to chlorination or not. A **maximum of 0.6 ppm** is advised. Contamination is inevitable with opening taps by hand or using dirty containers.

# Preparing the model for water quality

You can only do all these analyses if you are simulating in extended-period, or quasi-static, as you have to see the change over time. You will find more details in the section "Steady-state vs. Extended-period analysis" in Chapter 6.

To inform Epanet of your intention to work in extended-period mode, go to the Data tab of the Browser, and select Options. In that menu, select Times.
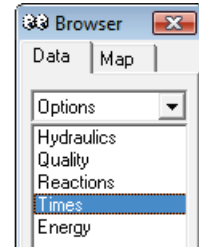
This choice opens the dialog box below to the side. Set "Total Duration" to 72 hours. Epanet will show the evolution of parameters during that time. Only select 24 hours for very simple networks. For networks with tanks, using 72 hours allows you to observe cumulative effects from one day to another that would go unnoticed in a 24 hour analysis. In the following example, tank 4's losses accumulate from day to day until after 40 hours it is completely empty. After this point it is as if the tank does not exist, as it will never fill again.
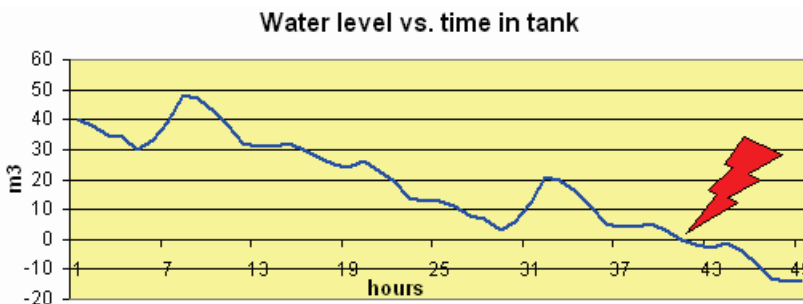
If the network is stable and properly designed, after a few days it starts cycling. Concentration, pressure levels and the tank level are very similar at the end of each day so that the network **goes back to its initial levels at the end of each cycle.**

The time that passes "between each snapshot" is called the **Time Step** and although it can be taken as milliseconds, months, or whatever, to make life simpler I recommend using hours. Human communities live according to the hours in a day, water age expressed in hours is easy to understand, and chlorine decay is sufficiently slow also to be evaluated in hours. To enter smaller intervals, for example a minute, will waste your time forcing you to go through the 1,440 images that the simulation will produce daily and more importantly, changes will pass unnoticed because they will be too subtle to be seen between if the step is too small. Below you can see the obvious differences between two images for the development of chlorine concentration "taken" three hours apart.
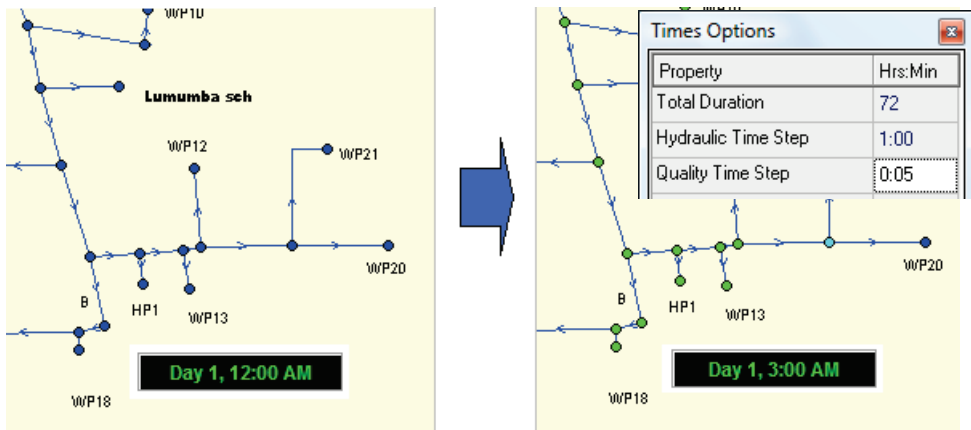


The configuration of the first three parameters in the menu, Total Duration 72 hours, Hydraulic Time Step 1h and Quality Time Step 5mins looks like this:



The remaining parameters allow more freedom for configuration and visualization of results but you will rarely use them except for "Report Start Time", which we will look at later. Detailed explanations can be found in the Epanet Users Manual.

**Configuring the quality**

To set in Epanet the type of analysis to make, open the dialog box for quality in the Data tab, as shown below.
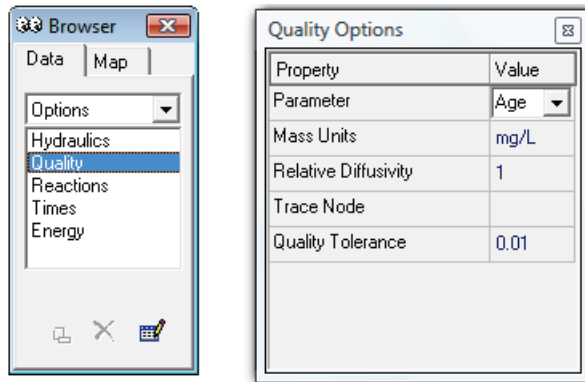
- **Chemical** is used to analyze the developing concentration of a reactive agent, usually chlorine.

- **Age** is used to see the water age.

- **Trace** is used to ascertain the percentage of water coming from a specific junction. This is useful where water is mixed from two sources and for example, when due to excessive salinity, it is necessary to dilute one source with the other to produce a mixed yield that is now acceptable.

To apply the configuration changes, press the lightning bolt.

# Ascertaining your chlorine decay coefficients

These coefficients are specific to the water you are treating and the pipes that transport it therefore are totally reliant on accurate measurements. There are no books to provide this information.

Chlorine is consumed in the water itself and through contact with the interior wall of the pipe. You can estimate this consumption through reaction coefficients.

## Wall coefficient for chlorine decay

This coefficient is found experimentally and is elusive. The good news is that plastic pipes which are normally used are considered inert and have a coefficient of 0. If metal pipes are installed, wait to see what happens once the network is built, because you will have a "what came first the chicken or the egg?" problem. Should you order the material to suit the design, or should you design the network to suit the materials? You can use 0 in a design phase and measure it later if really needed. The coefficient can be measured by passing water of a known concentration at the constant flow rate through a long section of pipe, minimum 300m. Use longer if the sensitivity of your measuring apparatus isn't good. By measuring the concentration of chlorine at the entrance, exit, and calculating chlorine consumption in the middle, you will see how much it consumes per length of pipe.
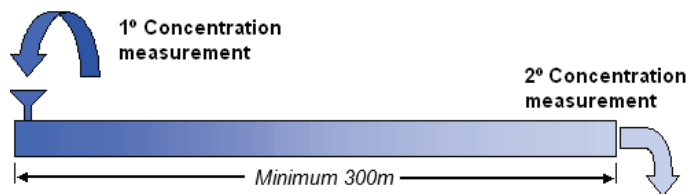


The pipes that you should suspect of high chlorine consumption are those of small diameter, metallic, and particularly if they are uncovered. The units are $day^{-1}$, negative values indicate that chlorine is consumed and positive values that it is generated. This value is entered in the pipe properties.

## Bulk coefficient

This coefficient is determined experimentally, measuring how the chlorine coefficient in a glass container filled with water from the source changes over time.

To determine the concentration of chlorine use a pooltester which uses a pigment to dye the water according to the quantity of chlorine in the container then, when compared against the color scale tester gives clear visible results. Variations of 0.1ppm are normal. Allow a sensible period of time between testing, for example, six hours to be able to compare color differences easily.

If concentrations in a working network are similar to what you are working with, subtle color changes will be difficult to measure with precision. If you measure higher concentrations, the speed of the reaction is different. To solve the problem test two samples side by side, one with half the concentration of the other. Remember that **one mg/l is the same as one ppm (part per million).**
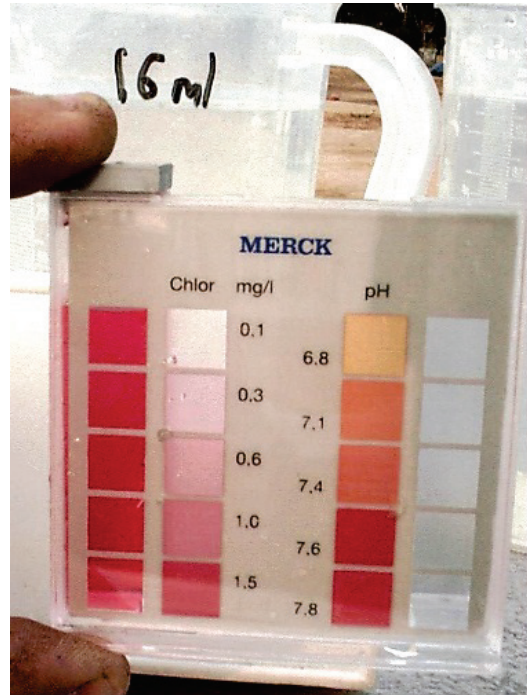
**Temperature can make the coefficient vary greatly**, up to 15 times more at 5º then at 25º. Do the test at a temperature close that found at the burial depth.

The procedure is as follows:

1. Add chlorine, for example from bleach, to the water to be tested until you measure a chlorine concentration of 1.5-2mg/l (1.5-2ppm) with the pooltester. If you use bleach try with 4 to 5 drops. This will be the first sample.

2. For the second sample either halve the quantity used for the first, or just add to a fixed volume of the first solution the same volume of water. The idea is that the second solution ends up with half the concentration of the first.

3.  Write down the concentration measured when the two samples are prepared. These are the initial concentrations.

4.  From this point, measure every 4-6 hours until the concentration has dropped in the first sample to the last mark above 0 on the pooltester.

5.  At this level you can ascertain the coefficient by apply the following formula:

$$K = \frac{Ln\dfrac{C_n}{C_0}}{t}$$

Where: K, bulk coefficient in $days^{-1}$
C$_0$, the initial concentration
C$_n$, the concentration at the time of the measurement n
t, time in days

6.  Find the average of the two samples and use this value.

For example, if the initial value was 1.2 and you measured 0.6 after 24 hours,

$$K = \frac{Ln\dfrac{0.6}{1.2}}{1} = -0.693 \ day^{-1}$$

# Defining the chlorine entry points

In networks for developing countries chlorination happens most commonly in tanks. This guarantees that the contact time is sufficient for the chlorine to take effect. Two other possibilities are for a chlorinator which adapts to the circulating water flow or one with a fixed quantity feed. The main problem with fixed chlorinators is that the final chlorine concentration is very variable. Imagine for instance a fixed drip chlorinator. In flowing water chlorine is washed away maintaining stable chlorine levels. If the flow slows down the chlorine level will build up due to lack of flow.

### Initial quality vs. Source quality

Both parameters are used to determine the concentration of all water that enters in a particular point whether it's a reservoir or a junction:

- **Initial quality**, is a parameter created to avoid computer calculation time by allowing it to start with situations closer to equilibrium. When dealing with reservoirs it can cause confusion as not only is it the initial concentration but also the concentration of the water entering the network. That is to say, if the reservoir has a concentration of 0.6ppm of chlorine, all the water entering the network during the simulation will have the same concentration.

- **Source quality** is used when you want to vary the "initial quality" with a modulation curve. This is a similar situation to demand, and as we have seen with that, you should enter a value and afterwards a modulation curve that contains the multipliers for each time frame.

    For example, to simulate a chlorinator that works for the first 8 hours in the morning with a concentration of 1ppm , the modulation curve that we would create (called "on-off") and the dialog box that appears when you click on the suspended dots in the reservoir properties is as shown below:
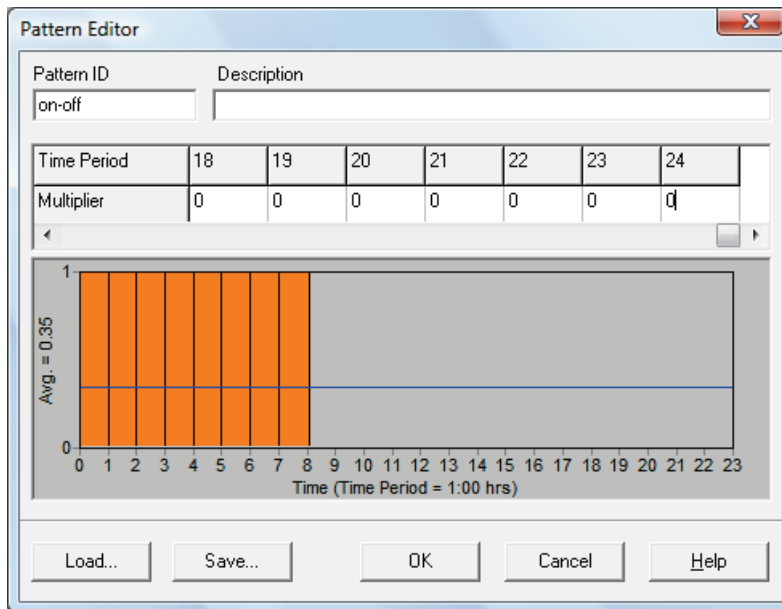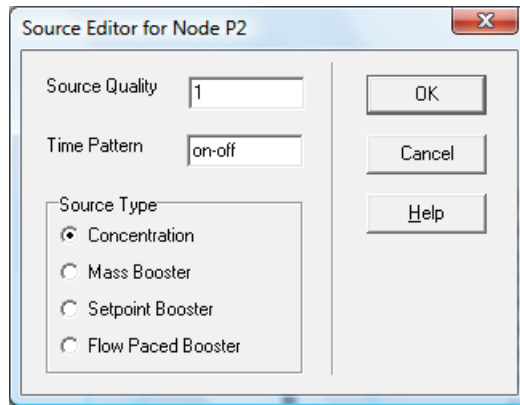
## Chlorination of a borehole

This is one of the simplest cases and usually chlorination happens with a fixed chlorinator that switches on and off with the pump. As pump flow is fairly constant it is not necessary to have much regulation. The chlorinators are more robust, cheaper, and their start/stop mechanism is simple. Boreholes can be represented in two ways in Epanet, as a junction with a negative demand or as a reservoir. In both cases to incorporate the chlorinator, assign an initial quality to the junction or reservoir, as shown in the following images.
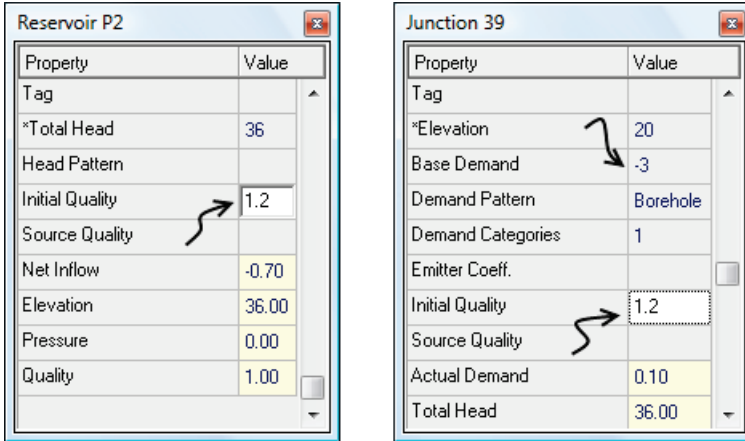
## Satellite chlorinators

These are used to increase the chlorine concentration in points that have dropped below the desired level. They are also called re-chlorination stations.

Click on the junction or tank where you want to situate it to bring up the properties editor. Click on the suspended dots of the 'Source Quality" parameter to open the following dialog box:
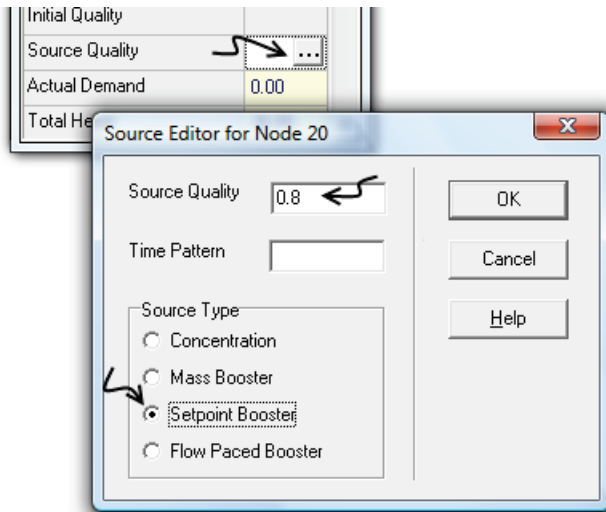


If the chlorinator is increasing the concentration in a certain quantity, select "Flow Paced Booster" and enter the value it adds. This is the most commonly used. If the objective of the satellite chlorinator is to restore a certain concentration value to the water, choose "Setpoint Booster" and then the value, which in the image is 0.8ppm.

This applies for treatment stations, for shock treatment, followed by an activated carbon filter that eliminates chlorine and a subsequent re-chlorination to the desired value.

## Full tank chlorination

For some simple systems every day the tank is filled, a quantity of chlorine added, and then is emptied completely. Here there are two ways to model this:

a.  Providing you have modeled tanks as tanks, enter in properties the average bulk coefficient as the Reaction Coefficient then after adding the chlorine in Source Quantity enter the chlorine coefficient. For a bulk coefficient of -0,4 day$^{-1}$ and a concentration of 0.8ppm it would look like this:

| Tank 51 | | |
|---|---|---|
| Property | Value | |
| Mixing Model | Mixed | |
| Mixing Fraction | | |
| Reaction Coeff. | -0.4 | |
| Initial Quality | 0.8 | |
| Source Quality | | |
| Net Inflow | #N/A | |

b.  If you have modeled as reservoirs, enter 1 as the initial quality and create a behavior curve that simulates the consumption of chlorine in the tank. To construct this curve use the average bulk coefficient equation again, with the concentration at time taken out,

$$C_n = C_0 \, e^{kt}$$

K, average coefficient in days$^{-1}$
$C_c$, initial concentration
$C_n$, concentration at hour n
e = 2.7182…

If the initial concentration in the tank is 0.8ppm and the average bulk coefficient is -0.7 day$^{-1}$ the points for this curve are plotted as follows:

Hour 1,   $C_1 = 0.8 * e^{-0.7 * (1/24)} = 0.78$ ppm
Hour 2,   $C_2 = 0.8 * e^{-0.7 * (2/24)} = 0.75$ ppm
….    …    …             …
Hour 24  $C_2 = 0.8 * e^{-0.7 * (24/24)} = 0.4$ ppm
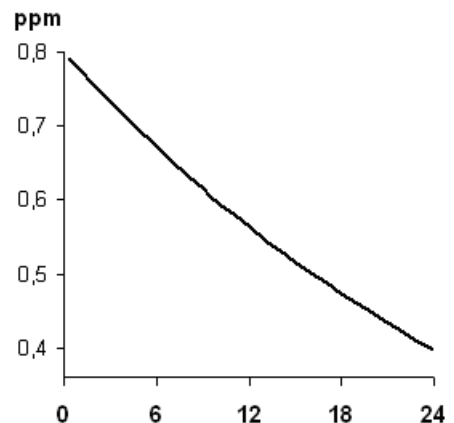
The graph shown right is typical for chlorine consumption.

To enter this data into Epanet, select "Patterns" from the Data tab of the Browser. Enter the data for concentration (ppm) for each hour. Having 1 as the initial concentration avoids having to calculate multipliers, the values can be entered directly.
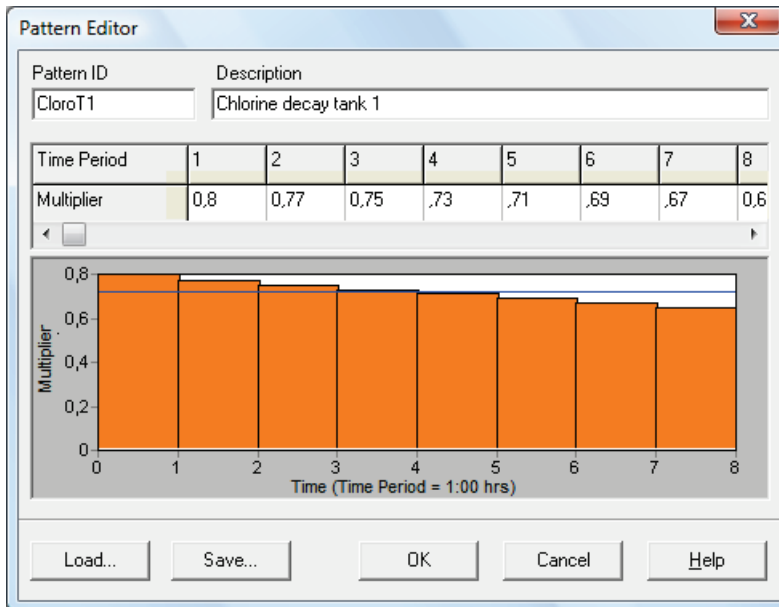
| Pattern Editor |
|---|

Pattern ID: CloroT1
Description: Chlorine decay tank 1

| Time Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Multiplier | 0,8 | 0,77 | 0,75 | ,73 | ,71 | ,69 | ,67 | 0,6 |



Load...   Save...   OK   Cancel   Help

# 6

# Working with the model

*The harder I work, the more luck I seem to have.*

*(Thomas Jefferson)*

# Beating the "Post-assembly laziness syndrome"

By this point you will have noticed that to set up a model requires a considerable amount of work. Sometimes time is short. Sometimes you have the false impression that you have done enough. Whatever the case, **a very common error is to rush the analysis.**

Here it's important to have clear ideas. You have spent all that time compiling data so the computer can give you a good analysis and now you should take advantage of that. Use it to the best of your ability to compensate for all the time you have invested in assembling the model and you will be rewarded with conclusive results. If you're not prepared to take time analyzing the results and working for the best design possible then don't turn on the computer in the first place. Get rid of this book and look for one more entertaining!

Every minute you invest in the analysis will save hours of headaches, changes and delays in a network that doesn't work. Badly planned networks lose their objectives before they are even built, however, with a small amount of your time you will add so much value for beneficiary communities.

It is human nature and inevitable that we all experience this syndrome at some point. The best way to combat it is:

1. **Start soon**. As with anything, don't spend time worrying about possibilities but focus your attention on the immediate problem. Once you have started, particularly tasks that make you worry or feel lazy you will find it much easier to continue.

2. **Establish clear objectives for this phase.** "After the analysis I want three alternative designs under 80,000 €, or "I am going to find one solution that involves installing less that 3km of pipes". A lot will depend on the characteristics of your job, but to set targets will keep you focused.

3. **Helping rushers to understand.** To analyze a network can take 2 or 3 days. Do you really need to rush so much? Is it so important that so-and-so has a piece of paper on such-a-day to jeopardize the outcome of the entire project? By avoiding speculative guesswork and presumptions you will undertake the job properly. If you have managed your time badly or time is limited, this is not the place to save time, sacrifice other things.

# Steady-state vs. Extended-period analysis

**Steady-state** only evaluates a single instant in time, generally the most unfavorable for the network. That is, it's like freezing time in that worst instant to see the velocities in the pipes, the pressure at the points, etc. As an analogy we can say that "Steady-state" is the moment of the total solar eclipse:



**Extended-period analysis** evaluates a succession of instants, usually an image of what happens each hour in a day, not just one of them, and is normally shown on the screen like a film. This is also called quasi-static. Going back to the analogy of the eclipse:



To start modeling the design with Steady-state makes it easy to make changes and see the results quickly. In this phase you can check if the capacity of the network is enough to meet demand using the calculation criteria as explained in the next section. Once the model is stable and effective for the demand we move to extended-period analysis to look at the parameters that depend on time, like the level of the tanks or the chlorine concentration.

# Calculation criteria

Before starting to analyze the model the calculation criteria need to be defined, that is to say, the range of values in which the solution for the model will be acceptable. Modeling in a development context, we are mainly interested in five parameters: pressure, velocity in the pipes, hydraulic gradient, water age and chlorine concentration.

## Pressure

Usually you would try to keep this **between 1 and 3 bars**, or 10 and 30 meters of head, which is the same. This can be easy or difficult, depending a lot on the terrain.
Networks with less than 1 bar have problems. For example, very low pressures mean that self-closing taps don't shut. Another problem is that the remaining flow at low pressure is so small that the people get tired of holding them open, so they tie them as in the photo on the left. Higher pressures can cause leaks, make the system more prone to breakages and become inaccessible. One of the consequences is that children cannot open the auto-close taps. At more than three bars the flow from the tap can become a spray leaving containers half full when the bubbles disappear and soaking the people (photo on the right). Flooding problems are widespread.

## Velocity

This is usually **between 0.5 and 2 m/s <u>at peak consumption</u>**. In the case of water without suspended solids, the minimum velocity can go down to 0m/s at all times and when the other parameters are correct, especially water age. At very low velocities, suspended solids start to settle and accumulate in the lower areas, reducing the actual diameter of the pipes. From 0.5 m/s the pipes are considered self-cleaning. Velocities more than 2m/s suggest the pipes are too small and create a risk of damage by water hammer and tear.

## Unit Headloss

This is a measurement of energy that is lost by friction inside the pipe and depends primarily on the flow rate and its velocity. It is measured in meters of head lost/km of pipe. The more meters of head lost the more inefficient the pipe is. Accepted values are below **5m/km for networks** and **0.04 m/m in buildings**. Occasionally it is desirable to have a lot of friction to dissipate pressure in low points in the network. This allows savings by laying a smaller pipe and prevents excess pressure providing you don't anticipate any future extensions to this line. As you can see in the example in the image below, the thick red pipes (dark in B/W print) exceed this value. You should suspect these pipes are too small and are probably choking the access of water to other parts of the network.
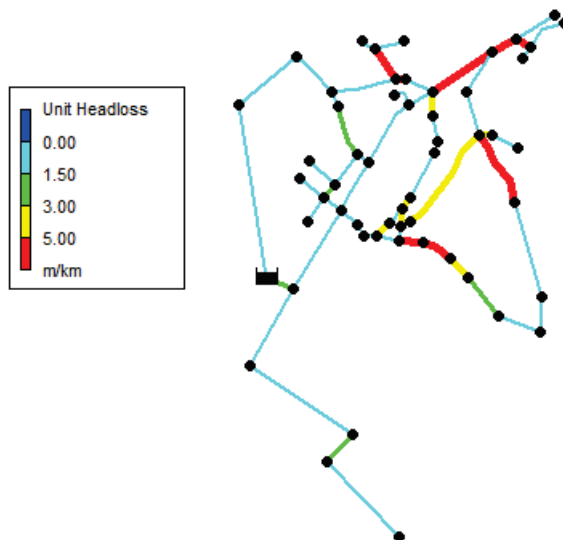


**Water Age** and **Chlorine concentration** was covered in the previous chapter.

# What to look for with what type of analysis

Now you know the basic calculation criteria and the two types of analysis, the following diagram will serve as a checklist, taking into account that every system is different and that there are situations where going outside the recommended values can be justified:

**Steady-state**

- There are no pressures below 1 bar.
- There are no pressures above 3 bars.
- There are no velocities above 2 m/s.
- Investigate unit head losses above 5m/km.

**Extended Period**

- There are no pressures above 3 bars.
- There are no pressures below 1 bar in other hours.
- The chlorine concentration is not less than 0.2ppm.
- At taps, concentration is below 0.6ppm.
- The water doesn't spend more than 24h in the network.
- The water tanks refill with each cycle.
- The pumps are working within their ranges.

Without overwhelming you, these are the most useful and simple although there are many other checks you can do. I will suggest some courses of action you can take for each case in the next section.

# A way of working

Now that you have built the model, you will be asking what you are going to do with it. Firstly, save a backup copy in your computer and have the discipline to only use it if you have destroyed the model you work on and need to start again. Afterwards, modify the elements so that they work as we have proposed. It is important to know that: **there are infinite solutions,** some better than others. Therefore look for the cheapest, the easiest to build, consumes the least energy, etc. Generally this means that you end up with various distinct solutions to compare (details in Chapter 7).

1. Modify the base model by adding pipes, modifying its properties, changing its route until you arrive at a solution, say solution 1. Start again, you may want to try putting in a new tank, add a pump and modify pipe 54 until you arrive at solution 2. Continue like this until you find that you have run out of ideas and you have various solutions to compare.

2. Compare the solutions and select one of them.

3. Work with this solution again to look for improvements. Also model what would happen if a pipe broke, if there was some very pronounced consumption in one zone, etc.

4. Check that the maximum pressures, water age and chlorine concentration are correct.

5. Lastly, review your model to look for mistakes.

Start by doing points 1, 2 and 3 in the **static model**. The main advantage of this is that it is less awkward to operate.

Once you have completed that, apply the consumption pattern to the **extended-period model**, that's to say, the succession of photographs corresponding to 0:00 hours, 1:00, 2:00…. and 23:00. The advantage here is that it can also analyze the hours of least demand, where maximum pressures and water age are the most problematic. It also opens the possibility of following the chlorine during 24, 48 or 53 hours. This mode is used for points 4 and 5.

**Avoiding changes and adjustments to multipliers**

As explained in previous chapters there are two types of analysis. In one you apply just the daily coefficient and in the other the corresponding coefficients at each hour. Explanations were also given of how to select the type of analysis.

However, the most common way is to analyze everything as though it was in extended-period the difference being that we start the visualization at the peak of consumption. This way, without change or adjustment you can move from a Steady-state (ignoring the rest of the hours) to an extended one (looking at the results for the rest of the hours). In order to do that:

1. Look for the hour in the day where consumption is highest. For example, 13:00.

2. In the Data tab of the Browser, select Options and then Times.

3. Enter the hour of highest consumption in the parameter "Report Start Time".
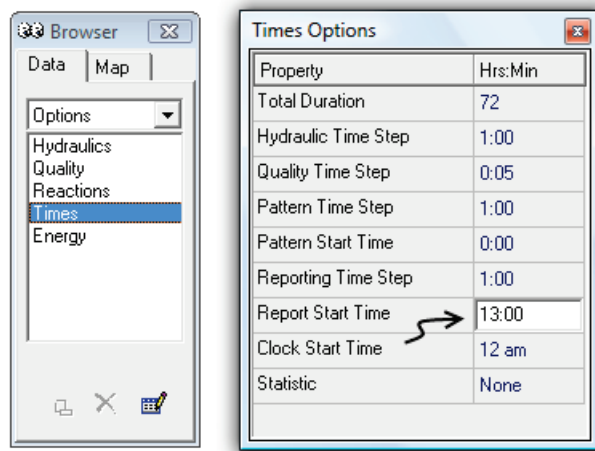


Once you have configured the dialog box as in the image Epanet will show you the state of the 24 hours in the day, starting with the photo corresponding to Steady-state without further changes. Remember that if you work like this, you don't use the daily coefficient when entering the demand into the nodes.

# Correcting errors

Once the model is loaded it's time to calculate it. To do this, press lightning bolt. It will leave a message while it is processing:
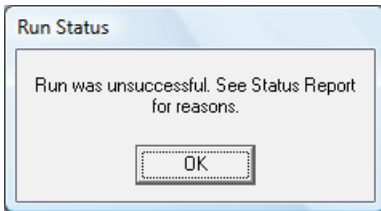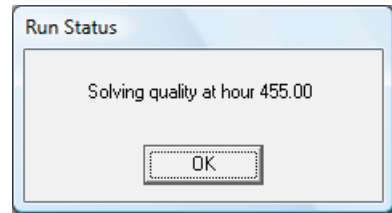
Afterwards, you will see an error message similar to this, except in the improbable case that you have a perfect network first time or your network is generously over-designed.

Don't worry, this is completely normal. You are entering a phase of eliminating possible errors. This phase is very simple and quickly resolved when you appreciate what's happening. We are going to see what these errors are.

## Disconnected junctions

After hitting OK you will receive a message informing you of the errors. This message has some general content followed by the error messages, some more intelligible than others. In the case of disconnected junctions the message is very clear:

```
Input Error 233: Node 51 is unconnected.
```

Look for it in the general message as shown below:

```
Status Report

Page 1                                    Fri Dec 11 09:21:11 2009

******************************************************************
*                           E P A N E T                          *
*                   Hydraulic and Water Quality                  *
*                   Analysis for Pipe Networks                   *
*                        Version 2.00.12                         *
******************************************************************

Analysis begun Fri Dec 11 09:21:11 2009

   0:00:00: System ill-conditioned at node 4
   0:00:00: Reservoir 3 is closed

WARNING: Node 4 disconnected at 0:00:00 hrs
System Error 110: cannot solve network hydraulic equations.
Analysis ended Fri Dec 11 09:21:11 2009
```

This error is very simple to eliminate. It's saying that there is a junction or section of the network that is not connected. Normally it will be in one of the following two situations, as detailed on the enlarged networks drawings:

**a)**  You drew an extra junction without realizing.
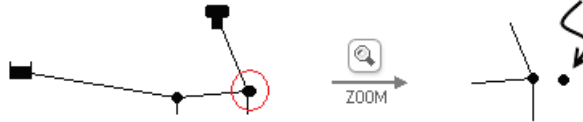
**b)**  You had a bad aim clicking on one of the ends of a pipe and left an unconnected junction in the middle
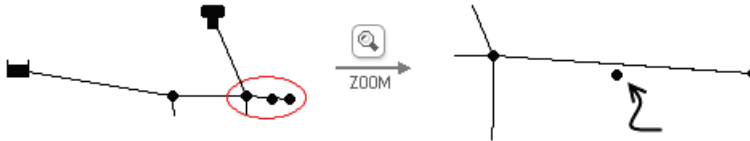
Pay particular attention to tanks as even although they might not be connected to the network, they do not show as an error. This means that to all intents and purposes they do not exist, but we will spend money building them because we think they are necessary. In the image the tank is not connected.
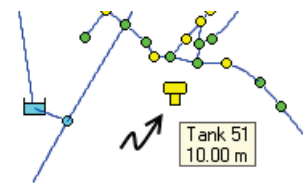
## It can't solve the hydraulic equations

This error, that seems so intimidating, is actually quite simple:

```
System Error 110: cannot solve network hydraulic equations.
```

In the majority of situations, there is a part of the network that has a demand, but is not connected or there is unrealistic value somewhere, i.e., Base demand =10000000. It is similar to the previous error except it should have at least two junctions and a specified demand. When the two sections are connected, it disappears.

Sometimes this is the companion error message:

```
0:00:00: System ill-conditioned at node 57
```

## Closed reservoirs

```
0:00:00: Reservoir P2 is closed
```

Basically, it's disconnected (without a pipe that connects it to the rest), as in the image. However it can also be the result of another error and disappears when this is resolved.

## There aren't any tanks or reservoirs

```
Input Error 224: no tanks or reservoirs in network.
```

You need to have an entry point or a drain in the network for it to be able to be calculated. If you are missing one of these, even if there is a junction with negative demand (bringing water into the network), it needs one of these two elements.

## You have not defined a certain parameter

It is obvious there will be many of these to do. Let's look at some examples:

```
Input Error 205: Junction 2 refers to undefined time pattern.

Input Error 206: Pump 2 refers to undefined curve.

Input Error 217: invalid Energy data for Pump 2.
```

## Tag or junk errors

You will have noticed the end tag:

```
Input Error 200: one or more errors in input file.
```

This is a good example of many error messages that appear in the box that in reality don't refer to anything and can be ignored as they will disappear when the significant errors are resolved. For this reason, start to eliminate the errors that you know. If you

resolve one of the known errors and leave the unknowns to the end, most probably they will disappear during the process of elimination.

To illustrate this point: notice that to inform you a pipe is missing between two parts of the network, Epanet gives you four different error messages. They all disappear when the two junctions are joined with the rest of the network.

```
Status Report                                    _  □  ✕
Page 1                              Fri Dec 11 09:21:11 2009

  *********************************************************
  *                    E P A N E T                        *
  *            Hydraulic and Water Quality                *
  *            Analysis for Pipe Networks                 *
  *                  Version 2.00.12                      *
  *********************************************************

  Analysis begun Fri Dec 11 09:21:11 2009

     0:00:00: System ill-conditioned at node 4
     0:00:00: Reservoir 3 is closed

  WARNING: Node 4 disconnected at 0:00:00 hrs
  System Error 110: cannot solve network hydraulic equations.
  Analysis ended Fri Dec 11 09:21:11 2009
```

Up to this point the most common errors have been described but if you encounter other errors, you can find more help in the Epanet Users Manual under "Error messages". Remember that Epanet has a help section to assist you. Now we concentrate on the error you work with …

**Negative pressures**

```
WARNING: Negative pressures at 0:00:00 hrs.
```

In other words, there are points in the network where the water doesn't arrive. Modify the legend as explained in the section Basic tools. If the first point is set as 0, then these points will be in dark blue as indicated on the image:
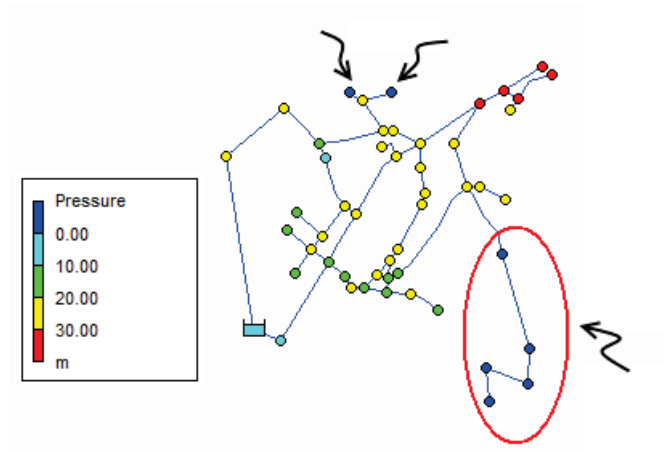
Epanet works using the artifice that negative pressures exist. In reality there are no negative pressures but simply pressure is not enough to get water past a certain point. However when modeling you may have situations, as in the image below, where junction B receives water, even though junction A is dry. In reality if water cannot reach A it certainly cannot continue to B.
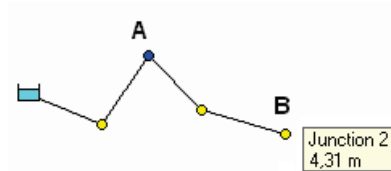


If you get negative pressures and no matter what diameter you enter they stay there, you are probably using coefficients of friction with the wrong formula. If you put values for Hazen-Williams (around 120) when using Darcy Weisbach (around 0.1), you will need enormous diameters. If it is the other way round the same would happen.

# Tracking down invisible errors

We have firstly covered simple errors. The ones we look at now are more dangerous and may go unnoticed leading to a design that in reality is incorrect.

### Beginner's luck



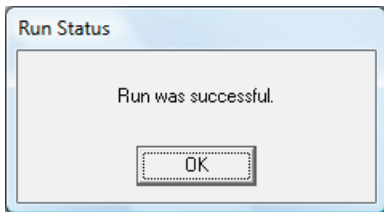You are tired from working in the field to collect the data, your eyes are stinging from being in front of the screen, you have been getting stressed and feeling pressure to finish, you click the lightning bolt and…. What luck! First time!

This message tastes as sweet as sugar, but will bring you back to down to earth faster than the slap of unrequited love. "Run was successful" can be translated as "the pipes are sufficiently big for the water to arrive at all the junctions with pressure". Sufficiently big goes from the minimum diameter capable of meeting this condition up to infinity. As far as Epanet is concerned, they could have the diameter of the Solar System. After all, it's not going to pay for them!

If you get the message "run was successful" the next thing you have to do is to track down the pipes that are too big and reduce their size to the minimum ensuring that you keep all points above minimum design pressure.

### Modeling without load

Another possibility for having an early "run was successful" message is the model doesn't have demand. This is the equivalent of putting it in neutral. It has no load and therefore "can cope". The first possibility is that you have forgotten to enter the demand value, that is to say, your junctions have 0 for the Base Demand parameter.

To find out if this is the case, examine the model by clicking Query:

Complete the menu as in the image and click Submit. The junctions that meet this condition appear in bold red (grey if you are reading the printed version of this book):
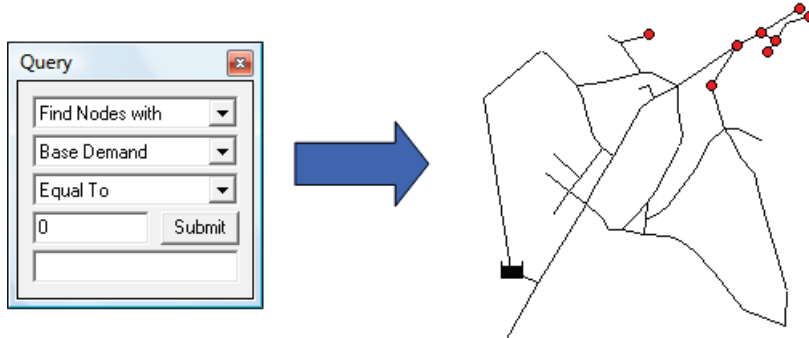


## Forgetting to click calculate

Often there is a phase of small modifications to a correct model or you have a last minute idea. You modify something just as the screen shows the results of the previous calculation and it looks as if it's OK. Always click the lightning bolt to calculate after a batch of modifications. In case you forget to calculate, Epanet will inform you by showing a broken tap at the bottom of the screen. Look closely because it is hardly noticeable!
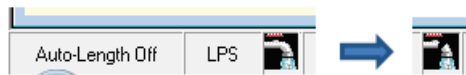


## Others

There are many possibilities, the majority of them due to errors in entering data. Using Query, as in the previous subsection, check:

1. That the points have an elevation by entering "Nodes with Elevation Equal to 0" in the Query box.
2. That the links don't have the default length → "Links with Length Equal to 100" (or the default value that you introduced in > Project /Defaults / Properties if you have changed it).
3. That the pipes have a coefficient of friction → "Links with Roughness Above 0".

# Visualizing the results of a calculation

The first time you click on calculate, the screen won't change to show any results. You will have to choose what you want to see first. All the viewing options are in the Map tab of the Browser. In the first of the dropdown menus choose the parameter that Epanet should represent in the nodes (or junctions), in the second menu for the links (or pipes), and in the third, the hour of the day.

The buttons ⏮ ◀ ◼ ▶ allow you to fast forward, rewind and stop the film resulting in superimposing the state at different hours. This will only be visible if you are in extended-period.
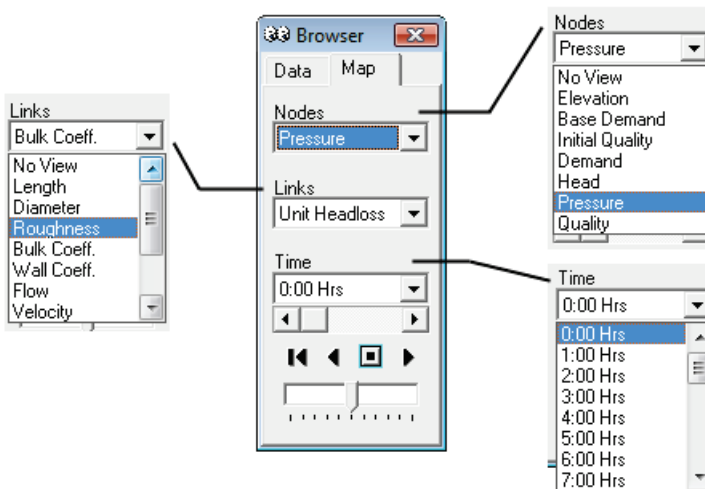


Select one of the criteria we have previously seen. As an example, for Unit Headloss you would select Unit Headloss in the Links dropdown menu. You would edit the legend as previously seen in Chapter 2, so that it shows the design limits. From here, it's a question of thinking about it and playing with the model to keep all the data inside the design limits.

The image below shows the results of such a selection for a network in Haiti:
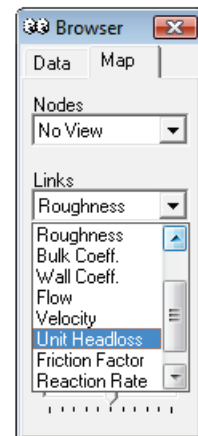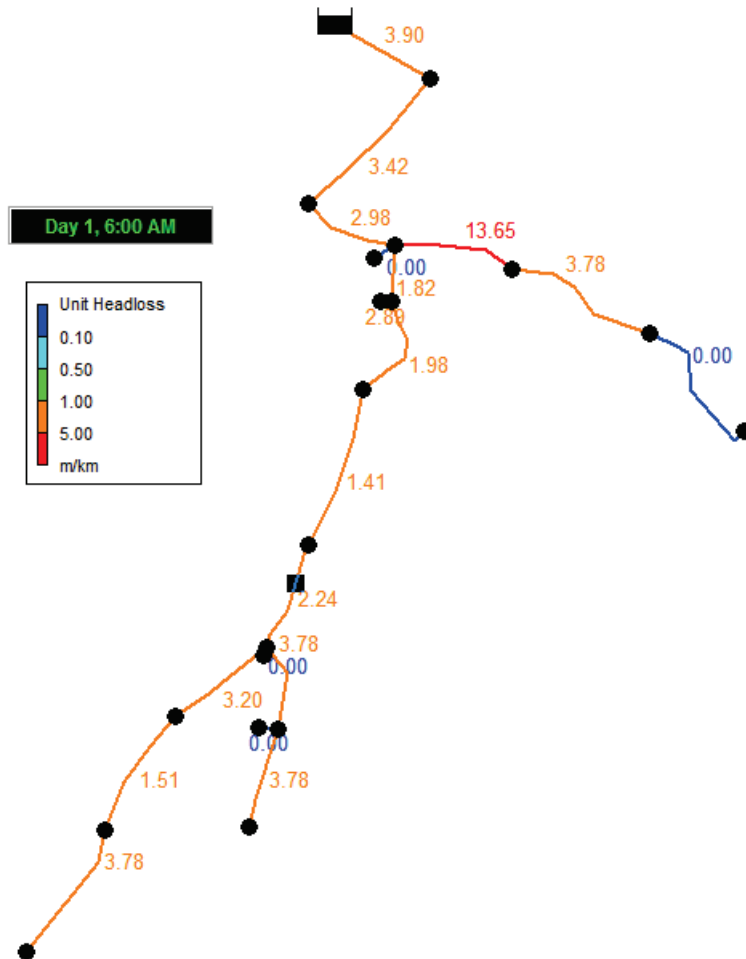
**Don't forget to click the lightning bolt if you want to see the result of your modifications.** If you change things without clicking it, Epanet cannot take them into account.

Although Epanet can show you the results in many different ways, the color scale is probably the most useful among them. For other forms, like tables or graphs, see the Epanet Users Manual, it explains them very clearly. A very common beginner's mistake is to try to read the pressure in the pipes. Remember that some parameters are visualized in the pipes (i.e. velocity) and others in the junctions (i.e. pressure).

# Some recipes for fulfilling the calculation criteria

With practice you will gain experience as to the best way of taking the design to complete the basic calculation criteria. Every network is unique and there isn't one recipe to optimize it. I know very well that a statement like this disheartens beginners who want something concrete to follow. With that in mind and to help speed up the first attempts at the learning process, these recommendations will provide you with the highest probability of success. I trust that you have understood that these recommendations have limitations and are not infallible:

### Steady-state

#### A. Some points exist with pressure less than 1 bar:

1.    Increase the diameter of the pipes that feed them.

2.    Add new pipes from other points.

3.    Increase the supply of a big consumer close-by.
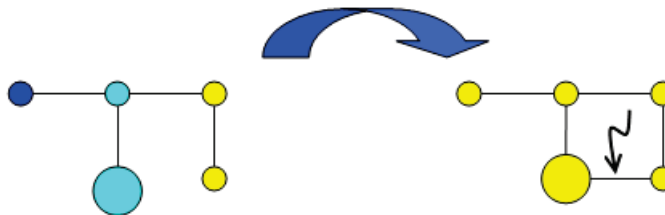
**B. A group of points exist with pressure lower than 1 bar:**

1. In the proximity of a tank, reservoir by gravity, or pumping station, increase the diameter of the pipes below them. Elevating the tanks should be the last consideration, because of the pumping costs it entails.
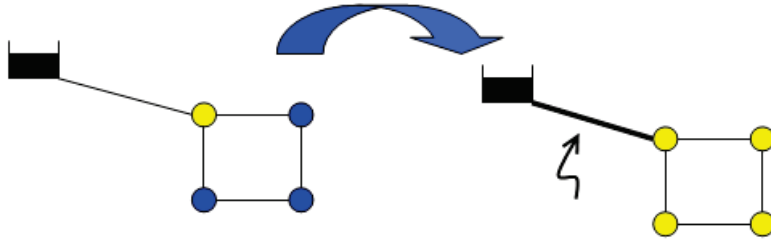


2. In points that are far from a tank, elevated reservoir or pumping station, try to increase the diameter of the pipe that feeds this zone (case A1) or try to put an elevated tail tank.
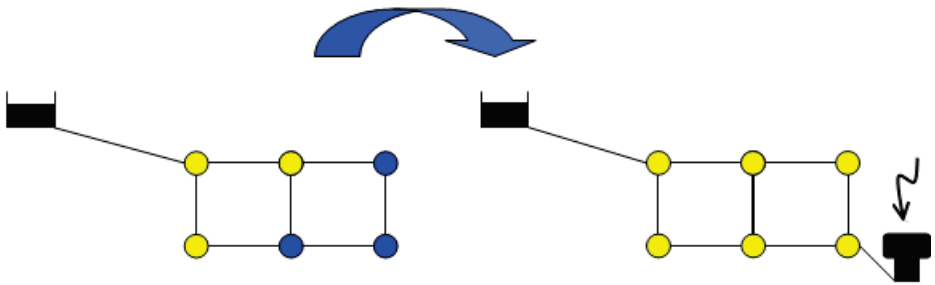


3. If there is a big difference in altitude between two parts of a network, limit the descending paths of the water, reduce diameters or eliminate pipes downstream (alternative to Pressure Sustaining Valve). Consider establishing different pressure zones.
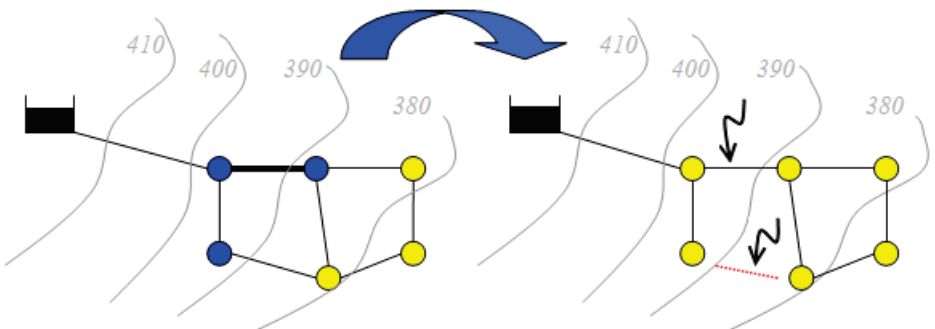
**C. Others:**

1.  If there are velocities above 2 m/s, the pipe is probably too small  → Increase the size.

2.  If there are velocities lower than 0.5 m/s at peak hour, the pipe is probably too big → Reduce the size.

3.  If the friction is more than 10 m/km, the pipe is too small → Increase the size.

Pressure is prioritized over the rest of the criteria given. It is what ultimately determines the flow received by the user. Once the pressure is inside the correct margins you can play with the rest of the criteria to get more efficient designs. Sometimes, as in the case of B3 or the example below, they are set outside the correct design frame initially on purpose in order to get the adequate pressures.
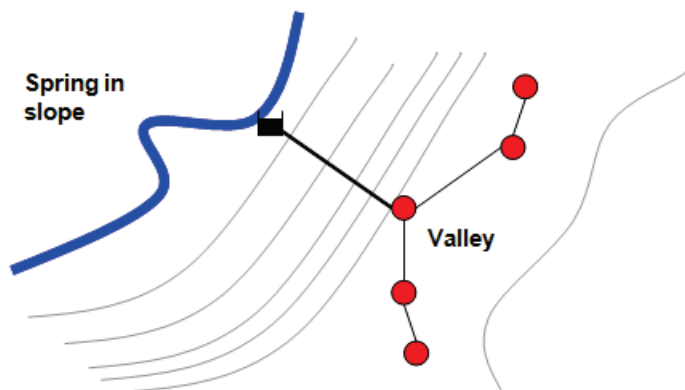


The water source is greatly elevated in respect to the points that it is going to serve therefore the pressure will be excessive. To avoid this, de-pressurize the pipe halfway through with a break-pressure tank. However, since you are going to de-pressure the network, the first pipe from the source tank to the pressure-break can be made very small in diameter and save money on the installation. This implies making it exceed the usual values for velocity and hydraulic gradient. You may consider simply installing all the pipes smaller to avoid excessive pressure however water only looses energy while moving so in hours of low consumption the pressure will still be excessive.

Below is shown the position of a break pressure tank with a photo to illustrate:
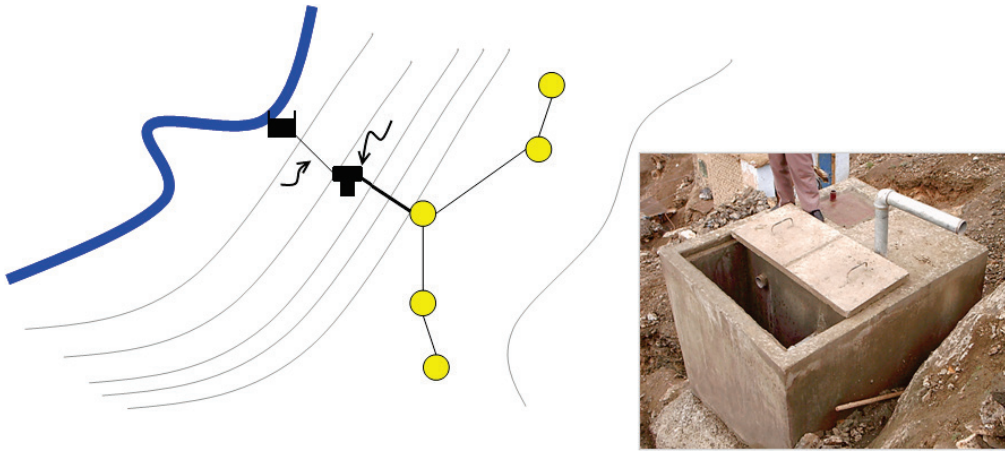
## Viewing the model in extended mode

Once you have stabilized the model statically, move on to analyzing in extended-period. If you have configured Epanet as suggested in the "A way of working" section, you simply go to the Data tab of the Browser and click Forward:   ▶

Watch how the colors of the objects change with time. If they don't change, it's because either there is no modulation curve defined for consumption or that the ranges of the legend are too big to see the changes.

Confirm that the design parameters are correct, bearing in mind that the most interesting things to observe are:

1. The periods of least consumption.
2. The periods of greatest consumption.
3. The evolution of a parameter with time.

On the following page is a diagram to help you check that you haven't forgotten anything plus a general diagram that includes routes that apply to existing networks.

**a. Determination of the WATER ALLOCATION l/day/person**

**c. Determination of the GEOGRAPHIC ENVIRONMENT**

Determination of the DAILY PATTERN

Determination of the WEEKLY PATTERN

Determination of the SEASONAL PATTERN

Grubb Test?

**b. Determination of the POPULATION TO BE SERVED**

Obtain the CENSUS

Estimation of the GROWTH RATE

Study of POSSIBLE EXTENSIONS

Determination of the DESIGN PERIOD

Define DEMAND ALLOCATION criteria

Obtain and calibrate AERIAL PHOTOS, GIS, MAP

Map EXISTING WATER SYSTEMS

Determination of the POPULATION DENSITY

Geo-positioning of LARGE CONSUMERS

Geo-positioning of FIRE HAZARDS

Determination of UNNACCOUTED-FOR WATER

Determination of FIRE DEMAND

Determination of the INDUSTRIAL DEMAND

Determination of the SPECIAL DEMAND

Backdrop

**POPULATION DETERMINED**

**COMPLETE CARTOGRAPHY, GIS?**

**MAXIMUM CONSUMPTION DETERMINED**

FIRE RESERVE volume

Computer modeling

Revision SUBSTANDARD CHLORINE concentration AREAS

**ENOUGH WATER PRODUCTION?**

**SCENARIOS**

**Determination of the STORAGE NEEDS**

Determination of PUMPING PATTERNS

Establish MAIN ELECTRIC BILL

Determination of the CHLORINE DECAY (BULK) COEFFICIENT

Determination of the CHLORINE WALL COEFFICIENT

Inventory of  SUBSTANDARD CHLORINE concentration AREAS

Determination of CONTAMINATION ROUTES

Decision of METER INSTALLATION

Evaluation of CONTINUITY IN CONTINGENCIES

Reduction of WORKING PRESSURES

Guarantees EQUAL ACCESS

Selection of MATERIALS

**e. ASSESSMENT OF THE SAFETY**

**d. ECONOMIC OPTIMIZATION**

## Fire Protection

This refers to the water that is available in case of fire. This is to make sure that at all times there is:

a)  A **fire reserve**, a volume stored exclusively for the purpose. The regulations vary from country to country, but normally is the equivalent of fire flow for two hours.

b)  A **fire flow** that is determined according to the type and number of population.

In practice, the requirements are so large, greater than the peak demand of the population, that the fire flow determines the size of the networks. In development I have seen two approaches, either to completely ignore the protection against fires or to apply the western regulations blindly.

To ignore the necessity of protection against fires is an irresponsible thing to do that deserves no more comment. Applying the western standards or that of the country frequently is disproportionate (in Chapter 1 we made the case for a fire flow of 32 liters per second in a community that only has buckets available to fight a fire).

I think that there is a middle point. Determining it is not simple. A good idea in any case is to talk with the local fire department and see what their ideas are, understanding that the firemen are going to participate in the extinguishing of a fire (they don't need to be in white helmets or uniform).

Many times, more than a flow, the important thing is that there is a quantity of water stored to fight a small fire so that it doesn't become catastrophic because the tanks were bone dry. A fire reserve is created in a normal tank by having the distribution main outlet at a higher point.

# 7
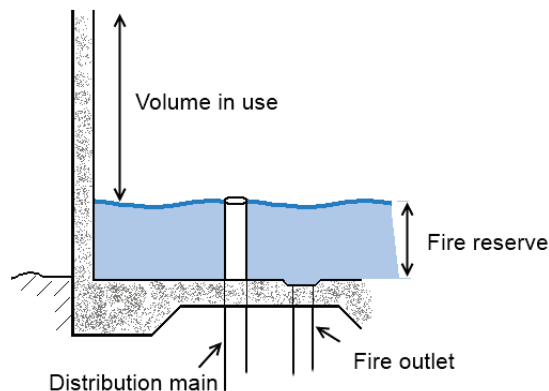
# Economic Aspects

Introduction to economic evaluation
Determining the willingness to pay
Determining the capital costs' bill
Determining the running costs' bill
Comparing and contextualizing the costs
Limitations and sources of uncertainty
Using Epanet to budget
Using Epanet to determine energy consumption
Ranking the expenses
"Dry diametritis"
Cost vs. Diameter
Most common wastages in assembly

*Money makes a good servant, but a bad master.*

*(F. Bacon)*

# Introduction to economic evaluation

Economic evaluation tries to answer questions like:

- Which of the alternatives is the cheapest to build?
- Which will be the cheapest to run daily?
- Can the population assume the cost of this operation?
- How will they meet payments to avoid the installations becoming obsolete?

Traditionally, the fundamental objective is:

➢ **To determine which of the possible alternatives achieves the desired result with the least cost in resources.**

Allow me to add one, which I consider more important in development:

➢ **Check that the running cost of the alternative is inside the beneficiaries' willingness to pay** and is therefore **sustainable** once the donors have left.

In practice, this is achieved by comparing the costs of the different alternatives. Each alternative has a capital cost (i.e. buying a car) and another for running costs (insurance, petrol, service …) In the following section we will see how to calculate them and their limitations however, we must firstly consider a serious issue.

## The importance of ethics

In my modest experience, projects seldom carry out an economic analysis. When considering if something works, that is the sole consideration. The button is pressed on the generator and it runs or the pump pumps water. If the generator is running outside its range and is inefficient then that issue is left for the beneficiaries to resolve.

The economic analysis of the beneficiaries is implacable. For them a structure that is wasteful doesn't work in the sense that it doesn't improve the living standards. As a consequence it will be abandoned, many times to the despair of the organization that promoted it who often has claims like that the beneficiaries "don't maintain anything" or "it is a very difficult context". If the maintenance of the infrastructure is a challenge in itself, the reality is that the absence of economic analysis doesn't help.

In the case of asking for participation from the community, more frequently than ever, it becomes a tricky issue. Here there is the potential to have a frankly negative impact through decapitalization. The beneficiaries placed their trust in the technical capacity of the assistance, and their contribution will be linked to results. If like the San fish factory in Mali, each kilo of fish ends up costing 4,000 dollars[1], despite the work, effort and commitment of many people the conditions do worsen.

## Common nonsense

Apart from the complete absence of economic evaluation, the three most common blunders with respect to economic issues are:

1. **"Granny Economics"**. This refers to the obsession to save by proposing activities that in reality are a waste of effort and money, compromising the overall results and disheartening and disheartening all involved. With this approach the most important thing is to go scrape money from wherever you can to make the costs small.

2. **"Economic Despotism".** This refers to the ideal that everything is determined economically but to avoid controversy, let's say our capacity to measure it is severely limited. For example, what is the value of educating someone? Does a dollar really have the same value for a middle-class westerner as to a person below the poverty line? Yet both dollars buy the same amount of potatoes. What is the flaw? To be fanatically guided by aspects of pure efficiency is inconsiderate in the majority of cases. The value to the people is obviously what really matters.

3. **Vague calculations of hazy ideas.** This refers to calculating and budgeting without clear definition. To calculate the costs you need a clear idea in your head of what components are required, so many km of pipe, so many valves of a certain type, so many truckloads of sand… To calculate the total cost of a water network without precise detail is like calculating how much *a machine* costs… a machine of what kind?? The design precedes the budget and never the other way round, as occurs so often in development. Approaches such as "we have 200,000 dollars I'd reckon that is enough for a network", betray and spoil the results.

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[1] *Handcock G. 1989. "Lords of Poverty"*

# Determining the willingness to pay

We have seen that the fundamental objective in economic evaluation is to check that running costs of the alternatives are within the beneficiaries' willingness to pay and therefore is sustainable once the donors have left.

That means the decision as to whether the capital and running costs are acceptable doesn't fall on the person designing but on the beneficiaries. It's therefore vitally important that the decision maker can communicate properly with the future beneficiaries.

What the users are willing to pay may be tricky to determine since they may not have favorable experiences from the past, or never had a proper system before. As a guide, according to the UNDP, the cost should not exceed 3% of the family income. Sometimes information is as easy to get as establishing the cost of the traditional systems:



The techniques to work out how much a person would pay fall outside the scope of this book, but a good place to start is "Willingness-to-pay Surveys" published by WEDC in English and downloadable for free in their site.

Next we see how to assess the costs the users will bear.

# Determining the capital costs' bill

This is the most obvious cost for the equipment and installation and because it is paid all at once is the largest component of the project's budget. It is also the one which commands the most attention.

### Repayment and devaluation of money over time

Although the capital cost is paid all at once, it can be distributed over the whole lifetime of the installation. One of the first decisions to be taken is to determine the **repayment period**, in other words, how long we expect to use what we are buying and constructing. This is not an easy decision. How durable is a water network? How durable is a house? To complicate things, the durability of a house, for example, depends on the maintenance costs that we are willing to assume, costs that don't form part of this bill.

Don't get overwhelmed by this. It's important to remember that economic evaluation is an approximate method and that there are always some reasonable criteria to follow. For example, in the case of a water network, this repayment period should be at least equal to the design life. If it is designed for 30 years, the repayment period should be 30 years and to obtain the corresponding annual cost divide the actual capital cost by the number of years.

However there are other phenomena to take into account, mainly, that **the value of money diminishes with time.** In 1950 a bus ticket cost two cents now it costs $3. Why? Because to compensate the loss in value of that initial two cents, the price of the ticket has had to be increased each year. The initial two cents eventually arrives at $3 after 50 years. These costs are usually compared and taken into account at the start of the project.

### Obtaining the annual cost of a capital investment

Have a quick look at the theory which can be expanded in any economic analysis book; the way to proceed is as follows:

1.  Work out the **interest, i**, that a bank would give you to deposit a similar amount and convert it into a decimal. For example, 3% → i = 0.03.

2. Predict what the **inflation, s,** will be for the period considered. You can look at a few years in the World Bank data and make a guess:

   http://go.worldbank.org/WLW1HK71Q0.

   I say predict, because it's not possible to know how it is going to develop in the future. This will be your parameter **s**, also as a decimal.

3. Calculate the **real interest rate, r**. This rate takes into account interest and inflation. If inflation is more than the interest a bank would give you, the money is worth more in the present than it would be in the future. If they are equal, it will maintain the same value and if the bank interest is more than inflation, the value of the money will increase. It is calculated through this equation:

$$r = \frac{1+i}{1+s} - 1$$

4. Calculate the **repayment factor $a_t$** for T years:   $a_t = \dfrac{(1+r)^T * r}{(1+r)^T - 1}$

5. The annual cost of the capital investment is the invested amount, M, multiplied by the repayment factor: $F = M * a_t$

## Example

A network for water supply is budgeted at 100,000 € and designed for 30 years is evaluated in Uzastan where the banks give 5% interest and the inflation for the last 4 years is:



Inflation in Uzastan

The interest is i = 0.05 and the inflation is estimated at 4.5%, so s = 0.045.

The real interest rate is:

$$r = \frac{1+i}{1+s} - 1 \;\; = \;\; \frac{1+0{,}05}{1+0{,}045} - 1 \;\; = \;\; 0.00478$$

The repayment factor is:

$$a_t = \frac{(1+r)^T * r}{(1+r)^T - 1} \;\; = \;\; \frac{(1+0{,}00478)^{30} * 0{,}00478}{(1+0{,}00478)^{30} - 1} \;\; = 0.03586$$

The annual cost is F = 100,000 € * 0.03586 years$^{-1}$ = 3586.24 €/years, approximately 3586 €/year.

Notice that it's different to 100,000 €/ 30 years =3333.33 €/ year. That is due to the corrected value for the capital cost, called **present value**, is F * 30 years = 107,587 € and not the 100,000 € of the capital cost.

# Determining the running costs' bill

In water systems that aren't gravity-fed the main cost is energy or fuel for the pump, followed probably by the treatment of the water. Conceptually this cost is much simpler to produce; it is an inventory of all the expenses that the network will incur in one year of working. Saying this, there are some costs that are very evasive, for example, breakdown repair. In development, rarely the economic decisions are going to be so accurate. The servicing expenses are comparatively small in correctly designed systems and usually there are other criteria that prevail in narrow margins.

### Pumping expenses

In many instances it is not worth involving Epanet in the calculation of pumping expenses. They are easier to calculate by hand. Look at the following example.
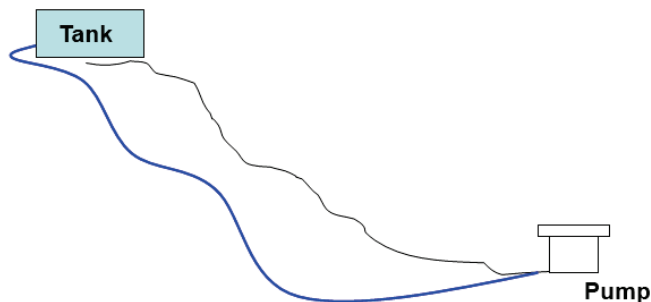


A pumping station fills a tank that supplies the city. The pump lifts 10 l/s to the tank and consumes 7.2 kWh according to the manufacturer. The population supplied is 1,000 people and it has been established that each resident will receive 50 liters a day. The price of a kWh is 2 € and doesn't vary during the day.

In one hour, the station will pump 10 l/s * 3600 s /h * 1 m$^3$/1000 liters = 36 m$^3$/h.

The cost of the pump per hour will be: 7.2 kWh * 2 € = 14.4 €/hour

The cost per m$^3$ is:  14.4 €/h  /  36 m$^3$/h = 0.4 €/m$^3$

The annual consumption is:  365 days * 1000 per * 50 l/per*day * 1 $m^3$/1000 liters = 18250 $m^3$.

And the annual cost will be 18250 $m^3$ * 0.4 €/$m^3$ = 7,300 €.

Often the electrical energy is generated on site with a generator. In this case, the cost of a kWh will be the price of diesel. The consumption of an average generator is 0.3 liters of diesel per kWh produced.

In the previous example, if the price of diesel is 1 €/ liter:

     7.2 kWh/ hours running * 0.3 liters/kWh * 1 €/ liter =  2.16 € / hour

Knowing the cost per hour of the pump you can proceed in the same way.


## When to use Epanet?

In all situations when the calculations become difficult but above all:

- Pumping directly to the network. The pressure that the pump encounters changes according to the hourly consumption and therefore the flow and price /$m^3$ of water.

- Many pumps, even if their workload is regular.

- Automatic start/stop pumps or variable velocity pumps, both uncommon in development.

# Bill comparison and contextualizing

You have devised three alternative interventions A, B and C. For each of these you have established the annual capital cost and the running costs. The only thing that you have to do now is to compare and contextualize them. The comparison is simple; the smallest of them is A.

| Type of cost | Alternative A | Alternative B | Alternative C |
|---|---|---|---|
| Capital | 8000 | 10000 | 7000 |
| Running | 3000 | 6000 | 4500 |
| **TOTAL** | 11000 | 16000 | 11500 |

## Contextualizing through ponderation

That alternative A is the cheapest doesn't mean that it is the most desirable. Other types of criteria exist; for example, in an emergency situation the speed of construction will be put above the construction cost. To take into account all the decision criteria called "contextualizing a cost", a ponderation must be made.

Ponderations are done because people have serious problems to manage more than 4 or 5 variables in the head. Imagine for a moment that someone asks you what you want to eat while you try to figure out the number of days between the 8th of January and 23rd February… As a consequence of that, we have a strong inclination to decide using only one parameter and ignoring the rest: "Huuummmm…, the same as you", I bet you would respond.

To maintain objectivity and to document the decision making process, each variable is analyzed independently. The process is very simple. For each criterion (speed, economy, gender approach…) a weighting according to its importance is given. In the same way, for each alternative (wells, water truck, gravity system…) give another weighting with respect to each criteria. The alternative should score highest points when it contributes something to the beneficiaries by its abundance/presence or by its absence/shortage, in other words, it scores more when it has a better impact.

Suppose that the pumping station of a small riverside city has broken down due to a flood and I am trying to decide between repairing the station or hiring water trucks from a neighboring town (I don't have the funds to do both). In this case speed is fundamental so I weight it 9 out of 10. I have sufficient funds for both alternatives so that the economics of the solution is not so important. I weight it 4 out of 10. The

implementation speed of water trucking is very much needed, and scores 10. The cost is much higher, I give it a 0. Rebuilding the station is a very lengthy process because there are parts to be ordered from abroad, it scores 1. However, it's very economical as it is only the electrical parts that have broken. It scores 8.

(A) Water truck:

| Speed | 9 * 9 = 81 |
| Cost | 0 * 4 = 0 |
| **TOTAL** | **81** |

(B)  Repair:

| Speed | 1 * 9 = 9 |
| Cost | 8 * 4 = 32 |
| **TOTAL** | **41** |

The score for the water trucks is higher and it is decided to implement this alternative.

Disappointed? Wasn't the decision obvious anyway? Sure, but this was a very simple example. This is a real one from Tanzania:

| Criteria | Pump (A) | | Gravity (B) | | Weight |
|---|---|---|---|---|---|
| | Score | Weighted score | Score | Weighted score | |
| Quantity of water produced | 2 | 20 | 9 | 90 | 10 |
| Water quality | 5 | 40 | 7 | 56 | 8 |
| Low risk of water trucking | 1 | 8 | 9 | 72 | 8 |
| Damage by returning refugees | 9 | 63 | 2 | 14 | 7 |
| Low risk of disturbance | 1 | 7 | 10 | 70 | 7 |
| Storage | 1 | 7 | 9 | 63 | 7 |
| Diversity of sources | 2 | 12 | 8 | 48 | 6 |
| Gender | 3 | 18 | 8 | 48 | 6 |
| Increase in population served | 0 | 0 | 8 | 40 | 5 |
| Donation of funds | 4 | 20 | 7 | 35 | 5 |
| Economic analysis | 7 | 28 | 4 | 16 | 4 |
| Social benefits | 2 | 6 | 5 | 15 | 3 |
| Implementation time | 8 | 24 | 4 | 12 | 3 |
| Organizational demand | 2 | 4 | 4 | 8 | 2 |
| Complexity | 8 | 16 | 5 | 10 | 2 |
| Technical risk | 7 | 14 | 8 | 16 | 2 |
| **TOTALS** | **Pump** | **295** | **Gravity** | **613** | |

# Limitations and sources of uncertainty

Throughout the explanation you will have picked up on some limitations with the way of working. These are some:

1.  We don't know what inflation will be in the future.

2.  The lifetime of equipment varies a lot from one unit to another. Although the average life of a car could be ten years, some cars with the same specification will last longer and others less.

3.  The average life is not clear, like the life of a person. It is difficult to determine when the service period of a water network will end. To a great extent it is a decision that depends on economic criteria. It will be abandoned when the maintenance costs become excessive, but that depends on the available alternatives and the costs in the long term.

4.  There are expenses that are very difficult to determine. For example, servicing.

5.  The stability of prices is unpredictable. Diesel can triple, skilled labor becomes more expensive with development, or pipes can become cheaper with the price of oil…
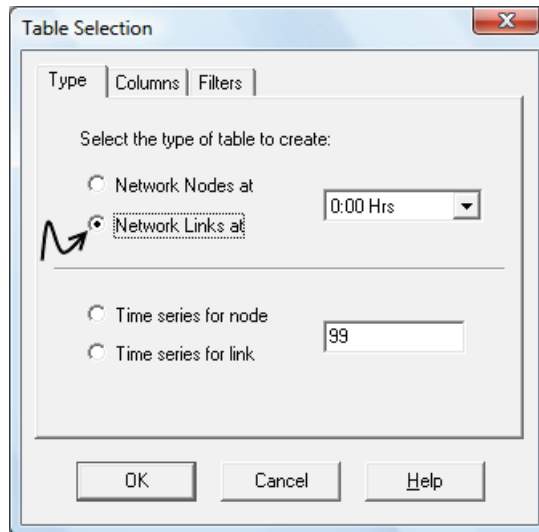
…

This is about arriving at a sufficiently good approximation, despite the uncertainties, to be able to base a decision on it. After all, no decision is taken completely informed; there is always a good number of unknowns. If you keep this idea of "sufficient approximation" in mind, you will see that limitations are not that restrictive.

# Using Epanet to budget

What we want is for Epanet to break down how many meters of each type of pipe rather than having to work it out one by one by counting. Unfortunately Epanet's export options are a little limited.

1.  Click the icon Table ⊞, so that this dialog box appears and select Network Links. In the Columns tab, tick the boxes besides diameter and length.
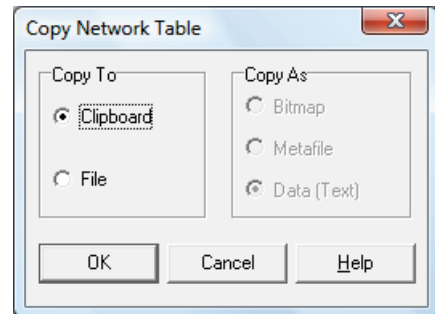


2.  Click accept to generate a table similar to this:



3.  Select the Diameter and Length columns clicking above the first box and dragging sideways and downwards until it includes all the pipes.

| Link ID | Length m | Diameter mm |
|---|---|---|
| Pipe 497.1 | 8.86 | 200 |
| Pipe 497.5 | 67 | 200 |
| Pipe 497.7 | 151,4 | 200 |
| Pipe 497.8 | 182,4 | 200 |
| Pipe 497.9 | 60,9 | 200 |
| Pipe 497.9 | 81.67 | 200 |

**4.** To copy you have to go to the menu Edit / Copy To (Control C and similar don't work). It displays this box and you should click accept.

**Copy Network Table**

Copy To
- ● Clipboard
- ○ File

Copy As
- ○ Bitmap
- ○ Metafile
- ● Data (Text)

OK    Cancel    Help

**5.** Copy your data into a spreadsheet:

|   | A | B | C |
|---|---|---|---|
| 1 |  |  |  |
| 2 | Network Table - Links |  |  |
| 3 |  | Length | Diameter |
| 4 | Link ID | m | mm |
| 5 | Pipe 1 | 187.67 | 50 |
| 6 | Pipe 2 | 69.40 | 50 |
| 7 | Pipe 3 | 60.06 | 50 |
| 8 | Pipe 4 | 182.47 | 50 |
| 9 | Pipe 6 | 292.82 | 75 |
| 10 | Pipe 7 | 112.99 | 50 |

6. In Excel, follow the path Data/Sort. In the menu choose Diameter. This will put the pipe with the same diameter together so that you can calculate the number of meters for each diameter.
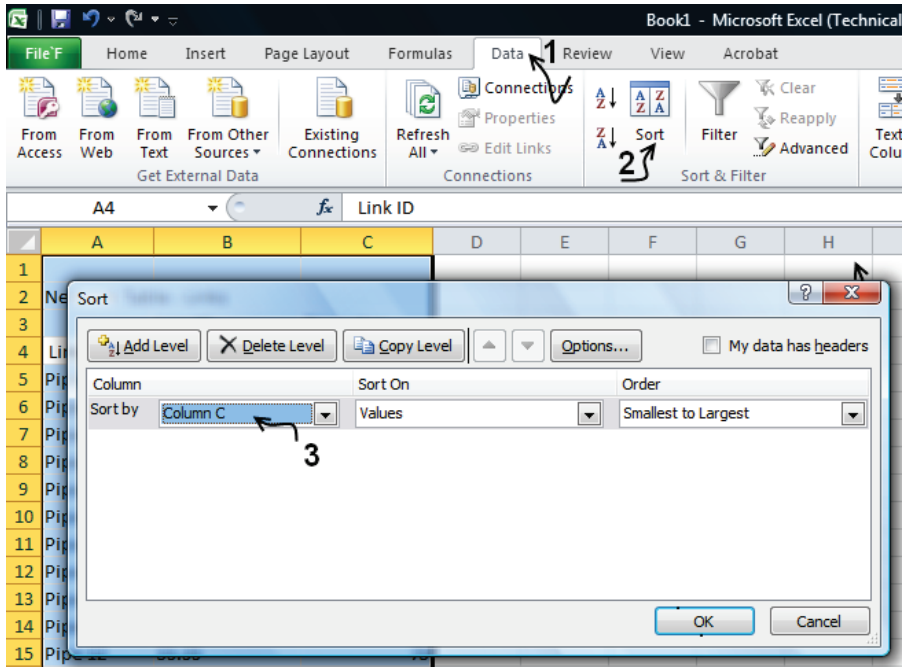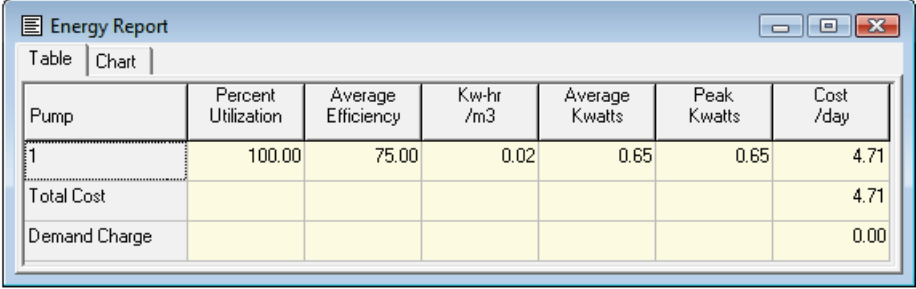


7. Calculate the totals for each diameter and assign a price per meter of line that includes excavation, backfilling, installation, etc.



From here it's in your own hands as it would leave the purpose of this manual to continue with the use of a spreadsheet or procedures to make a budget.
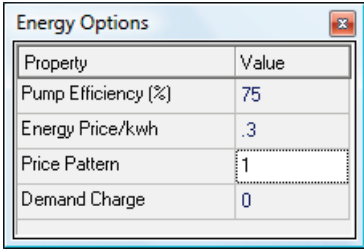
# Using Epanet to determine energy consumption

We have seen that in the majority of cases it is easier and less prone to error to calculate by hand. However if you are in a situation where it will be laborious and complicated to do it by hand, you can get an energy report that looks like this:

| Pump | Percent Utilization | Average Efficiency | Kw-hr /m3 | Average Kwatts | Peak Kwatts | Cost /day |
|---|---|---|---|---|---|---|
| 1 | 100.00 | 75.00 | 0.02 | 0.65 | 0.65 | 4.71 |
| Total Cost | | | | | | 4.71 |
| Demand Charge | | | | | | 0.00 |

To get it, follow these steps:

1. Determine the energy price and if it has variations. Many countries have an energy surplus at night making electricity cheaper.

2. In the Data tab of the Browser, select Options at the bottom of the dropdown menu and Energy afterwards, to display this dialog box:

| Property | Value |
|---|---|
| Pump Efficiency (%) | 75 |
| Energy Price/kwh | .3 |
| Price Pattern | 1 |
| Demand Charge | 0 |

3. Enter the price of a kWh. If the energy will be provided by a generator, assume the 30% price of a liter of diesel as the cost of a kWh. If there are hourly differences in price create a modulation curve as we have seen in sections of Chapter 3. The Demand Charge is used if there is a charge for the maximum power used, which is rarely the case.

4. To get the energy report, follow the path Report/Energy.

If you want to split it finer, you can enter a modulation curve for the output. You will get this curve from the pump manufacturer; it is expressed in % and can be labeled as η. It

is the overall efficiency that is also called the wire-water efficiency. It is created in the Curve Editor as explained in Chapter 3 for the volume curves. As a reminder :
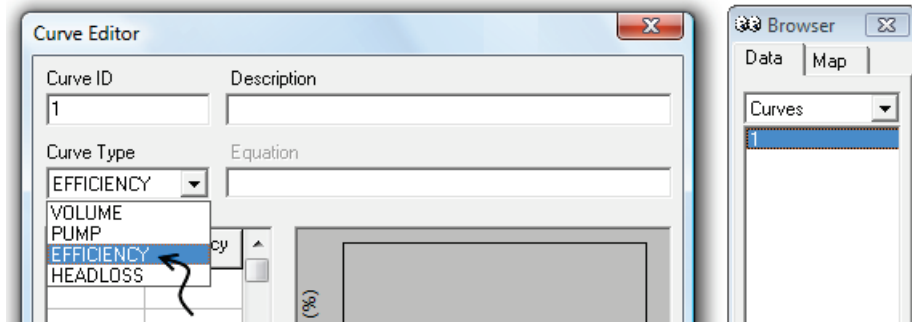


To enter it click on the pump in question and go to the property "Efficiency curve".

# Ranking the expenses

How much money is spent where in building a water network depends on the nature of the infrastructure. Some authors, like Stephenson[1], make a generic breakdown to distribute the costs like this: 55% for buying the pipes, 25% excavation and installation. In development, excluding the organizational costs of the NGO and of access to water (boreholes, etc.), the following figures are closer to my experience:

|  |  |  |
|---|---|---|
| **1º.** Pipes and accessories | 36% |
| **2º.** Excavations | 31 % |
| **3º.** Layer of sand | 16% |
| **4º.** Valve boxes | 11 % |
| **5º.** Pipe installation | 5% |

Here we can draw some interesting conclusions. Points 2, 3, 4 and 5 can be considered relatively independent to the pipe diameter. Thus, two thirds of the capital cost is independent of the pipe diameter.



Independent of the diameter
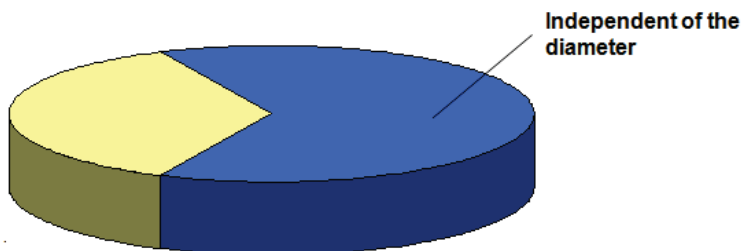
The conclusion is so important it deserves its own subsection.

[1] *Stephenson (1981) "Pipeline Design for Water Engineers".*

# "Dry diametritis"

Clearly this is not an engineering term but a tactic to help you remember this illness that many networks suffer from in development. The outcome generally is because of a granny economics approach or of a restriction *it has to cost less than x*.

Basically you try to save on the pipes by limiting the diameters to the very lowest. The resulting networks barely tolerate design errors or changes of use, are not easily enlarged, let down the beneficiaries at the time of day when they most need water and are costly to operate. It is not surprising that these networks are frequently dry. If this has been accompanied by savings in the sad bed for the pipe and the pipes laid in shallow excavations resulting in frequent bursting the result doesn't leave much cause for celebrations.

To duplicate a line because it isn't capable of transporting sufficient flow is very expensive. Let's look at an example comparing 1,000 meters of a pipe of 200mm, with two of 160 and 125mm that transport the same amount of water. Note that 160 to 200m is only one step in diameter:

|  | 200 mm | 160 + 125 mm |
|---|---|---|
| Pipe price | 21,000 | 13,500 + 8,100 |
| Installation etc. (64%) | 37,300 | 37,300 + 37,300 |
| **TOTAL** | *58,300 €* | *96,200 €* |

Therefore, **be generous with the diameter of pipes when they are plastic** and you will enable the population served to be able to:

1. Postpone enlargements.
2. Facilitate enlargements.
3. Radically lower the pumping costs.

## Be generous… but how much and how?

Being generous with the diameters has two main side effects, a worsening of quality by increasing the residence time in the network and an increase in costs.

The best candidates to promote are:

**(1)** Downstream of tanks or pumping lines.
**(2)** Pipes that form part of a grid.
**(3)** Important pipes that could form a grid in the future.
**(4)** Pipes that go to zones of possible development.
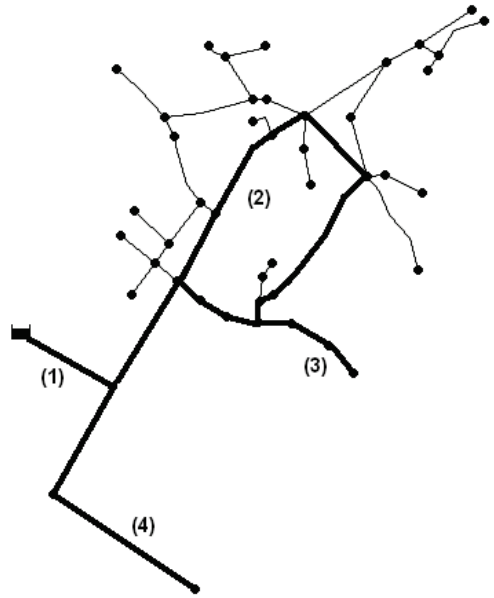
In the image on the right, possible candidates are in bold.



The next question is how much should diameters be increased. There is a diameter below which there is a spectacular decrease of the water transport capacity. Take two diameters larger than the failed size, that is to say, one size larger than required.

The illustration below represents the development of pressure of a pipe through time, assuming initially that it is 4" and increasing to 8". Each line on the graph represents a pipe diameter. The pressure interval has been exaggerated to make it easier to see:
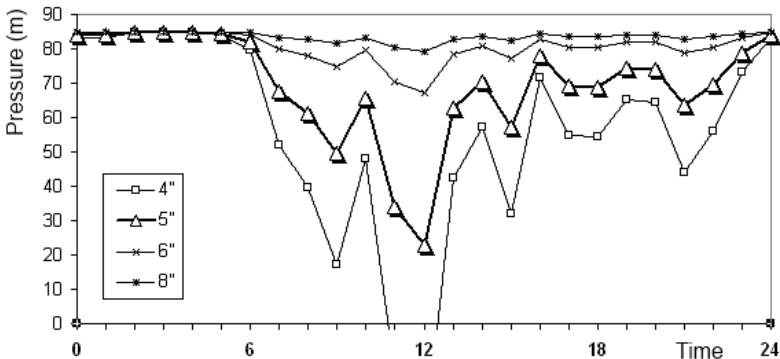


The first pipe that maintains the pressure is in bold, and corresponds to 5" (triangles). According to the recommended approach, the pipe to install would be the next available commercial diameter, 6". Look at hour 12 in the day and see that bigger diameters are very similar. In the majority of cases the practice of passing a diameter allows enlargements of the network without the need to install new pipes.

# Cost vs. Diameter

## Pipes and transport capacity

It is often assumed that bigger pipes transport the l/s at a smaller price. The logic behind this is that if you bulk buy 300 pens the cost per unit should be cheaper. However, for plastic pipes that cannot be taken for granted. The cost to carrying capacity ratio is almost constant.

The two graphs below illustrate this for PVC (Uralita) and HDPE (Chresky), approximately 1 €/m for each l/s in PVC and 1.1 €/m for the HDPE. The per-liter cost is the thick horizontal line close to the axis:
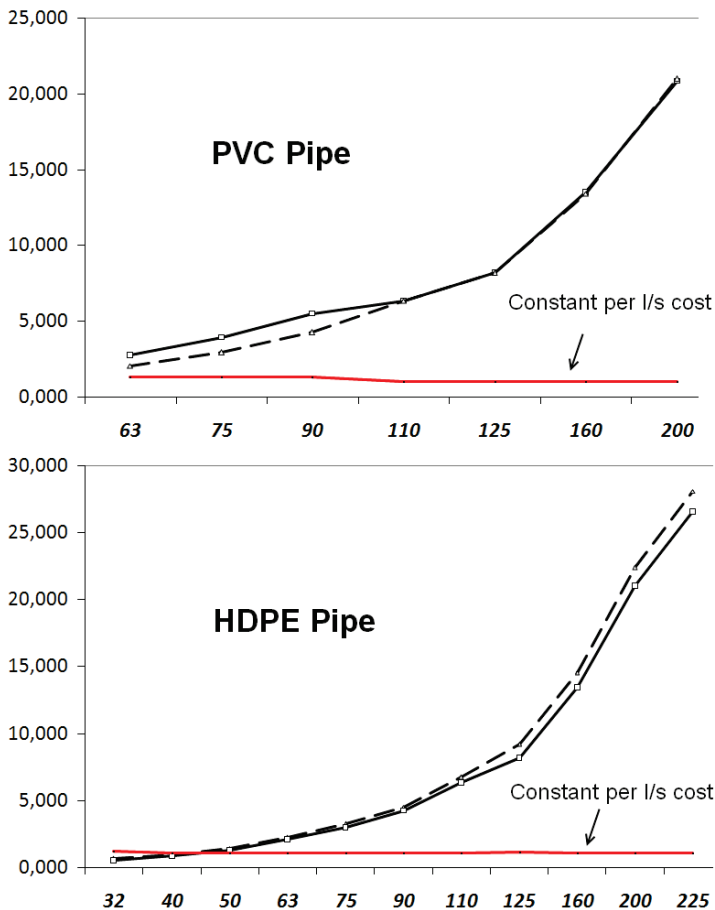
In both cases the transport capacity of the pipe in l/s (solid line) and the cost per meter (dotted line) increase parallel with the increase in diameter.

**Accessories**

An important problem is that the price of accessories, notably the valves, shoots up disproportionately with diameter. If a gate valve costs 11 dollars for 1", it costs 1,460 for 12". You can see the relationship of price against diameter in the graph that follows.
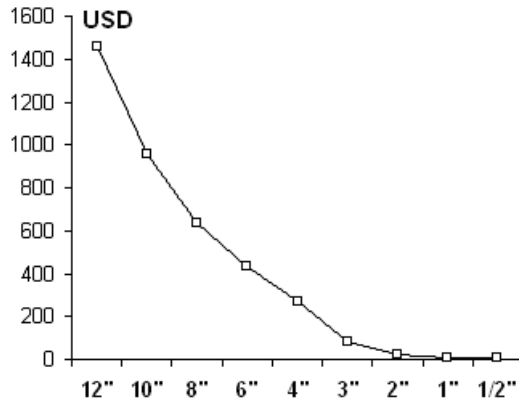


The bigger the unit price of an item, the lower the probability that it will be replaced by the operators or the community. Although it may not feel like a big deal to you especially compared to the total capital cost of the project, take into account that 700 dollars in some instances are many days pay. The ultimate consequence is that, **replacing control accessories for larger diameters can present a big challenge at the community level**.

Often, at first sight the network seems to work as it is common for communities not to notice a failed fitting. It's not as evident as a broken pump which stops supplying water. Nevertheless, if a gate valve breaks in the process of opening or closing, for example, they will remain half closed and the transport capacity of the pipes diminishes significantly.

# Most common wastages in assembly

As we are coming to the end of this introductory book you probably have a model loaded, you have worked it and it is ready to be implemented. Before you rush to implement it in the heat of the moment, finally check that you are not in one of the following situations:

## Strangling the sources

This happens in a network where pipes are too small at the exit from a tank or pump. The result is a drop in overall pressure in all points which can be "resolved" by putting the tanks at a higher elevation or choosing a more powerful pump. This is like accelerating a car while pressing the brake. The fuel expenses shoot up. To solve this, increase the diameter of these pipes and lower the tanks and/or reduce the power of the pumps.

## Gigantism

This is a case that often goes unnoticed because the network works fantastically. It comes as a result of laying pipes much bigger than necessary which damages the quality and increases the capital and maintenance costs. The simplest way to detect this is to look at the velocity the pipes have in the period of maximum consumption. If it is less that 0.5 m/s, it is a suspect of gigantism although it's not always the case.

## Redundancy

This consists of laying pipes that contribute nothing to the transport capacity in places where geographically it is unnecessary. We have seen the cost of installing a pipe parallel to an existing one that lacks sufficient capacity. To install redundant pipes is very similar.
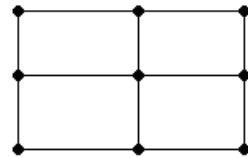
Remember the data:

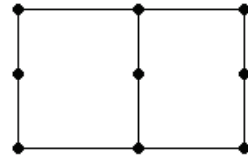|  | 200 mm | 160 + 125 mm |
|---|---|---|
| Pipe price | 21000 | 13500 + 8100 |
| Installations etc. (64%) | 37300 | 37300 + 37300 |
| **TOTAL** | **58300 €** | **96200 €** |

It is evident that to put pipes in practically the same
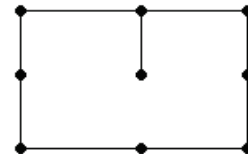trench is very similar to either of these two diagrams.
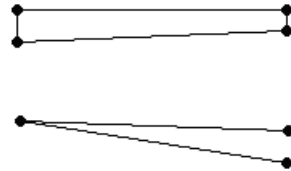
We have a strong tendency to draw networks similar to this
because you will see them frequently in books.

Would this not be equivalent in many cases?

Even this, providing the terminal distribution does not raise a
problem, for example with the quality.

One of the best ways to avoid this is by making use of simplification, similar to
skeletonization, but in reality taking out the actual pipes and not only in the model.

## By way of farewell

The end of the book has arrived, although you may still have many questions. Many of them can only be resolved with experience.

As with networks, this book has tried to find a balance between covering everything that is really important with a certain depth and not overwhelming or intimidating with an endless volume of data and situations. I hope it has succeeded.

To solve the rest, I have started the site www.epanet.org where you can ask questions.

If you believe that the book can be improved in some way or you feel something is missing, don't hesitate to write to me:

publicaciones@arnalich.com

**Remember that the computer screen shouldn't keep you from seeing the beneficiaries!**

# About the Author



**Santiago Arnalich**

At 26 years old, he began as the coordinator of the Kabul Project CAWWS Water Supply, providing water to 565,000 people, one of the biggest projects at the time. Since then, he has designed improvements for more than a million people, including refugee camps in Tanzania, the city of Meulaboh following the Tsunami, and the poor neighborhoods of Santa Cruz, Bolivia.

**Arnalich Water and Habitat** is an organization that helps improve the impact of humanitarian actors through training and consultancy in the fields of Water Supply and Environmental Engineering.

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This manual aims at walking the reader through the design of a water supply network in a Development context by explaining in a simple manner how to build and analyze a computer model of a water network with Epanet.

**Epanet** is a free and widely used software from the U.S Environmental Protection Agency that models the hydraulic and water quality behavior of water distribution piping systems.

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