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Modeling for water distribution system management in the 21st Century

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ABSTRACT: With the advent of new technologies, water distribution system are getting developed to cope with the continuously diminishing resources and increasing population with their desire for high living standard. However development and management of water distribution infrastructure to ensure customer satisfaction are becoming so complex that, water supply authorities are using computer model for integrated development, efficient management and future planning of the system. Various sophisticated modeling tools and complex algorithms enables the water supply authorities to make the optimized decision in planning, design and managements considering ins and outs of the whole system. This paper demonstrates the benefits of modeling tools and applications of difference analyses which can be used for efficient design and management of the water distribution system in Bangladesh, especially in Dhaka. Finally, a strategy has been outlined for Dhaka Water Supply Authority to make the system fully automated from the existing condition.

1 INTRODUCTION

Water distribution modeling is the latest technology in a process of advancement that began two millennia ago when the Minoans constructed the first piped water conveyance system. Today, water distribution modeling is a critical part of designing and operating water distribution systems that are capable of serving communities reliably, efficiently and safely both now and in the future. The availability of computer models and increasingly sophisticated model tools allow these goals to be realized more fully than ever before. This paper aims to familiarize the application of modern and sophisticated modeling tools in efficient management of water distribution system. Several possible case studies to understand the most efficient use of those tools have been discussed in context to the different geographical and environmental systems of Bangladesh. Finally, a conceptual strategy has been formualted and in betweeen milestone projects have been described to go for a fully automated water distribution system in future.

2 APPLICATION OF WATER DISTRIBUTION MODELS AND MODELING TOOLS

Water Distribution Models can be used to predict system responses to events under a wide range of conditions without disrupting the actual system. Using models, problems can be anticipated in proposed or existing systems, and solutions can be evaluated before time, money, and materials are invested in a real-world project. Models are especially important for WDSs due to their complex topology, frequent growth and change, and sheer size. It is not uncommon for a system to supply millions of people; thus, the potential impact of a utility decision can be tremendous.

Water distribution network simulations are used for a variety of purposes, such as

- System design and long-range master planning, including both new development and rehabilitation
- Fire protection studies
- Water quality investigations
- Energy management
- System design

- Daily operations

To efficiently accomplish these above operations following modeling tools and analyses are mainly used:

- Model building tool
- Elevation extractor
- Network skeletonizing tool
- Demand allocator
- Automatic design and calibration
- Valve criticality analysis
- Water quality analysis
- Fire flow analysis
- Energy optimization

2.1 *Model building tool*

Model Building is a very efficient tool for modern water distribution system design and management for its ability to quickly import data from various databases to build a computer model. It uses integrated GIS interface which allows modelers to work in the GIS to incorporate the topographic conditions in the model. With this tool, the existing GIS information can be easily incorporated in the model which would otherwise take months if the modelers had to digitize a large distribution system to build a computer model.

For example, nearly 2200 km of pipe networks of Dhaka can be imported into model within an hour if pipe information and junction informations are available in any other database format. However, for correctly georeferenced model, the source files also need to be correctly georeferenced.

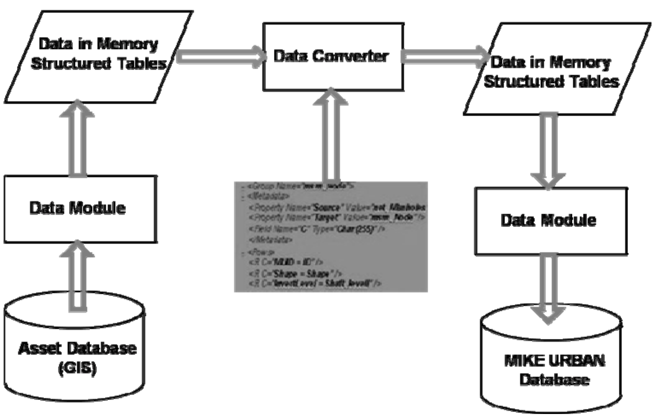

Figure 1. Data exchange during model building

2.2 *Elevation extractor*

Though in the pressurized water distribution system the affect of elevation on the system behavior is negligible, it may prove vital where the undulated topographical condition exists such as Mirpur area of Dhaka, Chittagong Town and other hilly terrain area etc. But considering the enormous number of junctions and other components for a large system like Dhaka, it is almost impossible to manually incorporate those data into the model. To overcome this tedious job, Elevation Extractor tool is used which can automatically incorporate elevation data of any database format into the model if the source database is linked with model matching the IDs of both source and model components. This tool will play most vital role in correctly simulating the system of hilly terrain area.

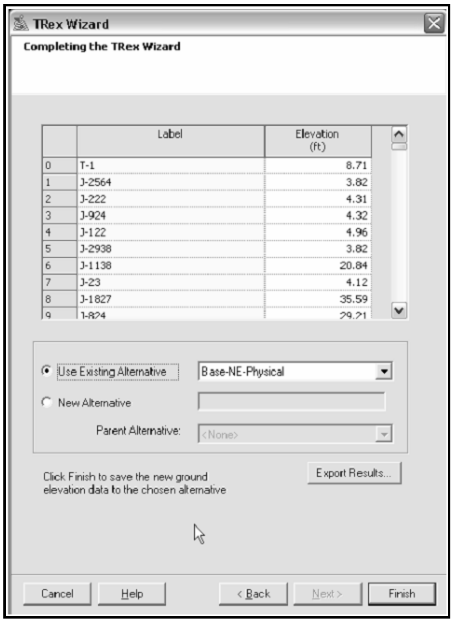

Figure 2. Elevation extractor

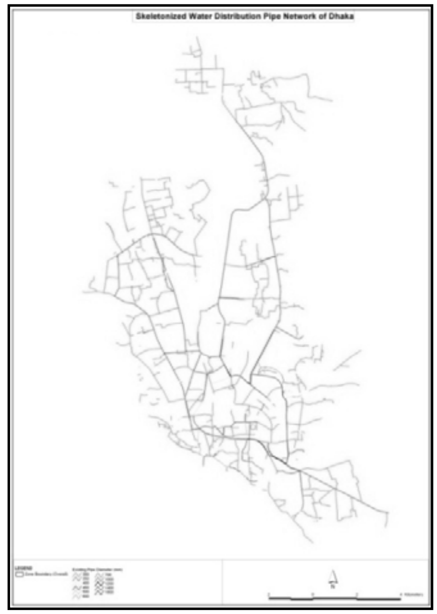

Figure 3. Skeletonized network

2.3 *Network skeletonizing tool*

A fully realized water distribution model can be a very complex network consisting of thousands of discrete elements, and not all of these elements are necessary for every application of the model. When elements that are extraneous to the desired purpose are present, the efficiency, usability, and focus of the model can be substantially affected, and calculation refresh times can be seriously impaired. Different levels of skeletonization are appropriate depending on the intended use of the model. For an energy cost analysis, a higher degree of skeletonization is preferable and for fire flow and water quality analysis, minimal skeletonization is necessary. This means that multiple models are required for different applications. Due to this necessity, various automated skeletonization techniques have been developed to assist with the skeletonization process. The portions of the network that are not modeled are not ignored; rather, the effects of these elements are accounted for within the parts of the system that are included in the model.

2.4 *Demand allocator*

For water distribution system design and management and to build a realistic model, accurate demand allocation is one of the most important parameter. Due to the numerous types and location of demands, demand allocation has now been so complicated that it has been made a computerized process rather than simple manual allocation. But it is unacceptable that some organizations in Bangladesh, especially which are responsible for water supply in sub-urban areas and non-capital cities are still using the outdated idea of manual demand allocation. The mixed pattern of households and variability of demands make them very vulnerable to a collapsable system during the peak time of the day.

The demand allocator tool helps designers to simulate and propose a system that will be more reliable and efficient to the consumers. Some criteria that are used by demand allocator tools are as follows:

- Billing meter aggregation
- Nearest node
- Nearest pipe
- Equal flow distribution
- Proportional distribution by area
- Proportional distribution by population
- Unit line

It is not necessary to apply single criteria for the whole area of consideration; rather different criteria appropriate for different parts of the area may be applied. Thiessen polygon may be used for distribution based on the proportion of area. For any known concentrated demand, manual allocation may be used for that particular junction. But for the whole network it is always a good choice to use demand allocator and appropriate criteria for that part of the network.

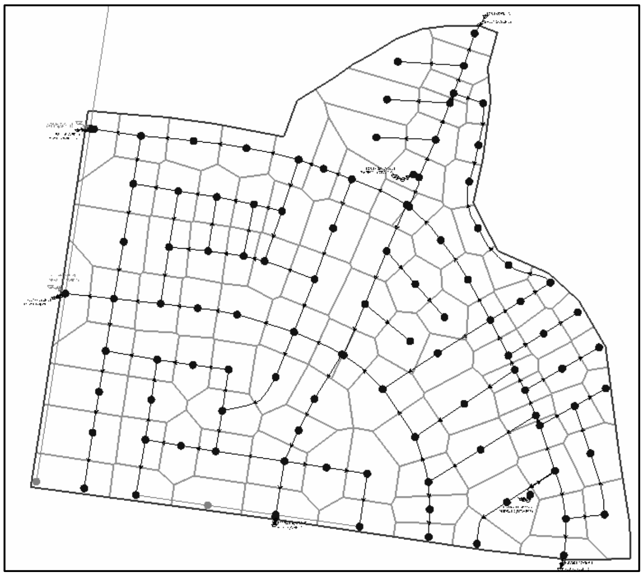

Figure 4. Thiessen polygon for demand allocation

For Dhaka water distribution system it would be best to use the Billing Meter Aggregation process, but due to the lack of accurate domestic water meter data, this process is not being applied in the ongoing water supply projects of Dhaka WASA. To make the best use of available data, “Proportional distribution by area” process is being used instead.

2.5 *Automatic design and calibration*

The latest technology in the water distribution system design is the automatic design and calibration of the whole system when necessary parameters, boundary conditions and constraints are mentionded properly. The optimization process is performed by genetic algorithms considering constraints and boundary conditions to avoid manual trial and error processes by designer. But the designers challenge lies in carefully choosing the constraints and parameters to get a desirable results after optimization process. To optimize a large system within a very shortest possible time this tool plays a very vital role. Though in Bangladesh use of automatic designer has been very limited so far in water supply projects, but this tool is being used in developed countries very efficiently. Only proper understanding of the system parameters, constraints & boundary conditions and increasing the reliablity of the input data can lead to efficiently use this tools for a developing country like Bangladesh.

Automatic calibration has also been of limited use in Bangladesh. For large networks, even for dhaka, manual calibration is a very difficult task. Calibration is necessary to make the computer model more realistic with physical system and for continuous monitoring of the system during service. A well calibrated model can be used as a leak detection tool by which network leakage location can be determined from computer model. In that case continuous automatic calibration will be necessary for the water supply system of that area.

2.6 *Criticality analysis*

To identify the impact of valve number and locations on the system reliability, criticality analysis is absolutely necessary. When a pipe fails in a real system, it not only removes the pipe from the system but also impair the system creating a source of major water loss. To make the whole network less vulnerable aginst any kind of such pipe failure, placement of isolation valves are necessary in the system. Criticality analysis ensures the isolation of the whole network into several segments and calculate other parameters like outage segments, demand shortfalls for each segements etc. The whole analysis get a bit more complicated for developing countries like Bangladesh where following the thumb rules of isolation valve placement (minimum N-1 valves at each junction where N is the number of pipes at that junction) become impossible due to budget constraints. Then, the location of isolation valves within budgets have to be optimized by criticality analysis so that total segement lengths, outage segments and demand shortfall for each segments reach their minimum values.

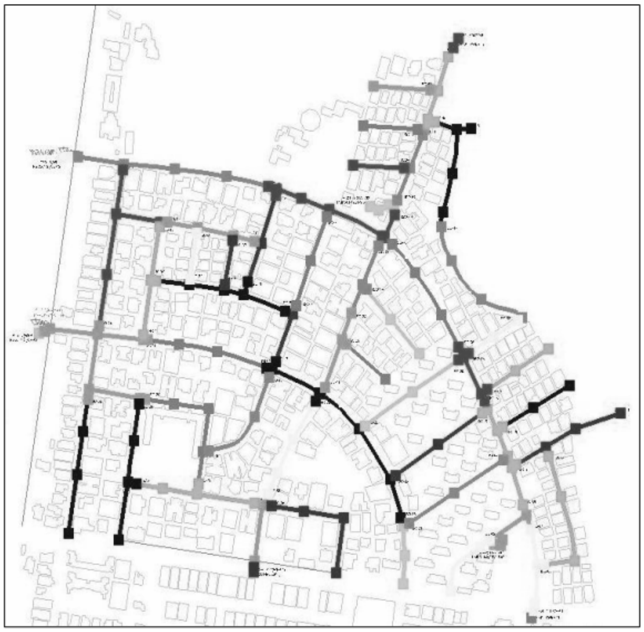

Figure 4. Segmented network by criticality analysis

During the implementation of Dhaka Water Supply Sector Development Project, Dhaka WASA faced the similar problem and criticality analysis was used to get the optimized location of limited number of isolation valves within the network. The result of the criticality analysis may be used in future during operation to find out the location of valves to be closed due to a failure of any pipe. It will be absolutely necessary in the system (e.g. Dhaka) when every junction doesn't possess sufficient valve to close a pipe attached to it.

2.7 *Water quality analysis*

The public health hazards due to the obnoxious water quality is known to all. When water is yielded from tube-well and/or treatment plant, it becomes contaminated in the intermediate route to the consumer.Water quality analysis make the water supply authorities capable of computing water age, constituent concentration or percentage of water from a given node (trace analysis) which are the three most important factors contributing to the contamination of water in the pipe networks. At present ground water sources are distributed within the whole network of Dhaka, so prolonged water age is less probable at this condition. But as the ground water level is depleting at a very rapid rate, the water supply authority of Dhaka is planning to go for a 100% external water source in near future and most of which will be provided through treatment plant located at the outskirts of the city. Some the waters discharged from these distant treatment plants may take several days to reach to the consumers. Due to this such a long contact period with pipe material, the treated water may undergo various chemical, physical and aesthetic transformations impacting water quality.

Following table shows the water quality problems associated with water age (courtesy of U.S. Environmental Protection Agency).

Chemical issues	Biological issues	Physical issues
*Disinfection by-product Formation	*Disinfection by-product Biodegradation	Temperature increases
Disinfectant decay	*Nitrification	Sediment Deposition
*Corrosion control effectiveness	*Microbial regrowth / recovery /shielding	Color
Taste and odor	Taste and odor	

* Denotes water quality problem with direct potential public health impact.

Another component of water quality analysis is constituent concentration, which investigates the chlorines residuals in the system over time. All production tubewells of water supply system of Dhaka contains a chlorination unit through which water is chlorinated and discharged into the system. Water quality analysis of constituent concentration enables the water supply authory to find out how the concentrations of chlorine change throughout the network.

Chlorination of water at Saiadabad Treatment Plant has been a major source of concern for public health to the different authorities including High Court of Bangladesh. Dhaka WASA can use a well calibrated water quality model to monitor the quality of chlorinated water at consumer points.To prevent any unfavorable reactions of chlorine with pipe materials and/or other contaminants continuous water quality monitor at different consumer points is necessary. Therefore a well calibrated water quality model can be the tool to gain public trusts regarding water quality and water supply authority.

A trace analysis determines the percentage of water at all nodes and links in the system from a specific source node (the trace node). Generally, the nodes where the possibility of leakages and subsequent contaminant intrusion are highest is considered the trace nodes. Then the percentages of contaminant from those leakage points traveling and accumulating to the other nodes are determined. This kind of leakage and contaminant intrusion is very common in water supply system of developing countries and also in Dhaka. In fact at present, the major contamination source of drinking water in Dhaka City is the intruded contaminants through the leakage of distribution systems. Though some ongoing major rehabilitation works by DWASA aim to reduce the network leakage from 40%-60% to maximum 15%, it is unlikely that the network leakage will not increase in future due to the operational mismanagement. So the trace analysis is very important for any leakage prone networks like Dhaka.

2.8 *Fire flow analysis*

The fallacy often pre-occupied by some people is that scarcity of drinking water obviates the assesment necessity of required water for any accidents like fire events. This case is most suited with the condition of Dhaka water distribution system. Though at present sufficient water is not available for consumer, fire flow analysis may be carried out to assess the vulnerability of the system during any fire events. If the network loss is reduced below 15% of total supply according to the target of Dhaka WASA, the problem with water scarcity will be mitigated a lot. In that case fire flow analysis for network will be mandatory for the system and automated fire flow analysis can be used to determine if the system can meet the fire flow demands while maintaining minimum pressure constraints.

Since the water distribution system of Dhaka is a very large system comprising of approxiamtely 2200 km pipe, 530 tubewell, two treatment plant and 12 million consumer , it is not necessary to increase pipe and other component size significantly if the network is designed considering fire flow requirements. According to the AWWA manual M31:

"In larger systems fire protection has a marginal effect on sizing decisions, but in smaller systems these requirements can correspond to a significant increase in the size of many components. In general, the impact of providing water for fire protection ranges from being minimal in large components of major urban systems to being very significant in smaller distribution system pipes and smaller distribution systems."

Other non-capital cities and suburban areas of Bangladesh where water distribution system is not significantly large, fire flow analysis may be carried out to assess vulnerability and available fire flow at City centers, imporant locations, densly popluated areas or commericaily significant areas. Automated fire flow analysis is the latest technology in this field.

Automated fire flow analysis can be used to determine if the system can meet the fire flow demands while maintaining minimum pressure constraints. Fire flows can be computed for all nodes or some selected nodes in the system. At each node fire flows are computed by iteratively assigning demands and computing system pressures. The model assigns the fire flow demand to a node and checks the model to see if all pressure and velocity constraints are met at that demand.

2.9 *Energy cost optimization*

Energy crisis in developing countries like Bangladesh is the major obstruction to the growth of GDP. But a significant portion of that energy are spent in the operation of water distribution system such as running pumps, treatment plants etc. So constant growth of interest among water supply authorities in optimizing pump operations are noticable now-a-days. Bangladesh as a country with energy crisis and low economic capabilities may also pay special attention in saving energy at the operation of water distribution system by optimizing pump schedules.

A main factor in energy management is time of day power tariffs. Such rate policy creates a major change in the pumps operation concept. Major change can be achieved by shifting the pumps operation from the peak period to the mid and off-peak period. Again such strategy may be in conflict with the cosumer water demand pattern increasing pressures and consequent losses at low demand period while interrupting continuous supply at high demand period. To solve this dilemma, energy cost optimization must be carried out during the design and operation of the system so that operational cost of the system becomes minimum without impairing the service to the consumer. It should be kept in mind by the water supply authorities that even a small percentage savings of operational cost by energy cost optimization analysis will accrue to a huge amount of savings at the end of a financial year.

2.10 *SCADA system*

SCADA is the abbreviation of Supervisory Control and Data Acquisition which is used to remotely collect data and monitor the whole water supply system. The central SCADA master system is typically installed in a control room of water supply authority along with other necessary hardwares such as servers, printers, and device for transmitting signals from/to RTU's. The central SCADA master system will communicate with field RTU's and all data for operation and monitoring of the water network (signals, measurements) will be displayed visually. RTU is the remote terminal unit which is installed at the field component to transfer data

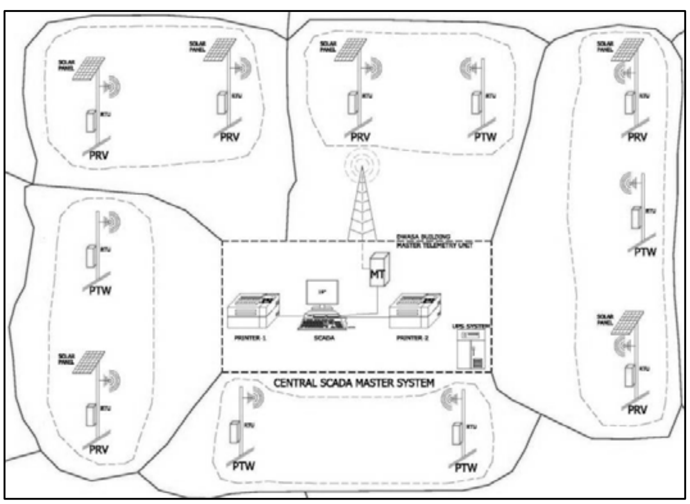

Figure 5. SCADA system

to the central SCADA master system of the water supply authority.

Though this technology may not still fully feasible for Bangladesh considering the economical and technological limitations, some pilot projects of small area may be undertaken for introducing the SCADA system and thus it may be a small step toward the development and introduction of latest technology to the whole area.

3 MILESTONES THAT MUST BE ACHIEVED BY DWASA TO BECOME AUTOMATED

Dhaka Water Supply Authority is currently responsible for supplying water to approximately 12 million consumers in the Dhaka City. To ensure an efficient and sustainable system, there are some milestones projects that the water supply authority need to accomplish.

- At present in Dhaka Water Supply Sector Development Project of Dhaka WASA, the whole network has been isolated into different parts to form District Metered Areas (DMA). At the end of the project Dhaka WASA will have the designed model of all DMA. Total water loss has been aimed to reduce below 15% by the 100% rehabilitation and required extension of pipes.
- The designed model will need to be calibrated properly so that model values conform to the field conditions.
- SCADA systems will need to be introduced to smoothen the continuous data collection process. SCADA Master System will collect the field data automatically at a certain time interval and store it to a central database of water supply authority.
- SCADA will be incorporated to the automatic calibrator and automatic designer of the master model and both tool will run at certain time interval. After proper calibration if there is any network leakage, leakage location and quantity will be displayed at the monitor. If any pipe needs to be rehabilated, examining the failure history, roughness, age and network performance, model will make that suggestion.
- A Water quality mode has to be developed for DWASA. Water quality of the system will be continuously monitored at source and several other points in the network and the data of which will be collected by SCADA system to incorporate in the model. From the collected data and water quality analysis of model, the water quality of the rest of the nework will be predicted. If any deterioration is found, most feasible corrective measures will be suggested by model.
- The whole process will be continuous and dynamic and model will be the basis of all activities of water supply authority. To increase the efficiency of the model and its performance, the input data always must be most accurate and be incorporated with model keeping the time consistent with collected field data.

4 ROLES OF ENGINEERS IN AUTOMATED SYSTEM

An automated water distribution system with network models will never eliminate the need for engineers in design and management of water distribution system, rather it will require the concerned engineers to be more prudent to understand real system, make decisions based on sound engineering judgement, assess the decisions suggested by model, monitor the efficiency of the whole system and above all to ensure a satisfactory customer service every time. A network model is just another tool (though a powerful and multipurposed) for an experienced engineer.

5 CONCLUSION

Clean drinking water is the single most important issue concerning public life and health. But in the developing countries like Bangladesh, people are still getting water of deteriorated quality and inadequate quantity. The water supply authorities are struggling to meet the drinking water requirements for the fast growing population. Vision must be set now for these water supply authorities to make the system better, to ensure satisfactory public services and to avoid a public disaster in near future. Using advanced technology like models would help the authorities to find a solution to their problems.

REFERENCES

AWWA. 2002. Effects of Water Age on Distribution System Water Quality. USA: Environmental Protection Agency.

DWSSDP. 2011. 1st Quaterly Progress Report. Dhaka. DWASA.

E. Granato, Gregory. 2004. Rhode Island Water Supply System Management Master Plan Database. Rhode Island: Rhode Island Water Supply Board.

Feldman, Mordecai. Aspects of Energy Efficiency in Water Supply System.

Giustolisi, Orazio; Savic, Dragan. Identification of Segments and Optimal Isolation Valve System Design in Water Distribution Networks. London: Taylor and Francis.

Goryashko, Alexandar; Nemirovski, Arkadi. 2009. Robust Energy Cost Optimization of Water Distribution System with Uncertain Demand. Moscow: Moscow State University Press.

M.Walski, Thomas; V. Chase, Donald; A. Savic, Dragon; Greyman, Walter; Beckwith, Stephen; Koelle, Edmundo. Advanced Water Distribution Modeling and Management. USA: The Bentley Institute Press.

Rahman Kanta, Lufthansa. 2006. Vulnerability Assessment of Water Supply System for Insufficient Fire Flows. Texas: Texas A&M University.

Weblink: http://www.dhakamirror.com/other-headlines/wasa-uses-chlorine-to-treat-water-flouting-court-rule/

Weblink: http://www.thedailystar.net/newDesign/news-details.php?nid=130256

Yesmin Mannan, Iffat. 2009. Corporatizing Dhaka Water Supply and Sewerage Authority. Ontario: Queen’s University.