WATER DISTRIBUTION NETWORK MODELING FOR THE TOWN BAILESTI

Ionuț BISTRICEANU, Constanța BISTRICEANU

The present paper is the result of a study made for modeling the water distribution network of the town Bailesti.

Keywords: Network simulations; Hydraulic calibration; Hydraulic and water quality simulations

1. INTRODUCTION

The term *simulation* refers to the process of using a mathematical representation of the real system, called a *model*. Network simulations, which replicate the dynamics of an existing or proposed system, are commonly performed when it is not practical for the real system to be directly subjected to experimentation, or for the purpose of evaluating a system before it is actually built. In addition, for situations in which water quality is an issue, directly testing a system may be costly and a potentially hazardous risk to public health. A simulation can be used to predict system responses to events under a wide range of conditions without disrupting the actual system. Using simulations, 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.

Municipal water utilities are by far the most common application of the water distribution models. Models are especially important for water distribution systems due to their complex topology, frequent growth and change. It is normal for a water distribution system to supply hundreds of thousands of customers, there for, the potential impact over a decision made by the public water network service can be fatal.

Water distribution network simulations are used for a variety of purposes, such (Walski T. M., et al., 2002):

- Long-range master planning, including both new development and rehabilitation
- Fire protection studies
- Water quality investigations
- Energy management
- System design
- Daily operational uses including operator training, emergency response, and troubleshooting

2. GENERAL PRESENTATION OF THE WATER DISTRIBUTION SYSTEM MODELING FOR THE TOWN BAILESTI

The town Bailesti is situated in the south part of the county Dolj, in a plain. To assure the water supply in the town Bailesti there is a working centralized water supply system, composed as following:

- Active face;
- Adduction pipeline;
- Water supply station;
- Main pipeline and the distribution networks;
- Inside plumbing.

Active face The active face is assured by a number of 20 water diggings of medium deepness, from what 16 are working; and it is located lengthwise of the Bailesti- Boureni railroad, with safety distances between drillings of 250m. The water diggings equipment is composed of L80 type pumps that have Q=35mc/h; H=40m**,** which aspire the water from the water diggings and send it in the collecting pipe of the water diggings which is of Dn400 mm.

Adduction pipeline The water diggings are linked on a single adduction pipeline made from steel with a diameter of 400mm, posed underground, pipeline which links the tanks from the water supply station. The total length of the adduction pipeline is of 5,0 km between the water supply station and the last water digging.

The water supply station is made from the following:

- two buried water tanks made from concrete steel at 5000mc each;
- water tank with $V=750\ m^3$ and $H_{maxwater}$ =45,30 mCA;
- chlorination station,
- pumping station.

The waters circuit in the station is the following: the water from the diggings is sent directly in the two tanks through the chamber of valves. From here it is aspired through a common pipe made from steel with a diameter of 400mm by the pumping station and it is sent in the water tank with $V=750\ m^3$ and $H_{maxwater}$ =45,30m. From the water tank the city is supplied by free fall, in a distribution pipe made from steel with the diameter of 400mm and the length of 50m until the first junction. The chlorination is made directly in the tanks by a chlorination station equipped with two machines of Valcea type (1+1) installed in a separate room. The pumping station is a underground construction made from concrete steel, equipped with four AN200 pumps. Made by SC Aversa Bucuresti SA, that have $Q=250\ m^3/h$; H=50m and two free trestles for installing tanks in case of necessity.

The water distribution network. The main distribution

pipe which starts from the water tank and links it with the water network is made from steel, and it has a diameter of 400 mm and a length of 50m. The network is made from stell, asbestos cement and cast iron with a diameter between 100-350 mm, posed underground. The age of the pipes that make up the water distribution system is over 30 years. The network configuration is of a annular and ramified type, and is common for the water supply and fire protection (interior and exterior). The total length of the water supply network is of 31975m.
For modeling the water distribution network of the town Bailesti I chose the program EPANET because:

- It is a free program supplied by the Untied States of America Environment Protection Agency;
- It allows a long term simulation, water quality analysis and it has a graphic interface;
- Because the town Bailesti does not have an electronic GIS map it is not needed for the chosen program to have the integration facilities with the GIS data base.

3. MODEL IMPLEMENTATION

It has been used as a background, on which the network elements have been assigned, a paper map which has been digitized and introduced in the programs window. After assigning the network's elements a network without data was obtained, like in the picture below(Bistriceanu I., 2005).

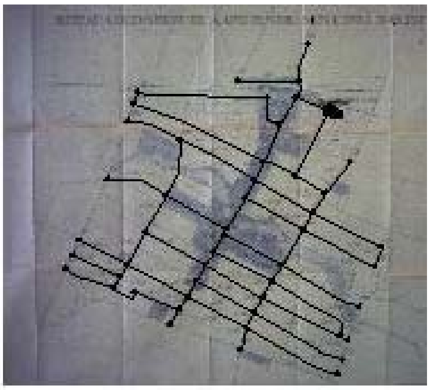

Fig. 1 Water distribution network representation for the town Bailesti

To every element of the network have been attached the characteristic proprieties as below (Rossman L. A., 2000):

No	Component	Proprieties
1.	Junctions	Junctions identifier: Junction coordinates; Junction elevation relative to the base of the tank; Base demand – the average demand in 24 hours(m^3/day); Demand model – demand variation in 24 hours
2.	Pipes	Pipes identifier; start junction; end junction; description – I assigned the street on which the pipe is; Label – I noted the material from which the pipe is made; length (m); Diameter (mm); Roughness coefficient Hazen-Williams; Loss Coefficient (dimensionless); Initial status (opened or closed)
3.	Reservoir	Reservoir identifier; coordinates; Total hydraulic pressure;
4.	Tank	Tank identifier: coordinates; Elevation (in the present case the base of the water tank has been considered as a reference level); initial level of the water (m); minimum water level (m); maximum water level(m); minimum volume; volume curve (because the tank has a cone shape); Water mixture model in the tank.
5.	Pumps	Pump identifier; Start junction; End junction; Pump curve (the reatiton between the pressure of the pump and the flow through it), initial status (opened or closed); pump efficiency; energy price.
6.	Valves	The valves have not been assigned separately, they have been considered only in the minor losses of pressure which characterize the behaviour of the pipes attached to them.

3. HYDRAULIC CALIBRATION OF THE MODEL

The calibration is the comparing process of the model results with the data collected from the field and if it is necessary adjusting the models parameter until the models results are similar with the ones measured in the system.

For measuring the pressure in the pipe network the existing hydrants on the streets Carpați-J7; Locotenent Becherescu-J38; Unirii-J22 and Dreptății-J48 were used. The measurements were made on the 09-15 august week, Friday 13 august and Sunday 15 august, at 06,10,14,18 and 22 hours (Bistriceanu I., 2005).

According with the specialty papers for a model to approximate the best way a real water network it must assure:

- An average pressure inequality of ±1,54 mCA with a maximum inequality of ±5,12 mCA (Walski T.M., 1983);
- An inequality between the measured pressure and the simulated values wich can be of 3,51 mCA to 7,02 m (Cesario, L. and Davis.,1984).

It was chosen as a calibration condition the difference between the measured and simulated pressure in the four above mentioned points.
The results of the measured pressure value and simulated are shown in the tables below. In the last column, between brackets is noted the value of the simulated pressure at ground level keeping count that the posing depth of the pipes is of one meter, and the measured pressure was made at ground level, and in the other columns in brackets was noted the difference between the measured and simulated pressure

(Bistriceanu I., 2005)

Street Carpati – J7, where is a number of 11 blocs of 4 floors and a maximum height of 15 m.

Day / Hour	Measured value (m)				Simulated value (m)
	Monday	Wednesday	Friday	Sunday	
06	42,56 (2,43)	41,87 (1,74)	42,23 (2,1)	43,75 (3,62)	41,13 (40,13)
10	29,06 (-2,7)	28,32 (-3,38)	28,16 (-3,6)	29,85 (-1,91)	32,76 (31,76)
14	37,05 (-2)	37,82 (-1,23)	36,94 (-2,11)	38,17 (-0,88)	40,05 (39.05)
18	42,18 (2,05)	41,76 (1,63)	42,56 (2,43)	43,72 (3,59)	41,13 (40,13)
22	41,23 (-3,38)	42,05 (-2,56)	41,67 (-2,94)	43,12 (-1,49)	45,61 (44,61)

Street Locotenent Becherescu - J38, where is a number of 14 blocs of 2 and 4 floors with a maximum height of 15m.

Day / Hour	Measured value (m)				Simulated value (m)
	Monday	Wednesday	Friday	Sunday	
06	38,26 (2,82)	37,86 (2,42)	37,18 (1,74)	39,28 (3,84)	36,44 (35,44)
10	20,13 (-4,49)	20,81 (-3,81)	21,06 (-3,56)	22,57 (2,05)	25,62 (24,62)
14	32,17 (-4,44)	32,98 (-3,63)	33,28 (-3,33)	34,76 (-1,85)	37,61 (36,61)
18	31,93 (-3,51)	32,22 (-3,22)	32,68 (-2,76)	33,81 (1,63)	36,44 (35,44)
22	43,24 (0,44)	43,81 (1,01)	43,72 (0,92)	44,02 (1,22)	43,80 (42,80)

Street Unirii – J22, where is a large house concentration with a maximum height of 8,50m.

Day / Hour	Measured value (m)				Simulated value (m)
	Monday	Wednesday	Friday	Sunday	
06	38,28 (2,95)	37,68 (2,35)	39,21 (3,88)	39,56 (4,23)	36,33 (35,33)
10	19,75 (-4,25)	19,96 (-4,04)	21,36 (-2,64)	22,40 (-1,6)	25,00 (24,00)
14	32,70 (-4,28)	33,16 (-3,82)	32,62 (-4,36)	34,58 (-2,4)	37,98 (36,98)
18	31,18 (-4,15)	32,27 (-3,06)	31,76 (-3,57)	33,98 (-1,35)	36,33 (35,33)
22	41,15 (-2,16)	39,82 (-3,49)	39,21 (-4,1)	42,22 (-1,09)	44,31 (43,31)

Street Balciului – J44, which is the farthest away from the water tank where the houses have a maximum height of 8,50m.

Day / Hour	Measure value (m)				Simulated value (m)
	Monday	Wednesday	Friday	Sunday	
06	22,31 (1,14)	23,18 (2,01)	23,21 (2,04)	24,17 (3)	22,17 (21,17)
10	-	-	-	-	2,35 (1,35)
14	27,02 (-3,34)	26,14 (-4,49)	25,98 (-4,65)	28,21 (-2,42)	31,63 (30,63)
18	16,73 (-4,44)	17,16 (-4,01)	16,56 (-4,61)	19,13 (-2,04)	22,17 (21,17)
22	35,21 (-3,96)	34,68 (-4,49)	34,56 (-4,61)	37,12 (-2,05)	40,17 (39,17)

Studying the measured values for the pressures and the differences between the simulated values for the four junctions, the following were noticed:

1. For all the junctions the measured value at 6 AM is bigger than the value simulated. This situation can be caused because of a bigger water consum in the model than the one in reality.
2. The further the junctions are from the water tank, the bigger is thedifference between the measured pressure and the one simulated, therefor for junction 44 we have 7 measurements which are different from the simulated model with more than 4mCA.
3. At the measurements made at 10,14,18 and 22 hours in most cases the measured value is smaller than the simulated value, excepting the measurements made for junction 7 at 18 hours and for junction38 at 22 hours, which could mean bigger pressure loss in pipes because of not knowing exactly the roughness coeficient C Hazen-Williams;
4. For junction 44 the pressure could not be determined at 10 AM because the measurement instrument did not show any value at ground level.
5. The pressure differences between the measured and simulated value were between 0,88 mCA the smalest and 4,65 mCA the highest. This values are among the calibration conditions for the water network.

4. SIMULATION RUN

It was settled the period of simulation of 72 hours, tracing the values of the following parameters: juction pressures, water quality (the age of the water in pipes and junctions), flow speed through pipes and the water levels in tanks and reservoirs. It was chosen a longer period than 24 hours because it needs to be watched if the age of the water in pipes stabilizes and if the water level in tanks is the same in different days at the same time of day.

From the calculation breviary for the water necessary it is considered the fire flow a flow of 10l/sec at two simultaneous fires. To introduce it in the simulation model we have to change it into m^3/day (10 l x 60 sec x 24 hour = 14400 l = 14,4 m^3/day). To simulate the worst scenario I located the fire flow at the junction which is furthest from the water tank (J44).

Two limit situations were studied:

1. When the demand is the highest, between 10 and 11 AM and the pressure in junctions is the lowest and the speed through pipes is high.
2. When the demand is the lowest, between the hours 24 and 01 and the speed through the pipes low and the age of the water big.

By studying the data provided by the EPANET program after the simulation of the water network it can be observed the following (Bistriceanu I., 2005):

Junctions pressure Because in the Public Services of organization and functioning regulation for the town Bailesti, there is no stipulation which says the exact minimum pressure value which has to be maintained at any point in the network, I took as a study base for the water network behavior from the point of view of the pressure the reglementation of the water distribution Reglementation Agency for the service levels of Water Channel os the city Bucuresti by SC APA NOVA Bucuresti SA, which specifies:

- For the domestic clients who's houses aren't bigger than 2 floors, the plugging pressure should be of a minimum 10m at a flow of 9 l/min (540l/hour). For blocs with more than 2 floors the pressure at the last floor should be the same as the pressure at costumers that live at the last floor in 2 floor blocs.
- For commercial and industrial clients it will be assured a flow according with the agreement between them and the service supplier.

For studying the behaviour of the water system it was taken as a study base the minimum pressure at ground level of 10 m for the junctions which supply houses and 20 m for the junctions which supply blocs with four floors to assure the necessary pressure for the water column to reach the last floors of the blocs as well as the height of the water for fire preventing.

Problemes regarding pressure appear between 9 Am and 13 Pm at junctions J27, J40, J41, J42, J43, J44, J45, J46, J47 and J50 when the pressure falls below 10m.

Fig. 2 The global representation of the pressure in the network at 10 AM

Trying to rise the pressure in the junctions mentioned it was simulated the close of all the pipes wich leave left from the main supply pipe situated on street Vctoriei. The result was that not even in this situation the pressure at J43, J44, J45 and J46 junctions does not pass the minimum 10 mCA.

Water quality In this study the age of the water in pipes and junctions was analised. This parameter is important because the growth of the water age in pipes has associated with it some difficult situations as water temperature growth, the growth of the basic sediments, water colour, taste and smell changes, problems which appear because of the biological and chimical actions.

The data base of the water industry in the USA indicates a time average of holding the water in the distribution system of 1,3 days and a maximum of 3 days, based on a study of more than 800 water supply systems in the USA (AWWA and AWWARF 1992).

The highest value for this parameter is at pipe C29 at 3AM when the age of the water is of 15,25 hours.

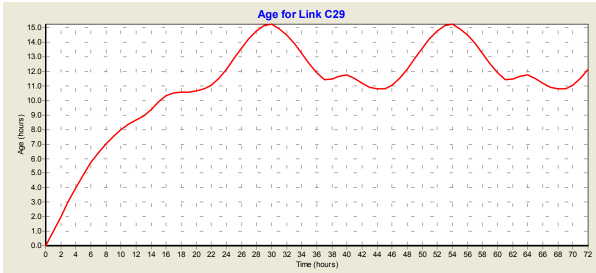

Fig. 3 Water age representation in the C29 pipe

Even if the speed and the direction of the flow can change very much in the water distribution system, there are higher or lower speed limits which indicate (Cesario, L., 1995):

- A speed higher than 2,13m/s can lead to great losses through friction and a high risc of destroying the valves and elbow because of the effect of water hammer;
- A speed lower than 0,15m/s shows the overdimensioning of pipes and can lead t problems because of the sediments at the valves and there can be ruined the water quality.

Studying the results of the simulation at 10Am when the flow speed through pipes is the biggest, because of high demand, you can see that there are six pipes C11, C15, C20, C29, C43 and C62 where the speed is under the minimum and a pipe C39 where the speed is over the maximum.

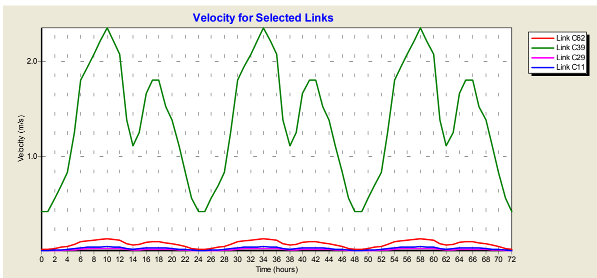

Fig. 4 Water velocity pipes C11, C29, C39 and C62

Water input from the reservoir and tank It was investigated if there are pressure variations (water level) in the tank at the same hour in a day (10 Am) for the three simulated days. Because the level is the same there is no problem regarding the exhausting of the water in the tank after a larger number of working days.

5. THE ACCOMPLISHMENT OF THE CASE STUDIE OBJECTIVES

After studying the existing situation of the water distribution network and the discussions with the management of the town Bailesti the following types of problems were settled which will be analised by modeling the water distribution network and by simulating the flow of the water through the network (Bistriceanu I., 2005).

Understanding of how the system operates and training water system operators. The implemented model is already working as a tool for the network operators which use it to model any situation in the network that might appear like: Pipe breakdowns, Water supply problems, pump breakdowns and other.

Assessing the carrying capacity of the existing system. The pipe network can face the flow at the maximum water demand, the only problem is on the pipe portion on street Victoria situated between street Unirii and Street Progresului where it was obserd an underdimensioning of it. Assessing levels of pressures at critical points within the system and assessing the available range of pressure at customer connections. As it was shown there are problems regarding the necessary pressure at the edge junctions between 10AM and 12AM, problems which can not b solved easily in the actual situation. Based on the results of the simulation, the existing water distribution netwrok can be divided in more preesure zones. This thing may lead to optimizating the hydraulic grade of water distribution and power economyat the pumping stations.

Daily operational use. The projects data base and the results are available at the water tanks in town Bailesti and serve for maintaining the water supply network.

The impact on pump stations of a power outage. It was simulated the systems alimentation with 3, 2 and 1 pump. The results indicated that maximum water demand period it is necessary for all the 4 pumps to work to assure the supply at the demanded rate. The problems regarding negative pressures appeared in junctions when running with 3 pumps at 10AM, when running with 2 pumps at 9 AM and running with 1 pump at 6,38 AM. After the study it came to the conclusion that there must be bought another two pumps that can be installed on the trestles that are not used to prevent the situations when, because of breakdowns, the water supply would be lower than the demand.

Assessing the available range of pressure at customer connections. A study was made for dividing the existing water network in several pressure zones. This shoul lead to optimizing the distribution pressure and from hee, to lowering water losses and power economy at the pumping stations.

Real time control of the system. There will be made several model with different demand values so they are evaluated, one by one, to be as close as possible to the real sitation, at one moment, and each of them should offer a good ability for resolving problems regarding a long-term simulation and water quality simulation.

Identifying the impact of future population growth and major new industrial or commercial developments on the existing system. At Bailesti town hall was initiated a study regarding the population growth and the industrial possibilities for the next 20 years, study which is needed to identify the necessary of water for that perspective.

Assesing the curent or future problem situations. The problem situation in supplying water to the costumers is mainly because of low pressures in some points of the network at a maximum demand. To solve this situation there are in study two possibilities:

1. Making a water repumping station, situated paralel with the water pipe on street Victoriei situated between street Unirii and street Progresului which would rise the pressure for the low pressure zone.
2. Replacing the pipe with a diameter of 125mm from street Victoria starting from street Unirii until the end with a pipe with a diameter of 200 mm.

Proiecting the system entries to face future demands. The total water flow that can be supplied from the 16 pumps paced in the water diggings is of 2380mc/day bigger than the maximum water demand in an year, therefore are no problems in satisfying the future water demands. Still it was intended to buy pumps for the other 4 water diggings which are not equipped, to prevent the situation in which if 3 pumps would breakdown it would be less than the maximum water demand.

Optimising the work programme. The possibility of modifying the work programme for the maintainance and fixing staff was studied so it should be the same as the peak demand period.

Assessing the effects of rehabilitation techniques. As it was shown just by replacing some pipes, a very important problem concerning the pressure at the edge junctions can be solved. It is still in study the evaluation of the water network functioning in case of replacing other pipes too, with other diameters and from a PVC material, which have a pressure loss coefficient lower than other materials, and settling the necessity of making the replacements.

Assessing the functioning of the system for different ages of the elements. Because the water network of the town Bailesti is older than 30 years the pressure losses caused by the deposits along the pipes are important. In an ideal situation all the pipes should be changed with pipes made from PVC.

Assessing the financial investment for future developments. It is still in study the financial investment and maintainance staff if there is to make a nea repomping station or to replace the pipes on the streets mentioned. The town hall of Bailesti is trying to obtain funds from the European Community for the rehabilitation of the water distribution network, one of the arguments being the cas study from the present paper. Determinating the age of the water in the system. As it was shown in the chapter about processing the results of the simulation, the age of the water in pipes is not an important problem because the highest value from this point of view is of 15,25 hours, a normal value according with the international studies.

Assessing the flow rate. As it was shown before, by assessing the flow rateit was determined the underdimensioning of the pipe portion on street Victoriei situated between street Unirii and street Progresul, and from here the problems regarding the edge junctions.

6. CONCLUSIONS

There are a lot of direct and indirect benefits by applying the advanced capacities of network modeling. The software can be used on-line in the operational day by day program. It can also be applied in strategic operations planed to investigate a large range of operational problems. As a general rule, the best results are obtained in the strategic operational planning and in projecting studies because decisions like this govern the short – term operational decisions.

Simulating the functioning of a water distribution network for planning the management of water supply and distribution systems from a hydraulic and water quality point of view has many advantages which include:

- Efficient data collecting, processing and postprocessing, advanced matemathical model, low losses, high operational security and economical maintainance.
- The analysis of all the operations of the water network, the interaction between subsystems, the balance between different sources, identifying different ranges were could be made economies;
- The optimization of total energy costs for the network, including the pumping costs and water production costs (energy and treatment costs).
- The modeling is used to produce more efficient operating strategies, to fix the existing problems like low pressures, low flow rates and water quality, etc. The allocated operational constraints can be investigated and can lead to identifying the programs and operational strategies for overcoming the problems;
- Unpredicted events analysis to model the effects and actions of the correcting plan in the case of major netwrok problems;
- Modeling leads to a better understanding of the network. Modeling shows the features of the network, which were not known before;
- The performing of some optim programming studies supply scenarios with low operational costs which can be compared with the existing operations. The results sugest new methods of exploiting the network and the comparison with the existing operations allows a benefit analysis regarding the costs of proposed operational changes.

In the case of the water distribution system of the town Bailesti it was made a model on which it was simulated the functioning of the water distribution system in different conditions, having as a study base the worst scenario when the demand of water is the highest. On the basis of the obtained results it was made a plan of development and rehabilitation of the water distribution system of the town Bailesti for the next years which include: the replacement of the cast iron pipe on street Amza Pelea; the replacement pipe portion on street Victoria starting from street Unirea to the end, because of the underdimensioning or projecting a station of repumping, parallel with the portion of pipe on street Victoria, situated between streed Unirea and street Progresul, for rising the pressure at the normal levels in all the demand points throughout the town; buying two spare pumps at the pumping station from the water supply station and four spare pumps for water diggings, for preventing the failure of one of the actual pumps and restricting water supply throughout the town; making an analysis of population growth and industry development in the town for forecasting the influence they might have over the water consumption and the possibility of solving them.

REFERENCES

1. American Water Works Association and American Water Works Association Research Foundation. *Water Industry Database: Utility Profiles*. Denver, Colo.: AWWA (1992);
2. Bistriceanu I., *“Applications of the hydraulic and water quality network simulations”*, Scientific Bulletin, University „Politehnica” of Bucharest (2005);
3. Cesario, L. *“Modelling Analysis and Design of Water Distribution Systems”*, American Water Works Association (1995);
4. Cesario, L. şi Davis. *„Calibrating network models”*, Journal of the American Water Works Association (1984);
5. Rossman L. A., *„EPANET 2”* . Users manual, (2000);
6. Walski T. M., Chase D. V., Savic D. A., Grayman W., Beckwith S. şi Koelle E. “*Advanced Water Distribution Modeling and Management”,* ed. Haestad Press Waterbury, CT USA (2002);
7. Walski T.M. *„Technique for calibrating network models”*. ASCE Journal of Water Resources Planning and Management 109(4):360-72, (1983);