

## **MODELLING INTERMITTENT WATER SUPPLY SYSTEMS WITH EPANET**

PETR INGEDULD, ZDENEK SVITAK

*DHI Hydroinform a.s.*

*Na vrsich 5, 100 00, Prague, Czech Republic*

AJAY PRADHAN, ASHOK TARAI

*DHI India*

*K-71, First Floor, Hauz Khas Enclave, New Delhi, Delhi 110016, India*

Modeling rural networks and intermittent water supply systems is a challenging task because these systems are not fully pressurized pipeline networks but networks with very low pressures, with restricted water supply hours per day, and with thousands of ferrule points and roof tank connections. The alternate emptying and refilling of water pipelines makes it problematic to apply standard EPANET based hydraulic models because of low pressures and pipes without water.

EPANET source code was adjusted to allow for modeling pressure dependent demands, for dealing with low pressure and “dry pipe” situations. A configurable tool was developed for incorporating roof tanks into the water supply analysis and for better formulation and schematization of the system hydraulics. Two cases studies, water distribution model of Shillong in India and detailed water distribution model of Dhaka in Bangladesh are used to illustrate the practical use of this approach.

The experience from using and adjusting the EPANET engine for the modeling of intermittent water supply systems is discussed in this paper.

### **INTRODUCTION**

As a result of rapid population growth and high water losses from the distribution network, the total water demand of the system in many developing countries exceeds available production capacity. To limit total demand and provide an equitable distribution of available water, intermittent water supplies with reduced system pressures are often introduced. Hours of available water supply vary, depending on the system, could be 1-2 hours per day or between 3-4 hours on every third day, for example.

*In intermittent supply system the duration of water supply is variable; it may be 1-2 hour per day or 3-4 hour per day.*

An intermittent water supply is common to many cities in India and Bangladesh. It can lead to a spiral of decline as management of the system is extremely difficult and customer’s willingness to pay declines. Specific problems include [Halcrow Water Services and Bristol Water Services, 2003]:

- serious risk to public health, resulting from ingress of contaminated groundwater into the distribution system;
- inability to practice effective supply management;
- inability to practice effective demand management;
- operational inadequacies, which unduly weaken the physical infrastructure;

- Customer inconvenience.

The consumers are forced to collect as much water as possible during the limited supply hours. The demand for water is not based on the notions of diurnal variations of demand but on the maximum quantity of water that can be collected during supply hours. This will be dependent only on the available pressure heads in the network. Such systems operate.

The details hydraulic model of the intermittent water supply system would need to simulate the “charging” process in pipes. This will require integration of the momentum equation and the water-column velocity equation to generate the positions of the water-front in the network at any time [Steffen Macke]. This is a short period (first 20-30 minutes or so), after supply is resumed when the pipes are filling from a near empty state to a fully charged pressurized state.

The objective of our modeling was not to predict the exact time at which different users get water but to develop a simplified model, where node demand is dependent on the pressure at the junction nodes.

### Pressure dependent demands

Initial idea of using the couple between EPANET and MOUSE (DHI) engines for accurate modeling the process of pipe filling i.e. free surface flow conditions was rejected due to the limited time available for the hydraulic analyses in case studies, and also with respect to the practical use of the hydraulic models. It was decided to adjust the EPANET engine to deal with low pressures and limited demand availability. Modified version of the steady state and extended period analysis was developed on the basis of the standard EPANET demand driven analysis.

Pressure condition	Demand (flow)
$H_i < H_{min,i}$	$Q_i = 0$
$H_i > H_{max,i}$	$Q_i = Q_{max,i}$
$H_{min,i} < H_i < H_{max,i}$	$Q_i = f(H) (*)$

Where:  $H_i$ : pressure at a node  $i$

$H_{min}$ : minimum required pressure at a node  $i$

$H_{max}$ : maximum pressure at a node  $I$  (defined as pressure above the estate height)

$Q_i$ : demand at a node  $i$

$Q_{max}$ : user specified (requested) demand at a node  $i$

(\*) The modified demand at a node is calculated from the equation:

$$Q_i = Q_{max} \sqrt{\frac{H_i - H_{min}}{H_{max} - H_{min}}}$$

This type of modified hydraulic analysis works therefore not necessarily with the demands as given by the user but it checks the water availability based on the pressure conditions at a node.

### *Household tanks*

Household tanks are used by consumers to collect as much water as possible during the limited supply hours. The inflow into tank is based on the pressure conditions in the network and it equals to the maximum quantity of water that can be collected during supply hours. Initial hydraulic analyses indicated the importance of including such household tanks in the hydraulic model. A configurable tool was developed for incorporating roof tanks into the water supply analysis and for better formulation and schematization of the system hydraulics.

Manual tank assignment to each appropriate junction node and estimation of the tank size would be tedious and long process. Automated procedure of the tank generation was therefore developed taken into account limited GIS data, such as ferrules, which are used to connect houses to the “water distribution network”.

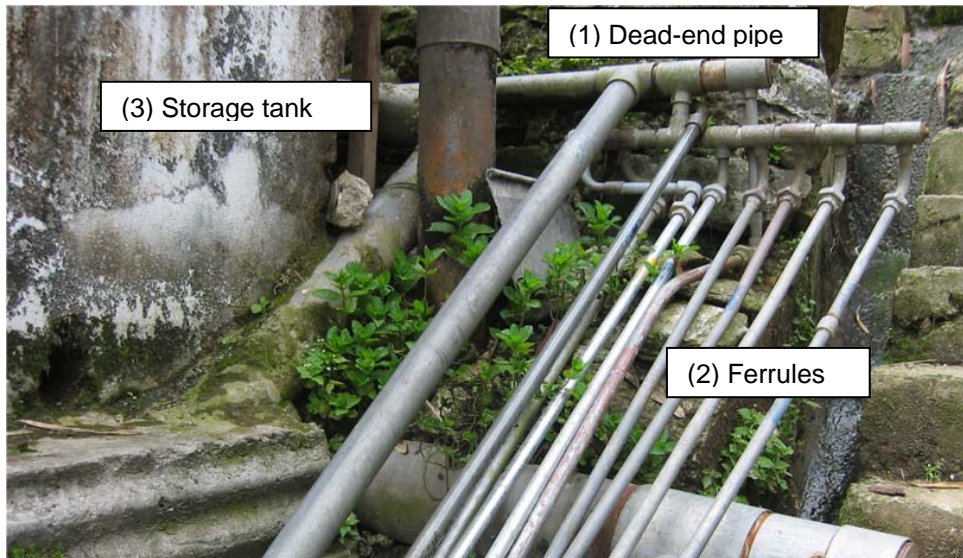


Figure 1. Ferrules (1) are used to connect houses to the nearest available “water distribution network”, such as a piece of a dead-end pipe (2) nearby a storage tank (3).

The tank sizes depend on whether the network is available down to the individual house connection level or not. If the individual house connections are available in a GIS, each tank in the model should represent one real household storage tank. In case the house connections are not available in the GIS, generalized house connections should be generated. It is practical to create one tank per junction and create a pipeline that connects the tank with the junction.

The individual tank fill rates depend mainly on the headloss over the pipeline that connects the tank to the network. For the case that uses generalized tanks it might be necessary to graduate the diameter of the connecting pipeline depending on the size of the tank [Steffen Macke].

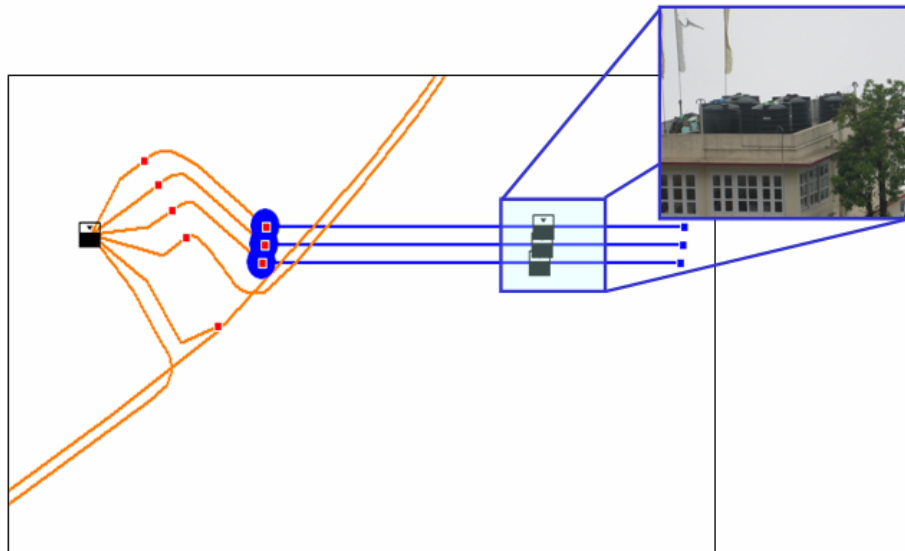


Figure 2. A configurable tool was developed for incorporating roof tanks into the water supply analysis and for better formulation and schematization of the system hydraulics. The figure illustrates the result of the automated generation of household tanks and their connecting pipes in the hydraulic model.

## CASE STUDIES

A concept of numerical modeling of intermittent water supply systems was developed and verified on selected case studies. The most recent ones are briefly described in the section below.

### *Shillong, India*

Shillong is a city in north-eastern India, and capital of Meghalaya state, one of the least populous Indian states. Shillong is about 65 km (40 mi) north of the border with Bangladesh and about 100 km (60 mi) south of the border with Bhutan. The water is being supplied for domestic, small industry and other purposes through Greater Shillong Water Supply Scheme and by Shillong Municipality Board. Water supply and distribution network of Shillong with nearly 3.46 lakhs (346,000) of inhabitants is a complicated large-scale network. The water distribution system of the Shillong is divided into ten supply zones.

The network and its attributes were imported from GIS data base to the MIKE NET with the use of import tool option. The tanks attributes like tank diameter, tank capacity and tank shape were collected from the tank questionnaires. The operation rules were collected from the operator of the water distribution network and then incorporated into the model. The water distribution system is functioned in gravity method. The demand distribution in the model is based on information of number of connections at ferrule points. Several logical discrepancies as well as mistakes were found in the provided GIS data. Large parts of the system are without ferrule points; some ferrule points have zero number of connections. The demand distribution is essential not only for model accuracy but for model functionality. Therefore in some cases 'fictive' ferrules were distributed in the network.

The average leakage of 15% has been assumed. The distribution of leakage to nodes using weight of length of connected pipes has been applied. The leakage was applied only during the supply hours; during non-supply hours the leakage stops

automatically based on advanced rules system. Thus the leakage distributed in the system must be recalculated by supply coefficient equal to the duration of supply period/24.

The hydraulic model was developed to study the low pressure areas and flow pattern in the distribution network.

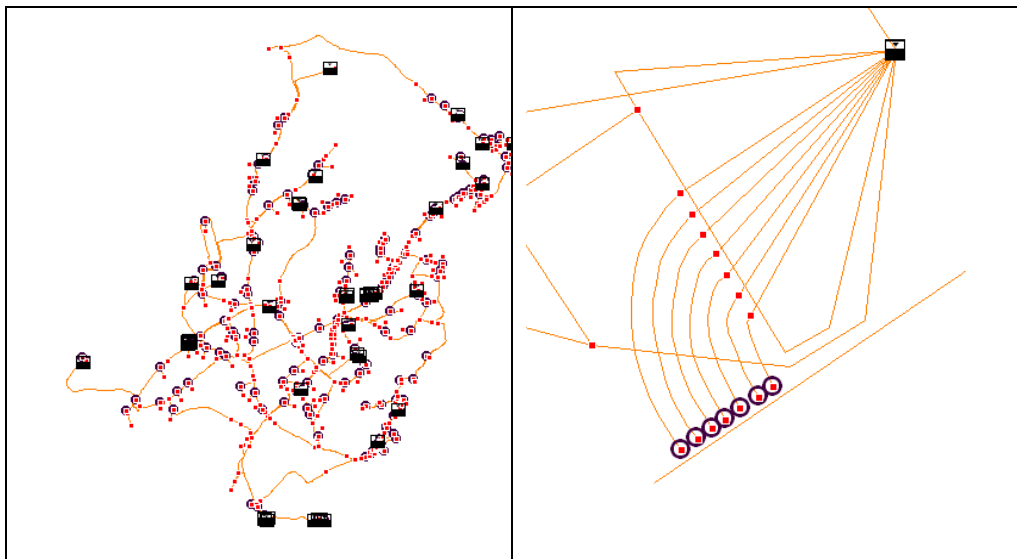


Figure 3. Shillong water distribution model, zone 3 model (left) and the detail of a tank with ferrule points (right).

### *Dhaka, Bangladesh*

Dhaka is a capital city of Bangladesh, in Dhaka Division, central Bangladesh. It is located on an arm of the Dhaleswari River in the populous and flood-prone Ganges-Brahmaputra delta and is a major commercial, cultural, and manufacturing centre.

The water distribution system supplies app. 4.5-6 mil inhabitants, depending on the daily fluctuation when people move into and out of the town. Water demand is app 25m<sup>3</sup>/s (400,000 gpm), while the available supply is only 17m<sup>3</sup>/s (270,000 gpm). 85% of water sources are groundwater wells (400) and 15% of water sources are surface water (there are 3 water sources) covering the area of more than 200 km<sup>2</sup>. There are almost no elevated storage tanks in the system, the total number of elevated tanks is 52, and only 16 tanks are in operation. 60% of service pipes are equipped by water meters. The intermittent water supply provides consumers with water twice a day. Water is pumped from ground water wells directly to the pipeline network. The pressure is very low and it ranges around 20-25m (30-35psi) but it can also be only within 2-5m (3-7psi); the low pressure can cause the infiltration of ground water into water distribution pipelines. Most residents used their own tanks (household tanks) in order to collect water during the supply hours. The leakage level is estimated as 40-45% with the following distribution: main pipes (55%), service pipes (30%), and illegal demand (15%).

The hydraulic model of the whole water distribution system was developed in MIKE URBAN based on the data collected in ArcGIS; this data included pipes, location of tube-wells, and elevation data. Node demands were developed based on the population estimates; leakage and unaccounted for water were also taken into

account. The hydraulic model was macro-calibrated based on the measured flows and pressures, collected during the monitoring campaign.

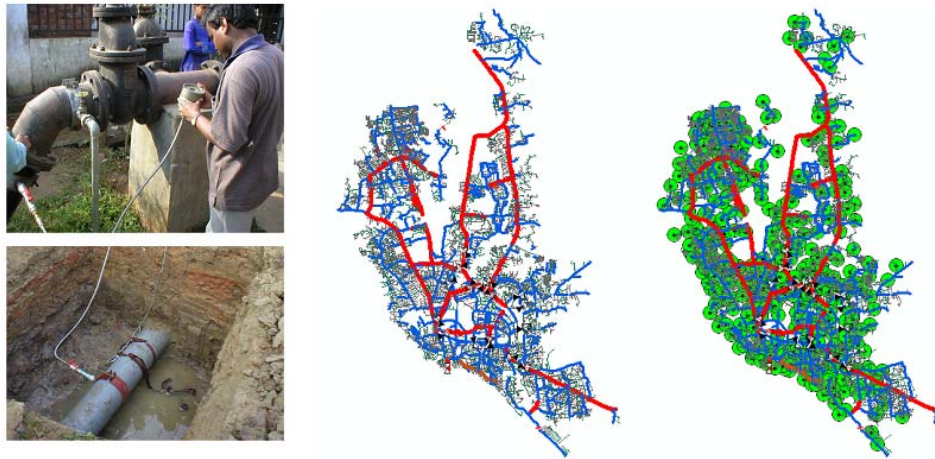


Figure 4. Dhaka water distribution model consists of app. 30,000 pipes and 400 tube-wells. The hydraulic model was developed in MIKE URBAN. A thematic map with pipe diameter (left drawing), and groundwater wells (right drawing). Flows and pressures were collected during the monitoring campaign (left).

Several hydraulic and scenarios were conducted including a dedicated modification of the EPANET algorithm allowing for modeling of low pressurized conditions. This proved to be necessary requirement for accurate modeling of flow and pressures in the network.

The main objective in developing the detailed water distribution model was to provide backgrounds for the further systematic network rehabilitation and improvement towards continuous water supply during 24 hours.

Water demand of the system exceeds produced water and this was the reason why the standard “demand-driven” EPANET analysis was replaced by the pressure dependent analysis, as described in the section “Pressure dependent demands”. The results were satisfactory and enabled completing the model macro-level calibration and prepare the model for the further use in the network rehabilitation and planning.

The next Figure 5 illustrates the results of the pressure dependent analysis comparing the to the normal EPANET analysis. Given distribution zone demand of 300l/s (4,800gpm) was automatically (iteratively while balancing the hydraulic solution) reduced to 130l/s (2,000gpm) in order to maintain the minimum pressures (3m, 5psi) in the distribution zone.

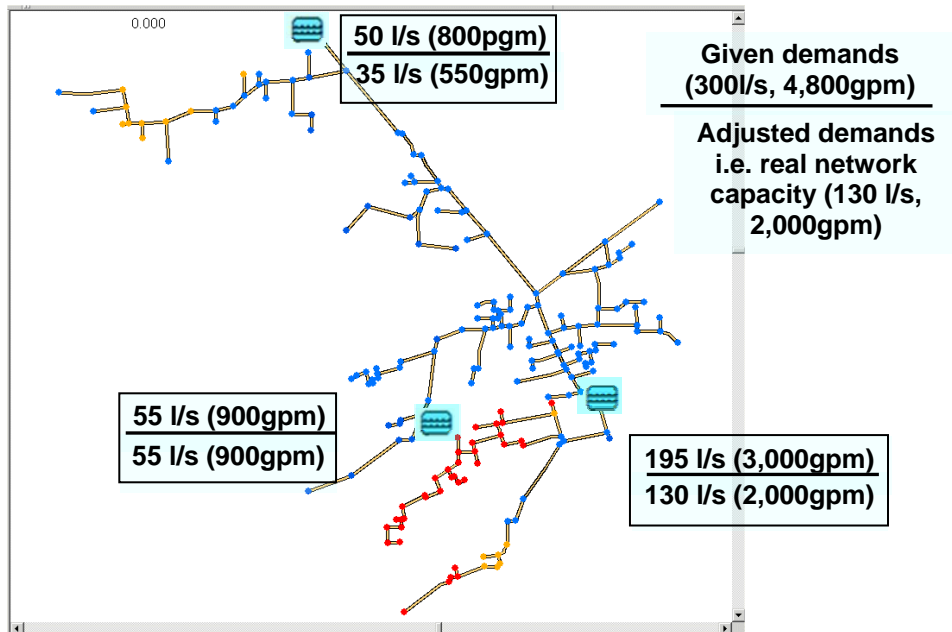


Figure 5. A sub-zone contains three tube-wells; original (given) demands versus new (adjusted) demands

## CONCLUSIONS

The presented solution for modeling intermittent water supply system is based on EPANET2 toolkit for hydraulic modeling. The solution is robust, simple, and it proved to be useful and practical for the modeling as it is illustrated on the hydraulic models of Shillong in India and Dhaka in Bangladesh. The algorithm is implemented to DHI's water distribution software packages MIKE NET and MIKE URBAN.

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