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Common Modelling Software for Piped Water Distribution Networks

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ABSTRACT: Based on the information provided by developers and distributors, selection of widely used commercial and non commercial software packages for designing and analyzing piped water distribution systems is presented in a uniform and easily accessible format. Appropriate and commonly encountered computer programs for the design and upkeep of drinking water distribution networks are then selected. Investigations are extended towards non-commercial software and the information, covering a revised listing of 15 programs, is categorized according to the sophistication of application under review. The aim of this study is to provide a general overview of these software. It provides comprehensive but concise facts, presented in a homogeneous format. The facts are compiled from the information given by software developers, distributors as well as users. The overview allows the reader to rapidly gain an overall insight into the existing software. It provides a general comparison among a multitude of common and famous software. The document therefore delves into elaborate details of software design; for quick reference a very brief comparison is provided. For further information on a specific program, relevant data are provided in tabular format.

Keywords: Hydraulic Modelling, Water Network Design, Pressure, Flow.

MODEL FUTURES

AquaNet

The Program was first shipped in 1992 and is currently used in 17 countries. AquaNet's structure includes a Graphical User Interface (GUI) for user input and data analysis and a separate computational engine that can be used with or without the GUI. AquaNet provides components to model pipes, pumps, valves, storage tanks, reservoirs and nodes. AquaNet's strengths are its reliability (the computation engine has not had a support call in years), its unlimited model size, speed and operating system portability. With the release of version 2.x of AquaNet it will become PPNS, which is a merger of the AquaNet and PipeNet software lines. AquaNet's new version PPNS will have a Java based GUI that will run on most operating systems. The computational engine will also be made available on most operating systems, providing a consistent interface and computational engine regardless of the desktop operating system. E-mail: info@finite-tech. com. Website: www.finite-tech.com.

ARCHIMEDE

The program ARCHIMEDE is a Windows-based software package, aimed at engineers and distribution networks companies (water and gas). It is capable of verifying and simulating steady state flow conditions in pressurised gas and water networks. ARCHIMEDE was developed by PROTEO S.r.l., a software house involved with hydraulic network analysis, remote control and automation of major water systems since 1986.

The software is very user friendly with a Graphical User Interface (GUI) and a resolute computational module. The graphic editor is based on an elemental description of the fluid network (reservoirs, delivering nodes, pipes, pumps, valves, etc.). The network description is simple and visualisation can be customised with personalised colours and line thickness. The results are easy to interpret and can be visualised graphically or in numeric form. The computational module controls the simulation stage and directly interacts with GUI receiving topological information of the network.

[1]Conference speaker

ARCHIMEDE has an algorithm capable of solving complex network formulae to calculate energy losses in pipes. It calculates the continuity equation at the nodes and the equation of motion within the elements, obtaining a non-linear system that is solved by iteration with an efficient algorithm. It can be used to calculate flow at different points of the network without sensors, using real field data as input. E-mail: proteo@proteo.it. Website: www.proteo.it.

The various program releases and user instructions available today are based on software that was originally developed during the 1970s by the University of North Carolina. The software was written in an attempt to help developing countries to plan and design water distribution systems that are better suited to their needs. The development was financially supported by the World Bank and the UNDP Inter-regional Project. Also having been superseded by newer and more elaborated software in recent years, we discuss here the public domain BRANCH and LOOP applications, knowing that they were fundamental in the development of latter software packages and that they still have their uses even today.

BRANCH

BRANCH is used to design pressurised, branched (tree-type, non-looped) water distribution networks by choosing from among a set of candidate diameters for each pipeline so that the total cost of the network is minimised, subject to meeting certain design constraints. Both construction costs and the design constraints can be expressed as linear, mathematical statements. The network is characterised by links (individual pipes) connected by nodes, which are points of flow input, outflow or pipe junctions. Version 3.0 of the software can handle up to 125 pipes. BRANCH formulates a linear programming model for the least cost design, solves the model and outputs the design as well as corresponding hydraulic information. LOOP simulates the hydraulic characteristics of a pressurised, looped (closed circuit) water distribution network. The network is characterised by pipes and nodes (points of inputs/demand or pipe junctions). Data required are the description of the elements of the network, such as pipe lengths, diameters, friction coefficients, nodal demands and ground elevation, and data describing the geometry of the network. The program outputs include flows and velocities in the links and pressures at the nodes. It does not accommodate inline booster pumps or pressure reducing valves. LOOP 4.0 handles up to 1000 pipes and can simulate up to 10 nodes with known hydraulic grade lines (e.g., storage reservoirs). It will accept any looped, partially looped/branched or completely branched network.

CROSS

CROSS is designed for the hydraulic calculation of water supply networks. All existing network elements (reservoirs, pumps, hydraulically operated valves, pressure controls, etc.) can be considered. It is possible to calculate branched distribution, ring distribution or a combination of the two. Ring systems are generated automatically by the program. A water intake can be defined as nodal intake, a section intake or a combination of the two. The water can be fed to the pipeline through rotary pumps, piston pumps and elevated tanks. E-mail: info@rehm.de. Website: www.rehm.de.

EPANET

EPANET is a Windows based program that performs extended period simulation of hydraulic and water-quality behaviour within pressurised pipe networks. A network can consist of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. EPANET tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of a chemical species throughout the network during a simulation period comprised of multiple time steps. In addition to chemical species, water age and source tracing can also be simulated.

The Windows version of EPANET provides an integrated environment for editing network input data, running hydraulic and water quality simulations, and viewing the results in a variety of formats. These include colour-coded network maps, data tables, time series graphs, and contour plots. 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. It is a public domain software that may be freely copied and distributed. EPANET was specifically developed to help water utilities maintain and improve the quality of water delivered to consumers through their distribution systems. It can be use to design sampling programs, study disinfectant loss and by-product formation, and to conduct consumer exposure assessments. It can assist in evaluating alternative strategies for improving water quality, such as altering source utilization within multi-source systems, modifying pumping and tank filling/emptying schedules to reduce water age, utilising booster disinfection stations at key locations to maintain target

residuals and planning a cost-effective program of targeted pipe cleaning and replacement. www.epa.gov/ORD/NRMRL/wswrd.

ERACLITO

ERACLITO is a Windows 95 and NT based software package, intended for the hydraulic and technical management of fluid networks. ERACLITO was developed by PROTEO S.r.l., a software house involved with hydraulic network analysis, remote control and automation of major water systems since 1986. Through ERACLITO's modules, which can be configured by the user, it is possible to simulate pressurized fluid networks (water and gas networks, pipe lines, etc) and open-channels systems (waste water networks, etc.) in steady, unsteady and gradually varied unsteady state flow conditions. Besides, it is possible to compute and evaluate the networks, and to integrate them with GIS applications, remote-control systems and management systems. The core of the ERACLITO environment is based on a user-friendly graphical interface. Data input is made easy, thanks to the possibility to import files in vector or raster format. Calculation results can be viewed rapidly in both numeric and graphic output. E-mail: proteo@proteo.it. Website: www.proteo.it.

H2ONET/H2OMAP

H2ONET/H2OMAP is a stand-alone, database-driven GIS-enabled software for complete modelling, analysis, design, rehabilitation and optimisation of water distribution and supply systems. It was released as a commercial product in 1996 and currently enjoys a worldwide base of satisfied clients. The program performs quick, reliable and comprehensive hydraulic and dynamic water quality modelling, energy consumption/cost evaluation, leakage management, reliability assessment, valve tracing, real-time simulation and control, fire flow and hydrant analysis, unidirectional flushing, and includes an automated on-line SCADA interface. Its state-of-the-art optimisation capabilities include automated network skeletonization, reduction and calibration, pump scheduling/optimal operations, and optimal design and rehabilitation.

The program is developed using ESRI MapObject and object oriented technology in an open-architecture GIS environment to provide a powerful decision-support application that combines spatial analysis tools and mapping functions with sophisticated and accurate network modelling and optimisation for complete infrastructure planning and management. An entire library of network elements can be considered, including pipes, pumps (constant/variable speed), turbines, static and control valves (including check, pressure regulating, pressure sustaining, pressure relief, pressure breaker, flow control, flow meters/totalizers, throttle control, general purpose, and float valves), tanks (cylindrical/variable area), and reservoirs.

The program bridges the gap between network modelling and GIS software to support many types of applications in distribution system analyses, including master planning, fire flow assessment, facility sizing, operations study, rehabilitation, emergency response, real-time simulation, sensitivity analysis, water quality improvement, source blending, source tracking, sampling program design, model calibration, operator training, energy management, pump scheduling, leakage control, water conservation, system expansion, new system design, reliability assessment, valve tracing, business planning and asset management. E-mail: mwhsoft@mwhglobal.com. Website: www.mwhsoft.com.

Helix Delta-Q

Helix delta-Q is a powerful tool for engineers and equipment suppliers to quickly and easily design and optimise complex pipe system networks for compressible and incompressible fluids. It can produce economically and technically sound pipe system designs in a very short time. The program considers pumps, tanks, junctions, nozzles (sprinklers) and any fittings, such as bends, valves, tee's, etc. It can calculate friction losses and pressure drop in pipes and fittings for liquids, slurries and gasses. It models complex process flow pipe networks and solves for unknown flow rates and node pressures at the press of a button. Delta-Q has database files for liquids, slurries, gasses, pipes, pipe fittings and pumps. Data from the database files can be pasted by clicking on an element in the network diagram. E-mail: helix@vianet.netau. Website: www.helixtech.com.au.

MIKE NET

MIKE NET is the most advanced EPANET based water distribution modelling package available. It can analyze an entire water distribution system, or selected portions, under steady state or extended period simulations, with water quality analysis if needed. In a complete graphical modelling environment it considers pipes sizes, flow rates, velocities, head losses, nodal pressures, nodal demands, hydraulics grades, elevations, water age, water quality concentrations, etc.

Network models can be easily and quickly developed, using a variety of different means. For example,

network components can be read-in directly from an ArcInfo®, ArcFM®, ArcView®, or MapInfo® GIS, or can be interactively created using a mouse by simply pointing and clicking. Graphical symbols are used to represent network elements, such as pipes, junction nodes, pumps, control valves, tanks, and reservoirs. In addition, data can be shared with any standard Windows spreadsheet (e.g., Microsoft Excel) or relational database (e.g., Oracle®, Microsoft SQL Server, Informix®, Sybase®) either directly or using ODBC links, or by simply cutting to and pasting from the Microsoft Windows clipboard.

MIKE NET's graphical capabilities are unparalleled, providing multiple horizontal plan plots, profile plots—either of which can be animated for extended period simulations-and time series plots. All graphical plots can be printed at any user-defined scale. MIKE NET can share water distribution data with any ArcInfo, ArcFM (Facilities Manager), ArcView, or MapInfo GIS database, allowing MIKE NET to be part of the infrastructure management and planning system. Comprehensive input data and output analysis reports can be automatically generated using the provided report templates. MIKE NET uses the Microsoft Access database engine for storing and manipulating network data. E-mail: info@bossintl.com. Website: www.bossintl.com.

NETIS

The NETIS software package is a tool for the design of new systems as well as the reinforcement of existing systems. It uses formal optimisation techniques to perform analysis of least cost pipe sizing, subject to different levels of service specified by the user. NETIS is a network design tool, incorporating specific routines to account for the unique features that exist in intermittent water distribution systems. These are systems that operate with insufficient quantities of water and are therefore unable to provide 24 hours supply (but only a few hours a day). E-mail: wdru @sbu.ac.uk. Website: http://www.sbu.ac.uk/wdru.

OptiDesigner

OptiDesigner is a Windows software for the optimal design of water distribution systems using "Genetic Algorithms" (GA). The program uses EPANET, a hydraulic simulator freely distributed by the US EPA (see this document). OptiDesigner will design the system pipes and find their minimal cost under a set of constraints. The system is drawn and the properties set using EPANET. The network is then exported to optiDesigner (as an INP file), which then runs the simulation once design options, pipes to be designed, junctions/sources constraints and optimisation parameters have been set. E-mail: selad@optiwater.com. Website: www.optiwater.com.

PIPE2000

PIPE2000 is a general-purpose pipe network hydraulic modelling program, which handles both steady state (KYPIPE2000) and transient (SURGE2000) analysis. KYPIPE2000 provides both hydraulic and water quality modelling. PIPE2000 is typically used for steady state and transient modelling municipal and rural water distribution systems. It is also widely used for hot, chilled, and process water systems. It is used for fire protection and irrigation sprinkler systems. It is also used for other liquids (oil, etc.).

Continuous research and development over the past 20 years has resulted in the most advanced hydraulic modelling capability available. KYPIPE 4 is the engine used for hydraulic calculations for the KYPIPE2000 modelling package. KYPIPE 4 is the fourth generation KYPIPE engine, which is the most widely used and trusted hydraulic analysis engine in the world. This engine has been an industry standard for 30 years and has been verified by numerous field tests and qualified for nuclear applications. It provides many capabilities not available with other hydraulic analysis engines. EPANET developed by the EPA (USA) is utilised by KYPIPE2000 for water quality modelling. SURGE2000 is a 6th generation transient flow modelling program, which carries out complex transient modelling. Standard PIPE2000 node elements include junctions, tanks, reservoirs, pumps, sprinklers, rack sprinklers, regulating valves, loss elements, loss elements defined by manufacturer data from a library, variable pressure supplies, active valves, check valves, hydrants, valves, metered connections, surge control devices, inline meters, and user-defined devices, etc.

The strength of PIPE2000 is in its advanced modelling capabilities, which include the direct calculation of operational and design parameters, development of system curves, optimised calibration (GA), automatedatic ageing of pipes (roughness) and many other capabilities. The PIPE2000 advanced graphical environment is extremely user-friendly, allowing graphical Model development and data entry. PIPE2000 has also been adapted to other calculation engines in addition to KYPIPE and SURGE. These include analysing gas (GAS2000), steam (STEAM 2000), fire sprinkler

systems (GOFLOW2000) and storm water systems (STORM2000). E-mail: kpfs@ bigfoot.com. Website: www.kypipe.com.

STANET®

STANET® is an integrated application for network analysis. It is used to calculate fluid and gas (including steam) flowing in pipes. The typical usage is for water and other fluid networks, gas and pressure air networks, steam and saturated steam networks, district heating networks and electrical networks. Besides calculation, graphic input, output, a database browser is included. The browser may be displayed together with the network map. STANET® may be used as a network information system because it uses standard database files, which may be extended by the user. Because graphics and database are integrated, data exchange with other applications is simple.

The program performs stationary simulation (calculation) of looped networks (water, gas, electricity, and district heating including steam, oil). Graphical input (mouse, digitizer) and output to monitor, printer or plotter are provided. STANET® allows simple creation and modification of networks, flexible ways to design and edit networks as well as analysis and simulation (extended period simulation, diameter and routing optimisation, etc.). E-mail: info@stafu.de. Website: www.stafu.de.

WADISO

The program originated from the WADISO model developed by Colorado State University for the Army Corps of Engineers. It was substantially improved by GLS Engineering Software (Pty) Ltd. with regard to optimisation, user friendliness and speed as well as interfacing with other application software. The resulting Wadiso SA integrates steady state simulation, time simulation, optimisation, and water quality analysis with graphical displays of data. The result is a single, multi-purpose tool for water engineers. It offers several modules for the design, calibration, modelling, analysis and management of a distribution system:

- *Steady State Analysis Module:* Basic module which allows for the input and editing of system data and parameters, and which calculates the flow and pressure distribution in the system under specific "snapshot" steady state conditions. Full graphical display of flows, pressures, etc. is available.
- *Extended Period Simulation Module:* For modelling of diurnal fluctuations in water demand, and control of pumps, valves, etc. in order to monitor system performance over an extended period of time.
- *Optimisation Module:* For the determination of future improvement needs, with the objective to minimise capital expenditure and the present worth of operational costs, while adhering to specified operational criteria. The cost trade-off between pipes and pumping costs, and pipe and storage costs are taken into account. Seamless integration with the public domain EPANET software allows for improved extended time simulation analysis. Further EPANET is used for the modelling of all water quality aspects. E-mail: software@gls.co.za. Website: www.wadiso.com.

WaterCAD

Haestad Methods has been involved in the water distribution modelling field since the original release of WaterCAD (a.k.a. CYBERNET) version 1.0 more than a decade ago. They continue to advance network-modelling technology by combining state-of-the-art matrix solutions with an intuitive, easy-to-use interface. WaterCAD is used to analyse potable water networks, sewage force mains, fire protection systems, well pumps, raw water pumping, and more. It allows calibration of large distribution networks, development of master plans, conducting operational studies and performing cost analysis. Users can perform a steady-state analysis for a "snapshot" view of the system, or perform an extended period simulation to see how the system behaves over time. The highlights of the most recent version are: advanced graphical editor, animated contouring and colour-coding, graphing and profiling, scenario management, automated fire flows, hydraulic analysis, water quality analysis, customisable tables, GIS and database connectivity. E-mail: info@haestad.com. Website: www.haestad.com.

EgyNet

EgyNet provides two separate scenarios. The first one is to design the network by obtaining the diameter for every branch and complete flow, pressure, and head losses profiles in new networks. The second option is to simulate the flow characteristics in existing and new networks. In the network simulation scenario the leakage and the valves partially close when setting out are obtained. The selection of the booster pump location and its required pressure is an additional output result in this model. The input data consists of flow, pressure pipeline length, and consumption in both model scenarios and the pipe diameter for use in the model simulation option. The model output data for determining the diameter of pipe of the network

consists of the pipe diameter, correct flow, pressure, head losses and head at any point. This model can be applied to study the conditions of existing or predicted networks instead of conducting field studies of leak detection. EgyNet is coded with C/C++ language with visual C6 interface. E-mail: alaamhmogazy@hotmail.com.

MODEL OBJECTIVES

The objectives of the present thesis are concerned with the following points:

1. Creating a new numerical model approach under the steady state condition to enable the determination of pipe diameters for water networks.
2. Creating a new numerical modelling approach for steady state network analysis to enable the simulation of the pipe network taking into consideration the leakage effect.
3. Establishing rules on how to obtain pressure values before and after the regulations in order to control the leakage level in all networks.

Model Assumptions

The assumptions for the mathematical model are:

1. Steady state condition and a one dimensional flow.
2. The continuity and energy equations are applicable.
3. The leakage flow is calculated by using the orifice flow equation.
4. The calculation of consumption depends on the number of consumers the data for which were collected from the field. The quantity of consumption collected from the field data is the average.
5. The consumption corrected factor is applied to calibrate the original consumption rates. The consumption corrected factor is equal to the original consumption rate multiplied by the square root of the present pressure divided by the square root of the pressure during the consumption studies.
6. The velocity limit is considered to determine the suitable diameter of pipelines in order to keep the head loss within the acceptable limit.
7. The head losses are calculated for every pipe by using the Darcy-Weisbach equation.
   The friction factor is calculated for every pipe by using the Colebrook -White equation.
8. The valve minor losses are considered as part of the head losses.
9. The partially closing valves are used to regulate the pressure in order to control the leakage.
10. The location of the booster pump is selected in the network, where the pressure is equal to (14 m or less) and at the node that has the lowest ground level.
11. The losses due to leakage are a function of leakage, area of pipe and gravitational acceleration

$$\text{Loses}_{\text{leakage}}\ \text{loses} = \frac{\text{Factor} \times (\text{leak})^2}{\text{area}_{\text{pipe}} \times \text{acceleration}_{\text{Gravity}}}$$

12. The minimum allowable pressure at the end of the network should be equal to the height of the elevated tank or the building height plus the minimum required pressure to cover the demand requirements.

Model Limitations

The model limitations provide general constraints and limits for the model as follows:

1. The booster pump can be selected where the water network head is ≤ 14 ms and at the node that has the lowest ground level.
2. The maximum allowable reduced pressure at a certain valve should be ≤ 10 m.
3. The minimum allowable pressure at the end of the network should be equal to the height of the elevated tank or the building height plus the minimum required pressure to cover the demand requirements.
4. For design purposes, the minimum velocity should be as follows:
   (a) (Diameter in m + .4) m/sec if the diameter < .2 m & (b) (Diameter in m + .5) m/sec if the diameter > .2 m.
   and the maximum velocity is ≤ 1.9 m/sec.
5. The minimum allowable pressure can be used in the model = 1. bar.
6. The Maximum allowable iteration = 100 iterations.
7. The minimum allowable nodes number to run the model is two nodes.

CONCLUSIONS

1. The software for water network design and modelling have a wide range of varieties either commercial or scientific.
2. The selection of the software depends on the user requirements.
3. The valid budget is one of the main factors for selecting the commercial software.
4. The size of the water network and the number of nodes are the basic functions to select the type and the size of the model.

Table 1: Features of Some Software for Pipe Network Analysis

Program	Purpose	MAIN FEATURE							Limit	Comment
		Simulation	Leak	WQA	GUI	GIS	DB	Design		
AquaNet	"Simulation and modelling for pressurised pipe systems"	Yes	No	Yes	Yes	Yes	No	No	No	
Archimede	"Simulation and verification of fluid pressurised distribution networks in steady state flow conditions	Yes	No	No	Yes	No	No	No	No	
Branch/Loop	"Least-cost design and calculation of branched/looped water distribution networks"	No	No	No	No	No	No	Yes	Yes	
Cross	"Hydraulic calculation for water supply pipes"	Yes	No	No	Yes	Yes	No	No	Yes	
Epanet 2.0	"Extended period simulation of hydraulic and water-quality behaviour within pressurised networks"	Yes	No	Yes	Yes	No	No	No	No	
Eraclito	"Modular system for the management of fluid under pressure networks and open channel systems"	Yes	No	No	Yes	Yes	Yes	No	No	
H2Onet/H2O map	"A comprehensive GIS-based water distribution analysis, design and optimisation software"	Yes	No	Yes	Yes	Yes	Yes	No	No	
Helix delta-Q	"Designs & optimises pipe networks quickly & easily for compressible & incompressible fluids"	No	No	No	Yes	No	No	Yes	No	
Mike Net	"Advanced EPANET based water distribution modelling software"	Yes	No	Yes	Yes	Yes	Yes	No	No	
Netis	"Design and analysis of intermittent water distribution systems"	Yes	No	Yes	No	No	Yes	No	Yes	
OptiDesigner	"Optimal design of water distribution systems" (EPANET based)	No	No	No	Yes	No	No	Yes	No	
Pipe2000	"Hydraulic modelling software for simple or complex pipe systems	Yes	No	Yes	Yes	Yes	No	No	No	
Stanet	"Simulation and analysis of distribution networks"	Yes	No	No	Yes	Yes	Yes	No	No	
Wadiso SA	"Comprehensive computer program for the analysis and design of potable water distribution systems"	Yes	No	Yes	Yes	Yes	No	No	Yes	
WaterCAD 5.0	"Complete water distribution analysis and design tool"	Yes	No	Yes	Yes	Yes	No	No	No	
EgyNet	"Numerical Modelling for Water Network analysis"	Yes	Yes	No	Could be	Could be	Yes	Yes	No	

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