

CREATING CORRECT DATA FOR HYDRAULIC APPLICATIONS

A contribution for strengthening and improving the drinking water network in Da Nang

Andries van Noorden

November 2009

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Executive summary

On the analysis of hydraulic calculation, the node pressure, pipe diameter, water velocity and hydraulic gradient could be adjusted for reducing the risk of leak or break in the pipe network, and cutting the cost. Because the network is a looped network, to ensure the quality of the network and the water itself, calculations are done by hydraulic applications. These applications are using a data model which are specific for each application. However each model must include some basic data so here for a general data model can be created.

These days businesses are more and more using a Geographic Information System (GIS). With some kind of programme the network can easily be analyzed although it takes a lot of effort to create the correct data. In this rapport you can find a way to use a GIS for the drinking water supply company of Da Nang, Vietnam.

Abbreviations

CAD	Computer Aided Design
CRM	Customer Relationship Management
Dawaco	Da Nang Water supply Company
DoC	Department of Construction
GIS	Geographic Information System
MDG	Millennium Development Goals
MDG7	Millennium Development Goal 7: Ensure environmental sustainability
NRW	Non Revenue Water
PC	People's Committee
PPP	Public Private Partnership
SCADA	Supervisory control and data acquisition
USP	Utility Support Program
VDG	Vietnamese Development Goals
VEI	Vitens – Evides International bv.

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Preface

I am glad to present the product of my internship at the drinking water company of Dawaco on which I spend the last for months of my Bachelor Civil Engineering. I would like to thank Vitens – Evides International B.V. for providing the opportunity to perform my research within their company. The time, freedom and the help I received from Gerard Soppe to formulate and execute my research was pleasant.

I want to say thanks to Ms. Duc Hanh Nguyen, Ms. Ngo Minh Phuong and Hung Dao Ngoc for the warm welcome and pleasant stay in the city. Special thanks to Ms. Le Phuong Thao who has made a lot of time to talk when I lost myself again in my research and showed me the Vietnam culture from a totally different view. Also the Dutch shorttermers, who stayed for some weeks in Da Nang and with who I exchanged the experiences of this country deserve a thanks.

1. Introduction

Water is essential to sustain life. The availability quality of water used for consumption has a profound influence on public health and economic development. The Da Nang Water supply Company (Dawaco), the People's committee of Da Nang (PC), the Royal Netherlands Embassy and Vitens-Evides International (VEI) started a public-private partnership (PPP) in October 2007, to strengthen and improve the water supply in Da Nang. With a Utility Support Program (USP) the goals of the partners involved were agreed. One of the main goals was to contribute to the Millennium Development Goals to improve water availability for the urban poor.

In 2007 the water production was amounted to 40.5 Mm³/year, with a Non Revenue Water (NRW) percentage of 39%. This percentage is too high and has to be lowered to become a prosperous company. By comparing data like the production and the total quantity sold the NRW can be determined. The NRW is a result of leakages in the network, illegal water use and not paying customers. Computer programs can be used to locate possible leakages, but to use these programs correctly a lot of effort has to be done.

1.1. Current situation

The water company is implementing the hydraulic application Epanet to improve the handling of the drinking water network by getting a better grip on pressure and flow and be able to find the cause of unexpected changes in the network. To build the digital network, a large number of incomplete AutoCAD drawings have been used to transfer into the hydraulic application. This was done by checking and importing most of the data manually. The data are stored in a database. At the moment the basic data are stored at several locations and divisions of Dawaco. Later on a central databank could or could not be chosen depending on the interest from the USP. Other applications like a Customer Relationship Management System (CRM) or, in the future, a Geographic Information System (GIS) could also extract their data from this storage (Figure 1).

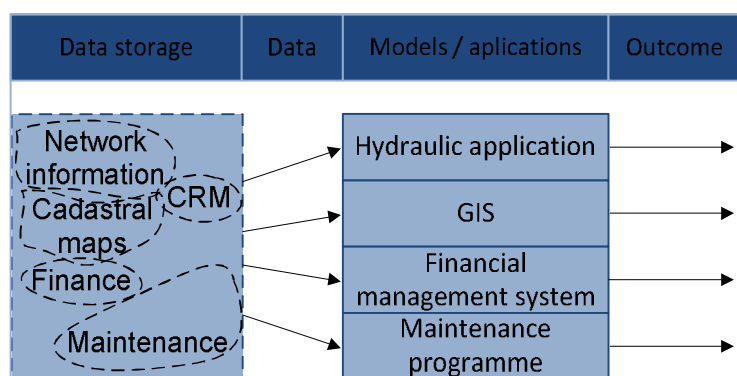


Figure 1 Overview of data usage

There are different hydraulic applications on the market to use. At the moment Epanet is the most appropriate choice for Dawaco, because it is freeware and easy to learn compared to other hydraulic applications. Later on another model could be chosen depending on the skills, requirements etc. from the company.

Data of the network in the storage are subdivided into objects and accompanying attributes. An object is a phenomenon like a pipeline, fire hydrant or a distribution point but also non physical things like a license or the project name. Attributes are characteristics of an object. So for an object like a pipeline the attributes can be the length, the coordinates of the location, the diameter, the materials and others.

1.2. Problem

The combination of incomplete AutoCAD drawings and the manual import results in errors in the data used by hydraulic applications. Information like units and accuracy are inconsistent while they are important for the data in the data storage to give a correct outcome in the hydraulic applications. First the correct units and accuracy of the data in the data storage has to be determined.

In the future the information of the network will be implemented in a GIS. The GIS has the objective is to make it easier to adjust data and analyze the network by making visualizations. So a second thing that has to be researched is whether the hydraulic application uses data from the storage, from the GIS or both (Figure 2).

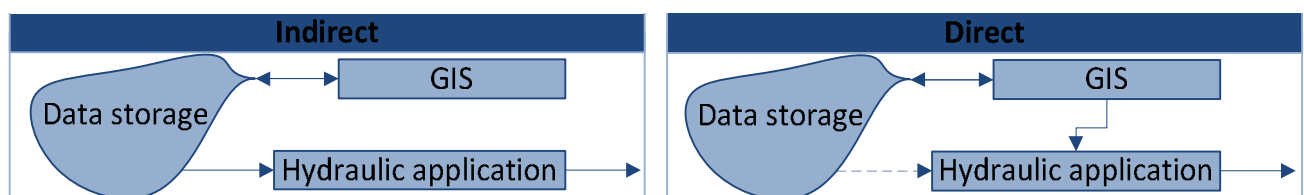


Figure 2 Two options of the data usage by the hydraulic application

1.3. Objectives en research questions

The main objective of this research is to create a data model of the object and attributes of the drinking water system in Da Nang. These attributes need to be quantified with a certain accuracy to make the calculations of the applications possible and correct. The possibility of a direct connection between the GIS and the hydraulic application will also be determined by evaluating the pros and cons of such a connection.

The data are stored in several kinds of databases. The integrations of these databases faces a number of complex problems such as the naming of variables and objects, classification of objects and the difference in dimensions of the variables. For that reason standardization of the description of this information is very useful. The easiest solution is to agree upon a glossary describing the essential terminology (van de Looij, 2000). When a database is structured in this manner, it is easier for an application, like a Customer Relationship Management System (CRM) or, in the future, a Geographic Information System (GIS), to retrieve the desired data for their variables.

Data have to be stored in a form which matches with basic drinking water principles. At the moment the USP made a choice for Epanet, so this application will be analyzed. The research will be done irrespective of the programme for the GIS.

The main objective is divided into several sub objectives:

- Determine what objects and attributes are used in Epanet,
- Determine the required accuracy of the quantitative attributes,
- Analyze the possibility of using a GIS application in a drinking water company

This brings us to the primary question of the research;

What data and accuracy of these data are required for hydraulic applications and what are the benefits to use a GIS as a data source?

1.4. Structure of the report

First chapter 2 gives an analysis of drinking water in Vietnam, followed by the position of Dawaco in this culture. In chapter 3 and 4 respectively the hydraulic applications and GIS will be analyzed by consulting literature and experts in the USP. For the hydraulic application and the GIS the objects and the attributes will be determined. On base of these data the accuracy will be mentioned in chapter 5 and an advice can be given in chapter 6 based on preceding chapters (**Figure 3**).

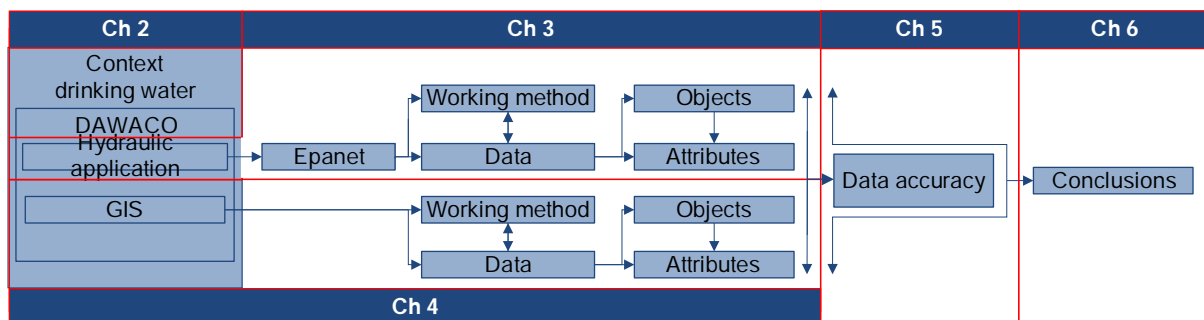


Figure 3 Overview of structure of the report

2. Drinking water in Vietnam and principles

Public drinking water contributes to improve people's health and economic development. Because of access to good and inexpensive water people live a more hygiene way of life. Industries and companies are less tied to direct surroundings, so they can flourish more easily.

In countries, like western developed countries, access to drinking water is quite common but in other countries it is not. A difference exists between countries where clean drinking water is coming out of water taps e.g. in most western countries, clean drinking water has to be supplied by bottles or tanks because the the water coming from the taps is for sanitation (Spain, Egypt or Vietnam) and countries where access to drinking water is not common at all (Congo or Sudan).

First the situation of drinking water in Vietnam will be explained, scoping on the situation in Da Nang (Figure 4) and the cooperation between Dawaco and Vitens – Evides International. At the end of the chapter the drinking water production and distribution principles will be clarified.



Figure 4 Location of Da Nang in Vietnam

2.1. Vietnam

In 2002 only 60 percent of the Vietnamese population has access to drinking water. The water demand will rise in the future especially in the bigger cities. The Ministry of Construction declares that only 200 of the 689 cities have access to clean drinking water by municipal water companies. The water distribution network in Vietnam has to be expanded to satisfy the rising demand for water. The government expects that 95 percent of the urban areas and 85 percent of the rural areas will have access to drinking water in 2010 (Water Environment Partnership in Asia, n.d.).

The lack of a good quality water system causes health problems and a huge amount of water is lost because of leakages by bad maintenance. The United Nations, the Worldbank and the Asian Development Bank advised the Vietnamese government to give high priority to the development of water systems. With help of financial donors and foreign authorities and companies big investments can be made for better water control and management.

The government used to be in control of water systems, but it has become more decentralized so it is possible for foreign companies to participate. In most cases the local market has not got enough expertise for a sustainable and good quality development. (EVD, 2009)

2.2. Da Nang Water supply Company

Formally the PC of Da Nang is responsible for the implementation and the management of drinking water services in the area under its jurisdiction. The management is executed by Dawaco. Dawaco is at part of the Provincial People Committees and is an company what focuses on the urban area. Hence strictly spoken, the PC has two roles, that of asset owner and of regulator.



Figure 5 Company logo of Dawaco

2.2.1. Organizational structure

The organisational structure is typical for an urban company, in which the managing supporting departments determine policy and operational directives, whereas the production and distribution organisation are responsible for executing operational tasks.

Dawaco has 466 staff members and nearly 150.000 connections. Taking into account the low degree of automation of drinking water production and distribution and a high degree of (manual) cash transactions, Dawaco as a whole can be considered slightly overstaffed.

2.2.2. Production and distribution

Nearly 100 percent of the raw water source is the Cam Le River. The origin of Cam Le tributaries is partly situated in Da Nang Province, which assist administrative prevention of industrial en residential raw water pollution to some degree. The catchment areas are sparsely populated, mainly used as agricultural area, and no major pollution of either industrial, domestic or agricultural origin exists.

In 2008 the total water production of Dawaco amounted to 44.5 Mm³/year, with a maximum production of 126.000 m³/day. This water is produced at five water treatment plants (WTP). The network covers the built up area of Da Nang city and is owned and managed by Dawaco. The exact data on the length, location and geometry of pipelines are not available. It is estimated, that the total length of the transport and distribution network is 1.200 km. The present total length of service pipelines is in the order of 400 km for about 120.000 connections (active and non-active).

Dawaco owns the raw and clear water transport system and the distribution network. The customer is owner of the service pipeline and the water meter of the connection. Dawaco manages the whole transport and distribution network up to and including the water meter. (Doppenberg, 2009)

2.3. Vitens Evides International bv.

Vitens-Evides International (VEI) is the international alliance of the two largest water companies in the Netherlands: Vitens and Evides. The focus is on projects for urban water supplies. The aim is to improve day-to-day operations within local water companies by serving as a manager, operator and consultant. Vitens-Evides is active in countries such as Mozambique, Vietnam, Suriname, Mongolia, Yemen and Ghana.



Figure 6 Company logo VEI

Vitens and Evides make €2 million available each year for international projects. This internal budget is leveraged by contracting public-private partnerships (PPP) and deploying the financing opportunities of the various parties, such as the Netherlands' Ministry of Development Cooperation and Economic Affairs, the World Bank, the European Bank for Reconstruction and Development (EBRD) and the Asian Development Bank. Vitens has also formed the independent foundation 'Water for Life', enabling its clients to contribute to international Vitens-Evides projects through their water bills.

The UN target of halving the more than one billion people without safe drinking water by 2015 is actively supported by the Dutch Government. In this context Vitens and Evides do all they can to share their expertise and experience in water purification, maintenance and waste water solutions with water companies in developing countries. Through the international alliance Vitens and Evides are helping to provide safe drinking water to over 10 million people in parts of the world where reliable water services are not readily available. (Vitens, 2008)

2.4. Utility Support Program

During a period of three years, starting October 2007, Dawaco, the PC of Da Nang, the Royal Netherlands Embassy and VEI are committed to a PPP to strengthen and improve the water supply in Da Nang. The PC of Da Nang seeks to improve water service delivery to all its citizens. That is likely to mean improved water services against the lowest possible costs. Dawaco seeks know-how and expertise in both operational and strategic utility management. VEI seeks to share its know-how and expertise in this specific domain, with utilities in developing countries, in order to contribute to the achievement of the Millennium Development Goal (MDG) on water supply and sanitation (MDG7). The Netherlands government is committed to contribute to the realization of MDG7 for 50 million people. Part of this contribution will be realized through public private partnerships of which the one for the Da Nang water supply is one.

The strategic objective of the PPP is to implement the USP as initial step towards sustainable operation and maintenance of its water facilities and network, inducing an overall improvement of the operational and financial performance of Dawaco. Secondly Dawaco will need to acquire funds

for investing in rehabilitation of and extensions to the production facilities and distribution network. This process of operational and financial improvement and increased coverage rate will manoeuvre Dawaco to a more autonomous utility. A strong and well performing utility is also an important prerequisite to provide sustainable water services to the low income groups and the urban poor, contributing to the MDG and Vietnamese Development Goals (VDG).

2.5. Drinking water companies

The drinking water is supplied by so called water companies. These companies can be divided in the size of their distribution area. Municipal companies supply districts or towns and provincial or regional water companies supply the larger rural areas.

To deliver the public drinking water to the users two aspects are important: production and distribution (Figure 7). First the water has to be abstracted from a water resource and treated for turning it into clear water. This process is called production. After the production the water has to be stored and transported to deliver it to the users. This second process is called distribution.

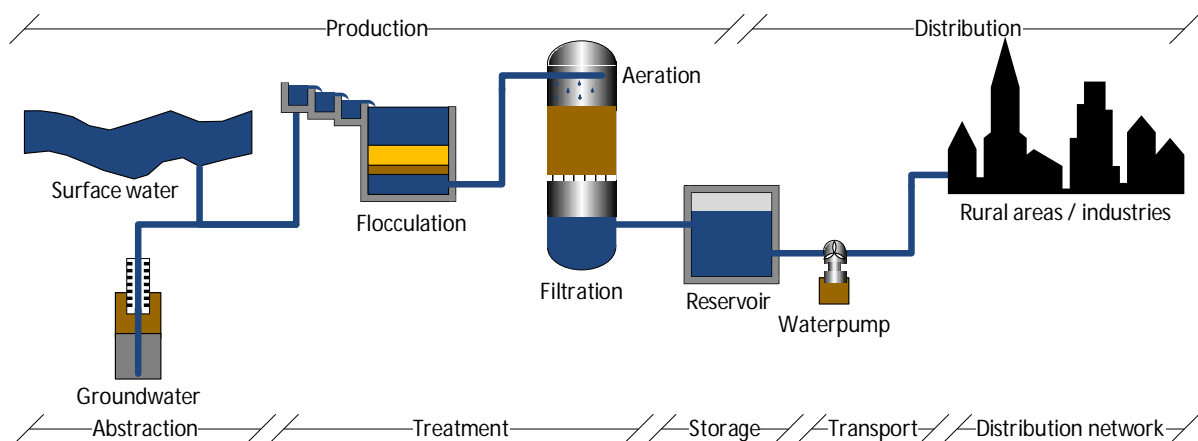


Figure 7 Watercourse of drinking water (de Moel, Verberk, & van Dijk, 2006)

2.5.1. Production

In the production process the water is going from raw (low quality) to clear (high quality) water. This is done by several steps depending on the source where the water is abstracted. The abstraction of water can be done from groundwater or from surface water. First of all this water is pumped to a water treatment plant. The water is treated to obtain the required quality. Because of the presence of chemicals and micro organisms, chemicals are inserted to form flocks. These flocks have a higher density compared to water so they can easily be removed from the water. Other chemicals like chloride can be added to disinfect the water. When the water is coming from the ground it is probably anaerobic (oxygen shortage) and contains undesirable compounds like iron, manganese, ammonium, methane and hydrogen sulphide. By aeration and rapid filtration

oxygen is brought back into the water and the dissolved gasses are removed. In the filters water goes through a sand layer so the last pollution will be filtered. Finally the water is pumped into a reservoir so it can be distributed.

2.5.2. Distribution

In the reservoir water is stored to create some kind of buffer between the production and the demand of water. By implementing a reservoir it is possible to produce water at a constant level. At night, when the demand is low, water will be stored in the reservoir. During the day the demand for water will rise and will partially be fulfilled with the stored water (Figure 8). After the storage water will go through water pumps to gain pressure so it can be transported over the distribution network to the users. This network includes pipelines, pumps, valves, fire hydrants, service connections etc.

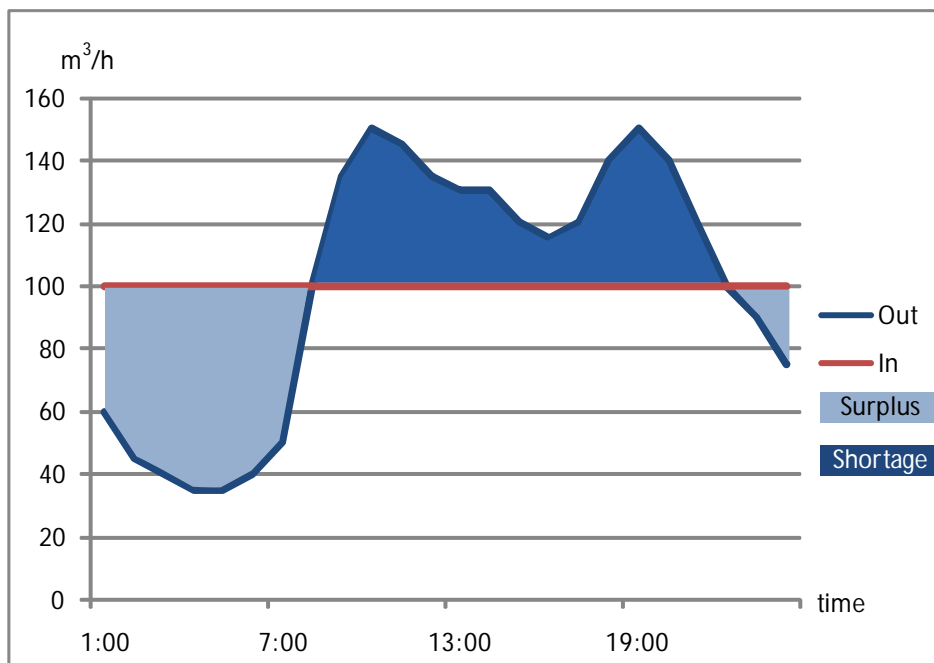


Figure 8 Water storage (de Moel et al., 2006)

The nature of a distribution area is a branched system; however, a branched system is vulnerable. During a disturbance (pipe fracture, changes, maintenance, etc.), the customers will receive no water. Because of securing the supply, there will need to be an alternative route from which an area can be supplied with drinking water. Such a distribution network is called a looped system (Figure 9) and is present in Da Nang. Note that not the whole network is a looped system; house connections are branches of the looped main network.

Calculations of distribution pipes are complex because of their looped structure, so computer programs are used. These programs use network algorithms in which pipes are schematized to one-dimensional connections and the demand is assumed to be concentrated in a node of pipes. (de Moel et al., 2006)

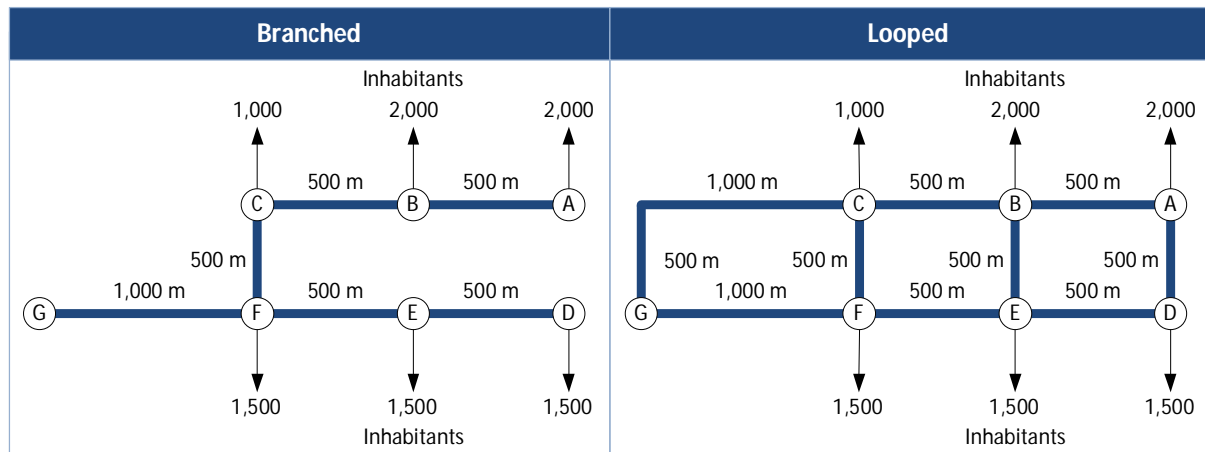


Figure 9 Difference between a branched and a looped distribution network (de Moel et al., 2006)

The computer programs that will give answers to hydraulic questions like *"How big should this new pipe be?"* or *"Do I have sufficient pressure and availability at the fire hydrant at Hilltop Elementary School?"* are called hydraulic applications.

3. Hydraulic applications

Calculations necessary to support design or maintenance decisions are generally too large and complicated to perform by hand. Over the years, more and more utilities have turned to hydraulic applications to support their asset management decision making. Once, these applications were so complex and difficult to use that they were mainly used by large utilities and their consultants. Now, competition and technology advances have driven costs down and the applications are so easy to learn and use that even the smallest water utilities can afford them (or can not afford not to have them!). More and more regulators are insisting on seeing the results of application runs before they approve system improvements.

A hydraulic application uses data of a water course and calculates the behaviour of water within that watercourse. A watercourse can be a water valley or a distribution network and connects objects like reservoirs, pipes, rivers and valves with each other so the advancing water flow can be calculated. Most of the hydraulic applications are capable of making calculations like water quality, water age, pressure flow and loss. Hydraulic applications help making decisions like cleaning, extending or replacing objects within hydraulic systems.

To create a network in an application, the minimum requirement is converting paper maps of the system and as-built drawings. Users can directly and easily draw the network and manually input descriptive data and demands. However, it is more frequently the case these days that commercial tools are used to automate the model building process. To relieve the user from the monotony and potential for error in manual data entry, data can be imported from existing sources such as CAD maps, GIS systems and databases. (Govindan, Walski & Cook, 2009)

Every object within the data storage must be connected to each other in the right way for the use of pipeline facility data in an hydraulic application. If the application is to generate the correct results, then it must correctly represent the objects in the network. In pressure/flow modelling, any molecule of water must be able to travel the same path within the application, that it could take within the real-life distribution network. If enough misrepresentations of pipe connectivity occur within the model, the results generated by the analysis would be too inaccurate for use.

At the moment the USP made a choice for Epanet as hydraulic application within the company. Therefore this hydraulic application will be analyzed. Now ever, several other commercial hydraulic applications are available. These models cost a lot of money, what isn't available within the project so it isn't possible to compare these models. A general description of Epanet and the working method is given.

3.1. Epanet

Epanet was developed by the Water Supply and Water Resources Division (formerly the Drinking Water Research Division) of the U.S. Environmental Protection Agency's National Risk Management Research Laboratory (Rossman, 2000). Epanet is probably the most used open source application for hydraulic systems. Open source means that the source code of the software is free to use so this permits the users to use, change and improve the software. The software places no limits to the size of the network.

Epanet tracks the flow of water in each pipe, the pressure at each node, the height of the water in each tank, and the concentration of a chemical species throughout the network during a simulation period. Chemical species, water age, source, and tracing can be simulated.

Epanet provides an integrated computer environment for editing network input data, running hydraulic and water quality simulations, and viewing the results in a variety of formats. These include color-coded network maps, data tables, time series graphs, and contour plots.

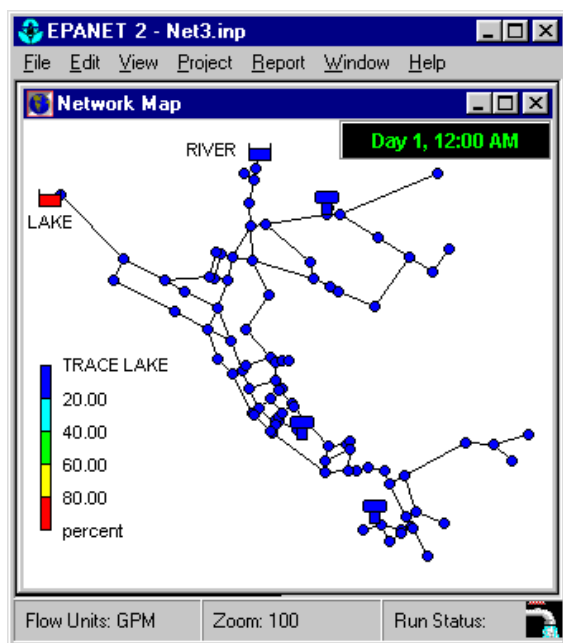


Figure 10 Epanet planar schematic diagram

The Epanet Programmer's Toolkit is a dynamic link library (DLL) of functions that allow developers to customize Epanet's computational engine according to their own needs. The Network Map provides a planar schematic diagram (Figure 10) of the objects comprising a water distribution network. The location of objects and the distances between them do not necessarily have to conform to their actual physical scale. Selected properties of these objects, such as water quality at nodes or flow velocity in links, can be displayed by using different colors. The color-coding is described in a Legend, which can be edited. New objects can be directly added to the map and existing objects can be clicked on for editing, deleting, and repositioning. A backdrop drawing (such as a street or topographic map) can be placed behind the network map for reference. The map can be zoomed to any scale and panned from one position to another. Nodes and links can be drawn at different sizes, flow direction arrows added, and object symbols, ID labels and numerical property values displayed. The map can be printed, copied onto the Windows clipboard, or exported as a DXF file or Windows metafile. (Rossman, 2000)

3.2. Working method

There are basically two types of equations that must be solved in any hydraulic calculations:

- 1) Mass continuity (conservation of mass) equation;
 - a) Flow rate of water into any junction of pipes equals flow out,
 - b) For any tank, flow in minus flow out equals change of volume in storage.
- 2) Energy equation – water gains or loses energy as it moves through a distributions system;
 - a) Losing energy due to friction/roughness as it moves through pipes,
 - b) Gains energy as it passes pumps,
 - c) Loses energy as it passes valves.

These equations are not terribly difficult to solve except that there is not a single energy equation or a single continuity equation. Instead, there is one continuity equation for every pipe, junction or tank and one energy equation for every pipe. This means that to solve the network hydraulics, the computer must solve hundreds or thousands of equations simultaneously.

Solving all those equations gives the model user a good idea of what is happening in their system at a point in time. It is usually referred to as a steady model and in many cases, that is all one needs. However, water systems are dynamic, with pumps turning on and off through the day as demands vary. Models can track these gradual changes over time in what are usually called extended period simulation runs. These are especially helpful in understanding system operation.

In addition to gradual changes in conditions, sudden changes in pump operation or valve status can trigger transient events that can damage the distribution system. A different form of the equations must be solved to predict what will happen during these events and what can be done to prevent damage.

Epanet's hydraulic simulation model computes junction heads and link flows for a fixed set of reservoir levels, tank levels, and water demands over a succession of points in time. From one time step to the next reservoir levels and junction demands are updated according to their prescribed time patterns while tank levels are updated using the current flow solution. The solution for heads and flows at a particular point in time involves solving simultaneously the conservation of flow equation for each junction and the headloss relationship across each link in the network. This process, known as "hydraulically balancing" the network, requires using an iterative technique to solve the nonlinear equations involved. Epanet employs the "Gradient Algorithm". (Rossman, 2000)

3.3. Objects

Table 1 Objects in Epanet

Item	Object
Nodes	Junctions Reservoirs Tanks
Links	Pipes Pumps Valves
Map Labels	
Time Patterns	
Curves	
Controls	

Epanet contains both physical objects that can appear on the network map, and non-physical objects that encompass design and operational information. These objects can be classified as in Table 1. Remarkable is that pumps and valves are presented as links while it is expected they would be presented as nodes. In reality however, these objects are attached to connection pipes. So in the application these connection pipes are included in the object.

All physical objects will shortly be described and the attributes will be analyzed. The non-physical objects will be described in Appendix A.

3.4. General Attributes

First some general attributes are given which are included in almost every object continuing with the description of the object and their specific attributes.

Table 2 General attributes

Attribute	Description
ID	A unique label used to identify the object. It can consist of a combination of up to 15 numerals or characters. It cannot be the same as the ID for any other object. This is a required property.
X-coordinate	The horizontal location of the junction, reservoir or tank on the map, measured in the map's distance units. If left blank the object will not appear on the network map.
Y-coordinate	The vertical location of the junction, reservoir or tank on the map, measured in the map's distance units. If left blank the object will not appear on the network map.
Start node	The ID of the node where the pipe, pump or valve begins. This is a required property.
End node	The ID of the node where the pipe, pump or valve ends. This is a required property.
Description	An optional text string that describes other significant information about the object.
Tag	An optional text string (with no spaces) used to assign the object to a category, such as a pressure zone.
Initial quality	Water quality level in the junction, reservoir or tank at the start of the simulation. Can be left blank if no water quality analysis is being made or if the level is zero.
Source quality	Click the ellipsis button to display a Source Quality Editor in which the quality of water entering the network from the junction, reservoir or tank can be specified (regardless of what the actual quality in the tank is).

3.5. Junction

Junctions are nodes in the network where links join together and where water enters or leaves the network.

Table 3 **Junction attributes**

Attribute	Description
Elevation	The elevation above some common reference of the junction. This is a required property. Elevation is used only to compute pressure at the junction. It does not affect any other computed quantity.
Base Demand	The average or nominal demand for water by the main category of consumer at the junction, as measured in the current flow units. A negative value is used to indicate an external source of flow into the junction. If left blank then demand is assumed to be zero.
Demand Pattern	The ID label of the time pattern used to characterize time variation in demand for the main category of consumer at the junction. The pattern provides multipliers that are applied to the Base Demand to determine actual demand in a given time period. If left blank then the Default Time Pattern assigned in the Hydraulic Options will be used.
Demand categories	When the ellipsis button is clicked a Demand Category Editor is displayed that allows base demands and time patterns to be assigned to other categories of users at the junction.
Emitter Coefficient	Discharge coefficient for emitter (sprinkler or nozzle) placed at junction. Leave blank or set to 0 if no emitter is present. See Emitters for more details.

3.6. Reservoirs

Reservoirs are nodes that represent an infinite external source or sink of water to the network. They are used to model such things as lakes, rivers, groundwater aquifers, and tie-ins to other systems. Reservoirs can also serve as water quality source points.

The primary input properties for a reservoir are its hydraulic head and initial water quality. Because a reservoir is a boundary point to a network, its head and water quality cannot be affected by what happens within the network. Therefore it has no computed output properties. However its head can be made to vary with time by assigning a time pattern to it.

Table 4 **Reservoirs attributes**

Attribute	Description
Total Head	The hydraulic head (elevation + pressure head) of water in the reservoir. This is a required property.
Head Pattern	The ID label of a time pattern used to model time variation in the reservoir's total head. Leave blank if none applies. This property is useful if the reservoir represents a tie-in to another system whose pressure varies with time.

3.7. Tanks

Tanks are nodes with storage capacity, where the volume of stored water can vary with time during a simulation. Tanks are required to operate within their minimum and maximum levels. Epanet stops outflow if a tank is at its minimum level and stops inflow if it is at its maximum level. Tanks can also serve as water quality source points.

Table 5 Tank attributes

Attribute	Description
Elevation	The elevation above a common datum of the bottom shell of the tank. This is a required property.
Initial Level	The height of the water surface above the bottom elevation of the tank at the start of the simulation. This is a required property. The format is in meters.
Minimum Level	The minimum height of the water surface above the bottom elevation that will be maintained. The tank will not be allowed to drop below this level. This is a required property.
Maximum Level	The maximum height of the water surface above the bottom elevation that will be maintained. The tank will not be allowed to rise above this level. This is a required property.
Diameter	The diameter of the tank. For cylindrical tanks this is the actual diameter. For square or rectangular tanks it can be an equivalent diameter equal to 1.128 times the square root of the cross-sectional area. For tanks whose geometry will be described by a curve (see below) it can be set to any value. This is a required property.
Minimum Volume	The volume of water in the tank when it is at its minimum level. This is an optional property, useful mainly for describing the bottom geometry of non-cylindrical tanks where a full volume versus depth curve will not be supplied (see below).
Volume Curve	The ID label of a curve used to describe the relation between tank volume and water level. This property is useful for characterizing irregular-shaped tanks. If left blank then the tank is assumed to be cylindrical.
Mixing Model	The type of water quality mixing that occurs within the tank. The choices include <ul style="list-style-type: none"> • fully mixed (MIXED), • two-compartment mixing (2COMP), • first-in-first-out plug flow (FIFO), • last-in-first-out plug flow (LIFO).
Mixing Fraction	The fraction of the tank's total volume that comprises the inlet-outlet compartment of the two-compartment (2COMP) mixing model. Can be left blank if another type of mixing model is employed.
Reaction Coefficient	The bulk reaction coefficient for chemical reactions in the tank. Use a positive value for growth reactions and a negative value for decay. Time units are 1/days. Leave blank if the Global Bulk reaction coefficient will apply. See Water Quality Reactions for more information.

3.8. Pipes

Pipes convey water from one point in the network to another. Epanet assumes that all pipes are full at all times. Flow direction is from the end at higher hydraulic head (internal energy per weight of water) to that at lower head. The status parameter allows pipes to implicitly contain shutoff valves and check valves (which allow flow in only one direction). The hydraulic head lost by water flowing in a pipe due to friction with the pipe walls can be computed using three different formulas:

- Hazen-Williams Formula
- Darcy-Weisbach Formula
- Chezy-Manning Formula

Minor losses caused by bends and fittings can also be accounted for by assigning the pipe a minor loss coefficient. Pipes can be set open or closed at preset times, when tank levels fall below or above certain set-points, or when nodal pressures fall below or above certain set-points by the use of controls.

Table 6 **Pipe attributes**

Attribute	Description
Length	The actual length of the pipe in feet (meters). This is a required property.
Diameter	The internal diameter of the pipe. This is a required property.
Roughness	The roughness coefficient of the pipe. It is unitless for Hazen-Williams or Chezy-Manning roughness and has units of millimetre (mm) for Darcy-Weisbach roughness. This is a required property.
Loss Coefficient	Unitless minor loss coefficient associated with bends, fittings, etc. Assumed 0 if left blank.
Initial Status	Determines whether the pipe is initially open <Open>, closed <Closed>, or contains a check valve <CV>. If a check valve is specified then any flow in the pipe must be from the Start node to the End node.
Bulk Coefficient	The bulk reaction coefficient for the pipe. Use a positive value for growth and a negative value for decay. Time units are 1/days. Leave blank if the Global Bulk reaction coefficient will apply (see Reaction Options). See Bulk Flow Reaction Rates for further description of this parameter.
Wall Coefficient	The wall reaction coefficient for the pipe. Use a positive value for growth and a negative value for decay. Leave blank if the Global Wall reaction coefficient will apply (see Reaction Options). See Pipe Wall Reaction Rates for further description of this parameter.

3.9. Pumps

Pumps are devices that bring in energy to a fluid thereby raising its hydraulic head.

Table 7 Pump attributes

Attribute	Description
Pump Curve	The ID label of the pump curve used to describe the relationship between the head delivered by the pump and the flow through the pump. Leave blank if the pump will be a constant energy pump (see below).
Power	Assumes that the pump supplies the same amount of energy no matter what the flow is. Leave blank if a pump curve will be used instead. Use when pump curve information is not available.
Speed	The relative speed setting of the pump. For example, a speed setting of 1.2 implies that the rotational speed of the pump is 20% higher than the normal setting.
Pattern	The ID label of a time pattern used to control the pump's operation. The multipliers of the pattern are equivalent to speed settings. A multiplier of zero implies that the pump will be shut off during the corresponding time period. Leave blank if not applicable.
Initial Status	State of the pump (open or closed) at the start of the simulation period.
Efficiency Curve	The ID label of the curve that represents the pump's wire-to-water efficiency (in percent) as a function of flow rate. This information is used only to compute energy usage. Leave blank if not applicable or if the global pump efficiency supplied with the project's Energy Options will be used.
Energy Price	The average or nominal price of energy in monetary units per kW-hr. Used only for computing the cost of energy usage. Leave blank if not applicable or if the global value supplied with the project's Energy Options will be used.
Price Pattern	The ID label of the time pattern used to describe the variation in energy price throughout the day. Each multiplier in the pattern is applied to the pump's Energy Price to determine a time-of-day pricing for the corresponding period. Leave blank if not applicable or if the global pricing pattern specified in the project's Energy Options will be used.

3.10. Valves

Valves are used to control the pressure or flow at a specific point in the network. Shutoff (gate) valves and check (non-return) valves, which completely open or close pipes, are not considered as separate valve components but are instead included as a property of the pipe in which they are placed (see section 3.8).

The General Purpose Valve (GPV) can be used to represent a link where the flow - head loss relationship is supplied by the user instead of following one of the standard hydraulic formulas. Each type of valve has a different type of setting parameter that describes its operating point (pressure for Pressure Reducing Valves (PRVs), Pressure Sustaining Valves (PSVs), and Pressure Breaking Valves (PBVs); flow for Flow Control Valves (FCVs); loss coefficient for Throttle Control Valves (TCVs), and head loss curve for GPVs). Valves can have their control status overridden by specifying they be either completely open or completely closed. A valve's status and its setting can be changed during the simulation by using Controls. (To restore a valve's control status after its status has been overridden to open or closed use a control that specifies a value for the valve setting.) Because of the ways in which valves are modelled the following rules apply when adding valves to a network:

- a PRV, PSV or FCV cannot be directly connected to a reservoir or tank (use a length of pipe to separate the two)
- PRVs cannot share the same downstream node or be linked in series
- two PSVs cannot share the same upstream node or be linked in series
- a PSV cannot be connected to the downstream node of a PRV.

Table 8 Valve attributes

Attribute	Description
Diameter	The internal diameter of the valve. This is a required property.
Type	The valve type (PRV, PSV, PBV, FCV, TCV, or GPV). See Valves for descriptions of the various types of valves. This is a required property.
Setting	A required parameter that describes the valve's operational setting. <div> Valve Type Setting Parameter <ul style="list-style-type: none"> • PRV Pressure (psi or m) • PSV Pressure (psi or m) • PBV Pressure (psi or m) • FCV Flow (flow units) • TCV Loss Coeff. (unitless) • GPV ID of head loss curve </div>
Loss Coefficient	Minor loss coefficient that applies when the valve is completely opened. Assumed 0 if left blank.
Fixed Status	Valve status at the start of the simulation. If set to <OPEN> or <CLOSED> then the control setting of the valve is ignored and the valve behaves as an open or closed link, respectively. If set to NONE, then the valve will behave as intended.

3.11. Units of measurement and accuracy

The following units and accuracies are being used at the moment by the USP:

Table 9 Units of measurement and accuracy of the parameters.

Parameter	Unit (metric system)	Accuracy
Demand	LPS (litres / sec)	$\pm 0,01$
	LPM (litres / min)	
	MLD (mega litres / day)	
	CMH (cubic meters / hr)	
	CMD (cubic meters / day)	
Diameter (Pipes)	millimetres	± 1
Diameter (Tanks)	meters	± 1
Elevation	meters	$\pm 0,1$
Flow	(see Demand)	$\pm 0,01$
Friction Factor	unitless	$\pm 0,001$
Hydraulic Head	meters	$\pm 0,01$
Length	meters	$\pm 0,01$
Minor Loss Coefficient	unitless	$\pm 0,1$
Pressure	meters	$\pm 0,01$
Reaction Coefficient (Bulk)	1 / day	$\pm -$
Reaction Coefficient (Wall)	mass / L / day or meters / day	$\pm -$
Roughness Coefficient	millimetres or unitless	± 10
Velocity	meters / second	$\pm 0,01$
Volume	cubic meters	± 1

Note that the quality of the water is not yet recorded for the data storage although quality meters are implemented into the system at the moment. The accuracy of the attributes currently is determined by the present data.

3.12. Import Data

To enter existing data into the hydraulic applications data need to have a certain form to make it readable for Epanet. In the next section the possibilities of importing data are given.

3.12.1. General import file

The input file for command Line Epanet has the same format as the text file that Windows Epanet generates from its Export command. It is organized in sections where each section begins with a keyword enclosed in brackets ([]). The order is not important. However, whenever a node or link is referred to in a section it must have been defined already in the Components section. Thus it is recommended that these sections be placed first, right after the [TITLE] section. The network map and tags sections are not used by command line EPANET and can be eliminated from the file. At the moment a lot of errors occur because of wrong implementation of the network coordinates.

Table 10 Import model

Network Components	System Operation	Water Quality	Options and Reporting	Network Map/Tags
[TITLE]	[CURVES]	[QUALITY]	[OPTIONS]	[COORDINATES]
[JUNCTIONS]	[PATTERNS]	[REACTIONS]	[TIMES]	[VERTICES]
[RESERVOIRS]	[ENERGY]	[SOURCES]	[REPORT]	[LABELS]
[TANKS]	[STATUS]	[MIXING]		[BACKDROP]
[PIPES]	[CONTROLS]			[TAGS]
[PUMPS]	[RULES]			
[VALVES]	[DEMANDS]			

3.12.2. Import from GIS/CAD

Epanet has the ability to import a geometric description of a pipe network in a format similar to that in which it exports a full network database to a text file. This description simply contains the ID labels and map coordinates of the nodes, the ID labels and end nodes of the links, and any intermediate vertex points associated with links. This simplifies the process of using other programs, such as CAD and GIS packages, to digitize network geometric data and then transfer these data to Epanet.

The format of a partial network text file looks as follows, where the text between "< >" describes what type of information appears in that line of the file:

Table 11 GIS/CAD import model

[TITLE]
<Optional description of the file>
[JUNCTIONS]
<ID label of each junction>
[PIPES]
<ID label of each pipe followed by the IDs of its starting and ending junctions>
[COORDINATES]
<Junction ID and its X and Y coordinates>
[VERTICES]
<Pipe ID and the X and Y coordinates of an intermediate vertex point (use a separate line for each vertex)>

Note that only junctions and pipes are represented. Other network elements, such as reservoirs and pumps, can either be imported as junctions or pipes and converted later on or simply be added in later on. The user is responsible for transferring any data generated from a CAD or GIS package into a text file with the format shown above.

In addition to this partial representation, a complete specification of the network can be placed in a file using the same format Epanet uses when a project is exported to a text file. In this case the file would also contain information on node and link properties, such as elevations, demands, diameters, roughness, etc.

4. Geographic Information System

GIS is an integrated collection of computer software and data used to view and manage information about geographic places, analyze spatial relationships, and model spatial processes. GIS provides a framework organizing spatial data and related information so that it can be displayed and analyzed. GIS gives you tools to analyze your data and see the results in the form of powerful, interactive maps that reveal how things work together, allowing you to make the most informed decisions possible. First the benefits of a GIS Are explained and an advice is given about how to use a GIS within a drinking water company. At the end an example is made for exporting data from a GIS into Epanet. For this case the platform ArcGIS of ESRI is used.

4.1. Why a GIS

In water management (geo-)graphical data is of great concern. Position and measurements are very important. CAD-applications are very suitable to store these data. Not all information needed in water management can however be modelled graphically. In most cases, information needed to make equations can better be stored in alphanumeric databases. This information is often related to graphical information. A GIS has standard functionality to store and link these two types of information. Current CAD-applications sometimes have also possibilities to store and link this information. However, these applications do not have the same functionality as a GIS regarding geographical relations between several object. (van de Looij, 2000)

4.2. How to use a GIS

A GIS can function as a central data control system. With this programme you can exchange, change and modify the data to make analyses of the network possible. The resulting GIS files are unsuitable for design but are sufficient in detail for planning and hydraulic analysis.

The main concerns, regarding selection of software and hardware, are costs, simplicity, flexibility and the use of existing data. Since the USP are using a PC-platform and AutoCAD, the evaluation of available PC-based GIS packages rapidly lead to selection of ArcGIS from Environmental Systems Research Institute, Redlands, California (ESRI) for this research. ArcGIS is a GIS which is fully integrated in AutoCAD. Another reason for choosing ArcGIS is the availability of ArcView, a low-cost application that gives the power to visualize, explore, query and analyze data (created in ArcCAD, AutoCAD, ArcInfo etc.) geographically.

A GIS is essentially the graphical representation or map of the objects and the associated non-graphical information. Additional information that are not typically required for hydraulic modelling but are very useful for collection system management can also be entered in the GIS on the request of Dawaco.

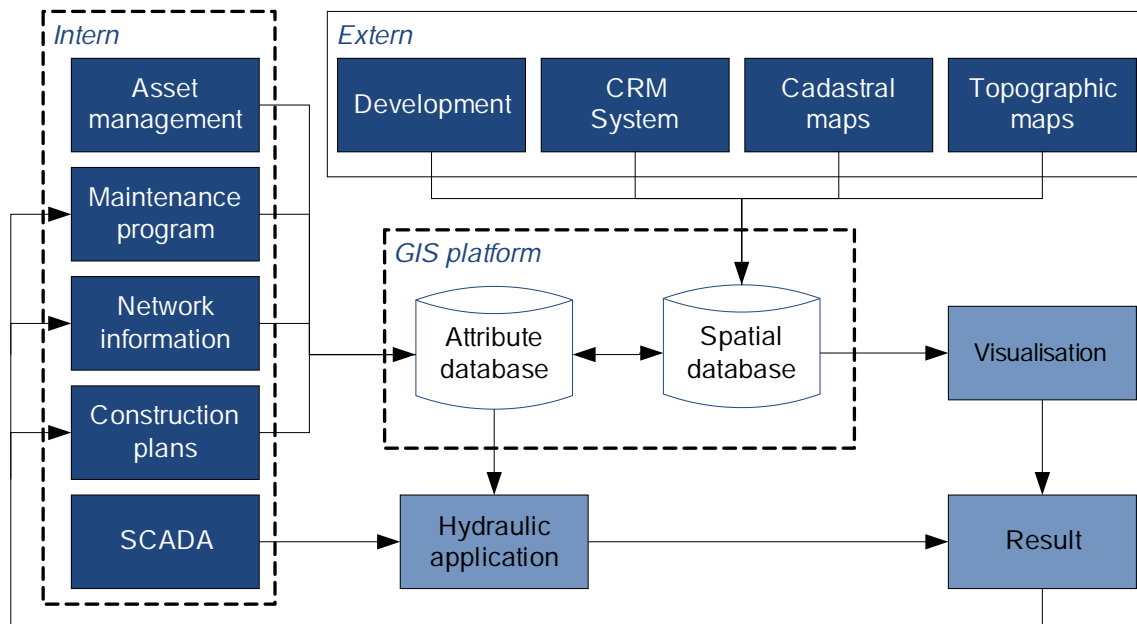


Figure 11 Overview of possible usage of a GIS by Dawaco

The GIS contains two kind of databases (Figure 11); attribute database and spatial database. The spatial database can give information about the service area of DAWACO. Information like the cadastral maps, household information, topographic maps and the plans for development in this area can be gathered from the (local) government or services. The attribute database is the database concerning the distribution network and WTPs which are stored at the company. The GIS can use both databases to make visualisations for further analysis. A part of the attribute database is suitable for the extracting of data into an hydraulic application what also uses data from the Supervisory Control And Data Acquisition (SCADA). This information is gathered from measure points in the network which delivers information like the pressure, velocity and quality in the distribution network. This time based information cannot be stored a GIS and will be implemented directly into the hydraulic application. With the visualisations of the GIS and the outcome of the hydraulic application a result is given.

4.3. ArcGIS

ArcGIS is a suite consisting of a group of GIS software products produced by ESRI. At the desktop GIS level, ArcGIS can include:

- ArcReader, allows to view and query maps created with the other Arc products;
- ArcView, allows to view spatial data, create maps, and perform basic spatial analysis;
- ArcEditor which, in addition to the functionality of
- ArcView, includes more advanced tools for manipulation of shapefiles and geodatabases;
- ArcInfo which includes capabilities for data manipulation, editing, and analysis.

There are also server-based ArcGIS products, as well as ArcGIS products for PDAs. Extensions can be purchased separately to increase the functionality of ArcGIS.

4.3.1. Working method

ArcObjects includes a wide variety of programmable components, ranging from fine-grained objects—for example, individual geometry objects—to coarse-grained controls and tools—for example, a map control that allows you to quickly embed a map interface into your custom application for working with GIS map documents created in ArcGIS. These developer tools aggregate comprehensive GIS functionality for .NET, Java, C++, and web developers.

4.3.2. Criteria and prerequisites

In Table 12 data models are given that can be used for exporting from a GIS into Epanet. Note that for a GIS the shape of the object must be given. This can be either a point, a line or a polygon.

Table 12 Overview of data models suitable for exportation

Object	Attribute	
Junction	Elevation	Head
	Base Demand	Pressure
	Demand	
Reservoir	Total Head	Elevation
	Inflow	Pressure
Tank	Elevation	Diameter
	Initial Level	Inflow
	Min. Level	Pressure
	Max. Level	
Pipe	Diameter	Flow
	Length	Velocity
	Roughness	Headloss
	Bulk coefficient	Friction
	Wall coefficient	Reaction Rate
Pump	Flow	Headloss
Valve	Type	Status

4.3.3. Exporting data

Several challenges arise when moving data between a GIS, a data storage and hydraulic applications. Most significant is the differing representations implemented by the GIS and hydraulic applications to represent the same facility types. In the GIS, hydraulically significant objects such as valves are usually represented as nodes, whereas the same object is represented as a line in the application.

5. Data accuracy

Data accuracy is arguably the most relevant factor in keeping a GIS and an hydraulic application useful, efficient, and effective. The standards designated by the Federal Geographic Data Standards Committee (FGDS) keep track of how geo-spatial data is organized, stored and distributed. However, the effort taken to fulfil the standards that describe how to maintain accuracy in the creation process remains at the discretion of the creator, provider of the data.

To facilitate efficient use of resources employed in the data collection effort, the overall goals of the program must be clearly established. For example, data collection efforts for the planning of a collection system are different than when the production of design documents is the primary goal. Similarly, systems which will become the primary record of the company for maintenance will have different requirements than those for modelling. For instance, in hydraulic modelling, capacity analyses are insensitive to which side of the street the pipe exists. On the other hand if there are several pipes sharing the same alignment, the maintenance crews will need to know the relative locations of the facilities. The company must also consider its existing policy in regards to the design of the system. For example, the data collection effort for the GIS may require sufficient accuracy to be used as the basis of engineering design (typically much more expensive) while existing policy requirements state that the engineering design be field verified by actual survey. In this case the additional money that is spent in the collection of initial GIS data at accuracy levels required for design is duplicated when the engineer must go into the field to verify the data through traditional survey techniques.

A “balanced” approach should be made to the data collection effort that considers each of the data points and their cost of collection. Again this balance should be made by considering the immediate and long-term goals of the company. All hydraulic applications are “representations” of the system. A balanced approach assures that effort is well directed in the collection of data.

Ideally the project will be approached with a clear inventory of what data exists and its relative accuracy. For example, portions of the system may be recorded only in a schematic with the relative orientation of facilities, estimated and visually correct. The spatial coordinates were not obtained by field survey. Additionally this representation may have annotations with attributes such as ground elevations and rim elevations that were entered into a “master” map from the original design drawing. In this instance the data is available but its accuracy is suspect. An improvement in data quality may be obtained by finding the “as-built” drawings which were annotated at the time of construction to reflect “field modifications” to the original design. The extra effort required to locate and enter all attributes and graphics in this manner of course requires additional costs. The most

accurate method of obtaining the data is a complete field survey of all facilities. This method assures that the company has a complete record of all facilities that are tied to a common coordinate system and datum. Again this is the most expensive and labor-intensive method of data collection for the physical system that may be offset if additional future costs are avoided by having highly accurate drawings that can be used as the basis of design and operations and maintenance functions.

Flow information may also be measured in a number of ways. Flow measurements that were made more than 10 years ago generally relied on depth-only measurements. These measurements of depth were translated into flow volumes based on empirical formula's such as Mannings equation. If the hydraulics of the site conform with the basic assumptions of the equations the measurements provide some useful information. In many instances however some sites, typically manholes, were not experiencing "normal" or uniform flow. Increases in depth did not have an associated increase in velocity. In these instances the flow rate and subsequently the volume was often overestimated as the increase in depth may have had a reduction in velocity which diminished the flow rate and volume. Within the last 10 years, the application of depth and velocity meters has yielded a significant improvement in the quality of flow data available for assessing the current hydraulics of a system. These meters may operate as accurately as $\pm 10\%$. The range of accuracy depends on the site, the equipment and the analysis parameters used in converting the raw data into final flow volumes.

The limits of modelling "accuracy" then depend on the least accurate aspect of the model. In other words, if we go to the additional expense of field surveying the physical system, but use flow data that is based on demographic data, we have gained nothing in the accuracy of the model from the field survey.

6. Conclusion

Several planned steps must be taken to successfully implement a drinking water GIS and to integrate that GIS with other information systems like an hydraulic application. Through a properly designed database, data can be efficiently shared by separate information systems and applications.

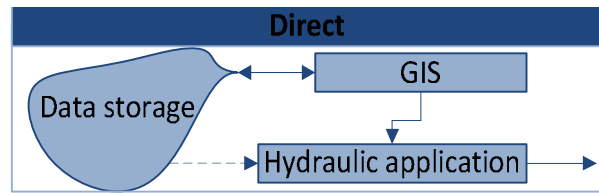


Figure 12 Direct link between GIS and hydraulic application

A GIS can function as a central data control system. With this programme you can exchange, change and modify the data to make analyses of the network possible. The resulting GIS files are unsuitable for design but are sufficient in detail for planning and hydraulic analysis in Epanet so a direct link is most suitable (Figure 12). For exporting data into the hydraulic application the data must have the GIS/CAD object model presented in Table 11. Because only points and lines are presented in this model an attribute modification must be applied to implement the reservoirs, tanks, pumps and valves into the network (Figure 13).

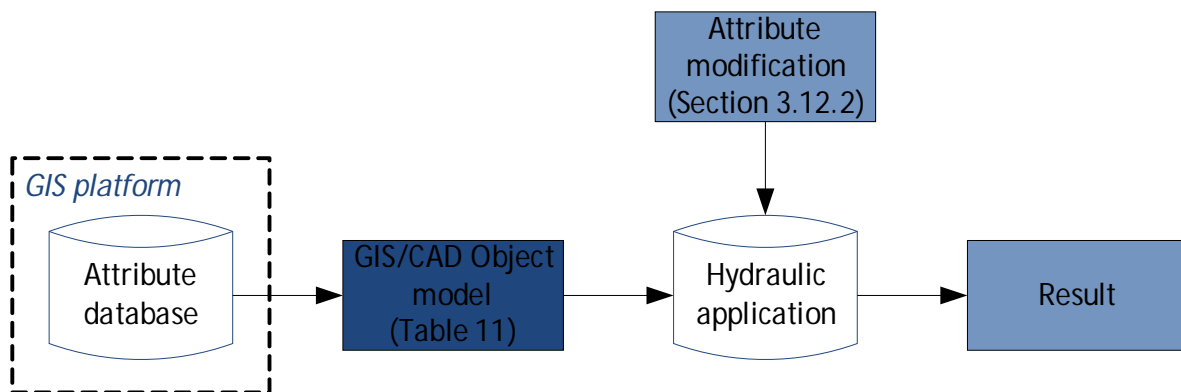


Figure 13 Overview of how to use a GIS for an hydraulic application

Data accuracy is the most relevant factor in keeping a GIS and an hydraulic application useful, efficient, and effective. To determine the accuracy of the data 'the balanced approach' is chosen. The limits of modelling accuracy depend on the least accurate aspect of the model. The balanced approach to data collection considers (1) the final application of the modelled data, (2) the available data sources and (3) the accuracy of these data sources.

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Appendix A Non-physical objects

Besides the physical objects in a network, hydraulic applications need non-physical objects to clarify events in the network.

A.1. Patterns

A Time Pattern is a collection of multipliers that can be applied to a quantity to allow it to vary over time. Water demands, reservoir heads, pump schedules, and water quality source inputs can all have time patterns associated with them.

The time interval used in all patterns is set with the project's Time Options. Within this interval a quantity remains at a constant level, equal to the product of its nominal value and the pattern's multiplier for that interval. Although all time patterns must utilize the same time interval, each can have a different number of periods. When the simulation clock exceeds the number of periods in a pattern, the pattern wraps around to its first period again.

A.2. Curves

Curves are objects that contain data pairs representing a relationship between two variables. Two or more objects can share the same curve. An Epanet model can utilize the following types of curves:

- Pump Curve
- Efficiency Curve
- Volume Curve
- Headloss Curve

A.3. Controls

Simple Controls change the status or setting of a link based on;

- the water level in a tank,
- the pressure at a junction,
- the time into the simulation,
- or the time of day.

There is no limit on the number of simple control statements that can be used.

Note: Using a pair of pressure controls to open and close a link can cause the system to become unstable if the pressure settings are too close to one another. In this case using a pair of Rule-Based controls might provide more stability.

Rule-Based Controls allow link status and settings to be based on a combination of conditions that might exist in the network over an extended period simulation.

A.4. Bulk coefficient

Bulk flow reactions are reactions that occur in the main flow stream of a pipe or in a storage tank, unaffected by any processes that might involve the pipe wall. Epanet models these reactions using n-th order kinetics, where the instantaneous rate of reaction (R in mass/volume/time) is assumed to be concentration-dependent according to $R = K_b C^n$

where K_b = a bulk rate coefficient, C = reactant concentration (mass/volume), and n = a reaction order. K_b has units of concentration raised to the $(1-n)$ power divided by time. It is positive for growth reactions and negative for decay reactions.

Epanet can also consider reactions where a limiting concentration exists on the ultimate growth or loss of the substance. In this case the rate expression for a growth reaction becomes:

$$R = K_b (C_L - C) C^{(n-1)}$$

where C_L = the limiting concentration. For decay reactions $(C_L - C)$ is replaced by $(C - C_L)$.

Thus there are three parameters (K_b , C_L , and n) that are used to characterize bulk reaction rates. General values can be selected for these parameters that lead to several well-known kinetic models:

- Simple First-Order Decay ($K_b < 0$, $C_L = 0$, $n = 1$)
- First-Order Saturation Growth ($K_b > 0$, $C_L > 0$, $n = 1$)
- Two-Component, Second-Order Decay ($K_b < 0$, $C_L \neq 0$, $n = 2$)
- Michaelis-Menton Kinetics ($K_b \neq 0$, $C_L > 0$, $n < 0$)

A.5. Wall coefficient

In addition to bulk flow reactions, Epanet can model reactions that occur with material on or near the pipe wall. The rate of this reaction can be considered to be dependent on the concentration in the bulk flow by using an expression of the form

$$R = (A / V) K_w C^n$$

where K_w = a wall reaction rate coefficient and (A / V) = the surface area per unit volume within a pipe (equal to 4 divided by the diameter). The latter term converts the mass reacting per unit of wall area to a per unit volume basis. Epanet limits the wall reaction order (n) to either 0 or 1, so that the units of K_w are either mass/area/time or length/time, respectively.

The parameter K_w appearing in the above rate expression should be adjusted to account for any mass transfer limitations in moving reactants and products between the bulk flow and the wall. Epanet does this automatically, basing the adjustment on the molecular diffusivity of the substance being modelled and on the flow's Reynolds number. (Setting the molecular diffusivity to zero will cause mass transfer effects to be ignored.)

The wall rate coefficient can depend on temperature and can also be correlated to pipe age and material. Epanet requires that water be flowing in a pipe for a wall reaction to occur. Pipes with no flow have no computed wall reaction.