Review of Water Distribution Systems Modelling and Performance Analysis Softwares

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Abstract-
Water is a critical and crucial substance for sustenance all over the world. The need for water distribution systems to satisfy increasing demand and also to satisfy quality requirements has birthed a surging need to model real-life situations in order to access the workability of Water distribution system (WDSs) and their ability to operate efficiently. Through the review of the analysis of modelling software and performance analysis, it was deduced that different licensed software and freeware products are available for design and model of various categories of WDSs, ranging from simple to complex, realistic and even hypothetical. It was discovered that software with licenses offers versatility, flexibility and precision in modeling various categories of hydraulic models with various features over software that are open for all. Therefore, the decision on which software to use for the design of water distribution systems is predicated on software precision, the overall project cost, software - required data, complexity of system, aspect of system to be modelled (quality, demand, valve operation and location etc.) software specificity related to the types of distribution systems that it can manage and computational and hydraulic criterion.

Key words: Water Distribution System; Performance Analysis; Modelling; Software; Hydraulic Simulation.

1. Introduction

Water is a highly important substance, globally for commercial and domestic use and for the sustenance of life. Due to the need for water distribution systems to satisfy increasing demand and quality requirements, there has being a surging need to model real-life situations in order to access the workability of WDSs and their ability to operate efficiently. WDSs challenges such as deteriorating system, Leakage and pipe line disruption, incapacity to satisfy demand, poor system design, unreliable systems and abuse/mismanagement of water [1-2] has necessitated the need to substitute the conventional techniques of designing WDSs with precise, and quick computer software and methods. Modelling of water distribution systems is fast becoming a crucial and critical aspect of the WDSs as it carries out hydraulic assessment of a system such that the system is able to satisfy demand and also quality requirements by water treatments [3]. By reason of the large attention and desire to model WDSs, a multidisciplinary team of Professionals, researchers, scholars, engineers and programmers came together to develop software for the design and modeling of water distribution systems [4]. These developed hydraulic simulation and modeling software tools make it possible to analyze the behavior of water.

Water modelling software are effective tools to simulate and predict water transportation and behavior in distribution system and this can contribute to saving system resources, maintenance of water quality and satisfying of demand [5]. The models have to be simulated, predicted, and assessed using numerical hydraulic simulation before projects are implemented. These modeling results under different scenarios using water modelling software are the major components of evaluated environmental impacts. More so, the modelling software are the important basis for water management decisions as they provide data for water resource agencies, engineers and designers to implement construction projects and as well provide technical supports [6].

This paper however discusses and analyses performance areas of WDS, reviews modern modelling software used in industry by engineers and professional and in research and development by scholars and scientist.

2. Brief History of Water Distribution Systems

Walski *et al.* [7] revealed that the practice of water distribution for end-use has been in existence for a long time. Starting from the first ever laid pipes about 3500 years ago in Crete, to today's modern sophisticated and complex hydraulic models like the water system called the "Big Apple" in USA, it is clear to note that water systems has experienced a great transformation across the world.

Kuo & Quarts [8] mentioned that China floated the largest water distribution system ever due to her severe water challenges. Schilling [9] also stated that USA has the second largest "water tunnel" with a storage capacity of 2 trillion liters and distributing 5 billion liters of potable water daily to the New York City's population of 8 million people; he also stated that 95% of the water is transported by gravity.

In general, the following processes are components of a water supply system; [10]

- extraction and transportation of raw water,
- water processing, treatment and storage,
- Clean water distribution.

Water extraction is the process of removing water from any source. This can be done either on a temporary or permanent basis, temporarily for flood control and permanently to obtain water for irrigation or domestic use after suitable treatment. Water treatment is the process which betters the water quality to make it fit for domestic use. Water treatment extracts contaminants and undesirable components so that water becomes more acceptable for its desired end-use.

Distribution is the processes by which water is transported or conveyed across a system of connected pipes and it auxiliary while being steadily pumped and stored so as to meet the demands and maintain pressures in the system; Water distribution systems WDSs entails a network or interconnection of pipes that deliver water for end use. For the purpose of achieving optimal operation, components such as reservoirs, pumping stations, water towers, and other elements such as hydrants, valves, measuring equipment, etc. are usually coupled in the system.

The main goals of WDSs are: [11]

- Adequate supply of water,
- Maintenance of quality of water across the system.

For all consumers, these objectives are to be satisfied at any given time, considering the demands of such systems, at a scalable cost. This caters for water supply for domestic, industrial and other uses.

Adequate water quantity and quality can be attained by steady pressure and flow of liquid. Ensuring that pipes are steadily under pressure minimizes and reduces the risk of external pollutants. Also, moving water at standard pressured flow minimizes the retention times and restrains the drop-in quality of water resulting from the emergence of sediments, abates the growth of microorganisms, and low chlorine residuals.

2.1 Performance Analysis of WDSs

This is simply aimed at quantifying the effectiveness, efficiency and efficacy of water distribution systems relatively with the cost associated with the system installation and operation. The performance analysis involves the methods used to make an evaluation of water distribution system performance.

Alegre *et al*. [12] stated that throughout the working life of a water distribution system, the main performance that's expected is its ability to supply uncontaminated water in sufficient quantity to meet demand with sufficient pressure at each point of delivery. To quantify the performance of WDSs, we consider the hydraulic aspect while neglecting the water treatment aspect. The hydraulic aspect is actually categorized into deterministic and probabilistic approaches.

The deterministic approach involves the evaluation of the investigated system's capacity to satisfy the users' demand under well-defined conditions. Performance analysis under the deterministic approach generally consists of its hydraulic analysis that assumes total component availability and peak demand [13]. The deterministic approach definitely has limitations due to the assumptions. These limitations are highlighted in the research works that use the alternative approach (probabilistic). Despite the limitations, deterministic analysis is mostly used in real life applications and if correctly applied, it gives substantially results.

The probabilistic approach unlike the deterministic approach enables uncertainties to be quantified by use of distributions instead of fixed values in assessing risk. The performance of a system can be measured using failures experienced during its working life. In particular, the performance of WDS is defined and can be measured using the following three concepts: [14]

- Reliability: the probability that the system does not fail. i.e. total failure times divided by total operating times
- Resilience: the swiftness at which the system begins full operation after a failure.
- Vulnerability: the probable harm after a failure.

2.2 Review of WDSs Modeling and Analysis Software

There are quite a number of software which models and analyze WDSs. We have the open source which are free to download and use by individuals and organization while there are some which are practically closed from public use and others are commercially available to individuals and organization that may need them either for research, analyzing development of new water distribution systems or managing existing WDSs. The software each have their different aspect of forte and specialty which can denoted in the review below.

Water GEMS is a robust, comprehensive and easy to use water modeling and analysis software with the advancements in system optimization, platform interoperability and model building. Water GEMS is a super-set of Water CAD. Water GEMS is an efficient and versatile modeling software which helps to improve comprehension of system behavior, system reaction to operational strategies and system ability to meet future demands. Its flexible multi-platform workspace allows fire flow and water quality simulation, pipe flow and pressure analysis and energy cost analysis. Water GEMS capabilities include intelligent system management and planning for system reliability, optimization of operation (pumping strategies, system shutdowns and preventive maintenance to minimize disruptions) for efficiency of system and asset renewal or renovation support to ensure sustainability. Its features include prefixed model building, integration with multiple platforms, design and other operations. The unique aspect of Water GEMS is the data presentation mode which is highly appealing and comprehensible. Its versatility also allows presentation with variety of graphical tools. Water GEMS is not an open source software but is commercially available. Water GEMS software was built with a strong design algorithm to meet the criteria of precision in modelling, analysis and design of WDSs [4].

WaterCAD is a sub-set of WaterGEMS. It is a user-friendly WDS modeling management and analysis software that has a range of functions which helps to improve design productivity. These functions include prefixed model building, data archiving and bespoke graphical data presentation, assessment of water demand, WDS configuration, design and operational scenarios and lastly CAD interoperability i.e. ability to model in any familiar platform of choice. WaterCAD was built with certain features and capabilities which differentiates it from other modelling software. These features include but not limited to ability to access fire flow capacity, analyze pipe and valve criticality, build and manage hydraulic models, design WDSs, development of maintenance, flushing and management plans, identify water leakages and manage energy use. WaterCAD is quiet easy to use and is generally considered a flexible and resourceful WDS modeling software [4].

Pipe Flow Expert is a commercially available software application for designing and analyzing complex water pipe distribution systems where flows and pressures must be balance to solve the system. Pipe flow expert has an intuitive user interface which is easy to use and also models water systems, not only in 2D but also in 3d isometric presentations. Its unique features includes a robust calculation engine that solves complex pipe networks, presents pressure, fluid and pipe data adequately in PDF format [15]

Branch (2014) is an open source WDS optimization software which is built and developed to design branched WDSs configurations. This software takes exact input system data like pipe

and reservoir elevation, length of pipe, coefficient of friction and demand nodes and sets the cost as function. The output data is the optimized pipe length and diameters such that overall cost of system is minimized [16].

EPANET is an open source hydraulic analysis software for WDSs. It performs extensive simulation of hydraulic and water behavior within pressurized WDSs. It was built to aid our comprehension of how water travels in WDSs. EPANET is a very strong and versatile application which provides workspace for hydraulic analysis of systems of any size by editing system input data, running hydraulic and water quality simulation and viewing the result in different choice platforms. It is mostly used as a research tool but can also be used to restore and develop existing and new WDSs respectively. EPANET is an innovation of the United States Environmental Protection Agency [17-18].

HydrauliCAD is water system design, hydraulic analysis and water modeling software integrated in AutoCAD using industry standard EPANET simulation ad modelling engine. It is an open source software and it is incredibly easy to use with unlimited application support. It was built as an AutoCAD extension software and consequently operates with advantages of AutoCAD including flexibility and familiarity. HydrauliCAD was developed to calculate pipe pressure, flow, pressure loss and other variables in WDSs. This software has an inbuilt pipe elements archive which contains detailed information about pipe materials, types and sizes which are used in modelling WDSs and also used for fire-flow analysis. HydrauliCAD is designed to be powerful, fast and intuitive [19]

Pipe 2018 is the latest version of KYPipe hydraulic modeling software developed 45 years ago with 9 distinct engines that can handle over 50000 pipes. Kypipe is not an open source software as they have sold over 5000 liscences. Pipe2018 is an intuitive, standalone workspace which supports a complete package of available hydraulic elements. Kypipe is of the opinion that operation in third party GIS or CAD workspace limits software usefulness. Therefore CAD interoperability is not a feature associated with this software because it doesn't allow integration into other familiar workspaces. However, Pipe2018 is generally a powerful software package which has a strong computational algorithm for water and other fluids. It also has capabilities like pipe sizing and optimization of pump operations [4].

Synergi Water is a hydraulic modeling and simulation software package for modelling and analysis of closed conduit system of pipes, regulators, valves, pumps, reservoirs, tanks, wells and boreholes. Some of synergi water tools include fire flow analysis, pressure dependent demand, extended period analysis of steady state flow with cost of pumping and other logical controls, importing and exporting of EPANET models, dynamic forward and backward tracing and modelling of electric power contract for pump stations. Synergi Water has a powerful database management deployed for enhancing the efficiency of WDS in existence as well as in the design and development of the new WDSs. This software provides versatile and strong workspace of tools for comprehensive and easy water modeling, performs fast and precise analysis, designing of complex systems with proper configuration of elements. Its integration with other workspaces is quick and flexible [4].

H2Onet and H2Omap are both commercially sourced software which basically have the same functionalities are both flexible enough to be integrated with the GIS and CAD workspaces. They are used for modelling, analysis, design and optimization of WDSs. There unique capabilities include leakage detection assessment, fire-flow analysis, cost-optimization, etc. The major feature which distinguishes both software includes preprogrammed and intuitive online SCADA interface. H20Map is a standalone GIS program [20].

HYDROFLO3 is an updated HYDROFLO series version. It is a strong, flexible and ready to use WDS analysis software. It can model systems with up to 10 sources, 9 branches and approximately 1000 elements. This means that virtually any WDS can be described using the wide range of WDSs elements and components available in its archive. The ease of unit conversions between Metric and SI units is one advantage of using HYDROFLO3, other advantages include calibration and validation of existing WDSs, easy manipulation of hydraulic parameters for all WDSs. HYDROFLO3 permits a peculiar feature as Pump base used for the calculation and analysis of pump hydraulic characteristics which is a requirement in forced flow systems. HYDROFLO3 is also useful in industrial applications, simulation of treatment plants, fire-flow analysis etc. It is robust software used to design WDSs with strong data management capacity [4].

InfoWater assist with hydraulic and spatial analysis and management of distribution networks models. It focuses on large urban network design and modelling of WDSs. Its features and capabilities include design, calibration, water quality modelling, system configuration scheduling and system maintenance. It is fully integrated with ArcGIS [21].

There are several other software which are built and developed for modelling, analysis, simulation and optimization of WDSs but have not being included in the review above, some of which are worthy to be mention include WATSYS, InfoWorks, Eraclito, AFT Fathom 10, Netis, Archimede, Cross, OptiDesigner etc.

3. Conclusion

Through the above review of the analysis of modelling software and performance analysis, it is deduced that different licensed software and freeware products are available to design and model various categories of water distribution systems, ranging from simple to complex, realistic and even hypothetical. These designing and modeling software are unique and peculiar based on certain factors including compatibility to different computational systems and requirements, functionality, searching and optimizing algorithms, graphical user interfaces (GUIs), base program development language etc. Some advanced softwares like WaterGEMS, Synergi Water, H2Onet and H2Omap allows time to time upgrades and they can be integrated with GIS, SCADA and other platforms but the free/open-ware modelling software such as EPANET and Branch are short of these functionalities. Licensed software offers great flexibility in modeling various types of hydraulic models with various features over software from the public domain. Therefore, the decision on which software to use for the design of water distribution systems is predicated on software precision, the overall project cost, software - required data, complexity of system, aspect of system to be modelled (quality, demand, valve

operation and location etc.) software specificity related to the types of distribution systems that it can manage and computational and hydraulic criterion.

4. Recommendation

The decision on which software to use for the design of water distribution systems is predicated on software precision, the overall project cost, software - required data, complexity of system, aspect of system to be modelled (quality, demand, valve operation and location etc.), however, freeware software such as EPANET is recommended for complex, hypothetical/conceptual research based activities while WaterGEMS and other licensed software may be used for Standardized, real and complex projects due to its flexibility and precision.

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