PERIODICA POLYTECHNICA SER. CIVIL ENG. VOL. 35, NOS. 1–2, PP. 17–25 (1991)

WATER SUPPLY NETWORK MODEL FOR OPERATION CONTROL

P. DARABOS and F. GÖCZE

Department of Water Supply and Sewerage
Technical University H–1521, Budapest

Received: December 5, 1991

Abstract

The well-known methods of elaboration of optimal operation strategies of water supply systems are based on quasi-stationary simulation. The aim of substituting models is the significant decrease of the simulation's time and memory demand. In the first applications the determination of the parameters of the substituting model was based on the result of the analysis made on the detailed system. This substituting model was suitable to work out the optimal operation for this system but it was not generalizable. The new method of elaboration of substituting models is based on a new structure of the network and consumption, and the regression analysis to calculate the parameters of the model. The identification of the substituting models is based on the comparison of the typical characteristic curves and on the comparison of the simulation results of the original and the substituting models.

Keywords: water supply, modelling, operation control.

Introduction

The well-known methods of elaboration of optimal operation strategies of water supply systems are based on quasi-stationary simulation. The aim of substituting models shown in this paper is the significant decrease of simulation time and memory demand. This aim can be achieved by the simplification of the models.

From the point of view of the operation management the most significant information is the following:

- discharge and changes of level and volume of the tanks and reservoirs;
- operation parameters of pumps (delivery, pressure, efficiency, etc.)

(DEMOYER - HOROWITZ, 1975; SHAMIR - HOWARD, 1977; FÀY, 1982; MÉSZÁROS, 1982; BOZÓKY-SZESZICH - DELI - DARABOS, 1983,1986). Obviously, in substituting models this information should be described precisely and others - for example the network - can be simplified.

In the technical literature there are several suggestions and examples for this method. They can be classified into two different trends:

- 'black box' models considering the behaviour of the system in a stochastic way without hydraulic correspondences,
- preserving the original model structure a significantly reduced network model is formed, while the hydraulic parameters of the substituting branches are determined from measured data.

For the first method there are some examples in AIRTF and in the paper of DEMOYER and HOROWITZ. For the second method we can present mainly Hungarian examples.

The theoretical necessity of substituting models arose in the research of the Department of Water Supply and Sewerage at the Technical University Budapest, some ten years ago. On the one hand, this was caused by the experience on the time demand of simulating water supply networks, on the other hand, by the progress of the research on the optimization of operation.

The structural elements of the substituting models were developed in this research program (BOZÓKY-SZESZICH - DELI, 1980). In the first application (MÉSZÁROS, 1982) the water distribution system contained one reservoir and one feeding point. The determination of the parameters of the substituting model was based on the results of the analysis made on the detailed system, using some of its typical data. This substituting model was suitable to work out the optimal operation for this system, but the results were not generalizable.

Model Development

According to our experience there are two main steps of model development:

- selection of the model type based on the analysis of the detailed system (structure, number of parameters);
- determination of the parameter values based on the analysis of the detailed system and/or operation data.

The analysis of the whole system can be carried out by computer analysis of the detailed model. The detailed (traditional) model contains the most branches of the real system and its analysis requires the hydraulic and geometric data of the reservoirs, the pumps, the pipes, etc.

The main steps of the system analysis are the following:

- creation of the detailed model of network, on the basis of the up-to-date operation data (registered according to the instructions of the Unified System of Utility Registers).
- supervision of operation register and collection of experience;
- examination of the spatial and temporal changes of consumption;
- creation of the detailed model of the system;
- comparison of the calculated characteristic curves with the operation points measured at the feedings. The identification of the detailed model;
- simulations for identification. Examination of interactions the of elements. Examination of the consumption.

The first step of substituting model development should be the allocation of the main water delivery directions between the feeding points and the reservoirs (main pipes). Several substituting model versions can be formed by transformation of these directions into substituting branches. The differences between the model versions are in the consideration of consumption. There are two ways of modelling consumption:

- concentrated on nodes,
- distributed along branches.

The choice between these two possible ways are determined by two requirements in substituting models:

- the accuracy of the results,
- the simplicity of the model.

Obviously, if a model with concentrated consumption gives the required accuracy, the application of the more complicated one has no reason. Accuracy should be examined by identification. A water distribution system and one of its possible substituting models are shown in *Fig. 1*.

Specification of Model Parameters

Characteristic curves determined by detailed model or precise measurements can just be approximated by the substituting models. Therefore the descriptive equation system of the substituting model should be adapted to the equation system of the detailed model, accepted as reference standard. It is obvious that the application of the method of regression analysis is suitable to solve this problem. In the regression analysis we determine those parameters of the chosen substituting model, which give the best approximation of the reference standard characteristic curves.

Supposing permanent flow conditions the Kirchoff laws are valid for the substituting models as well. In *Fig. 1* we present a model as an exam-

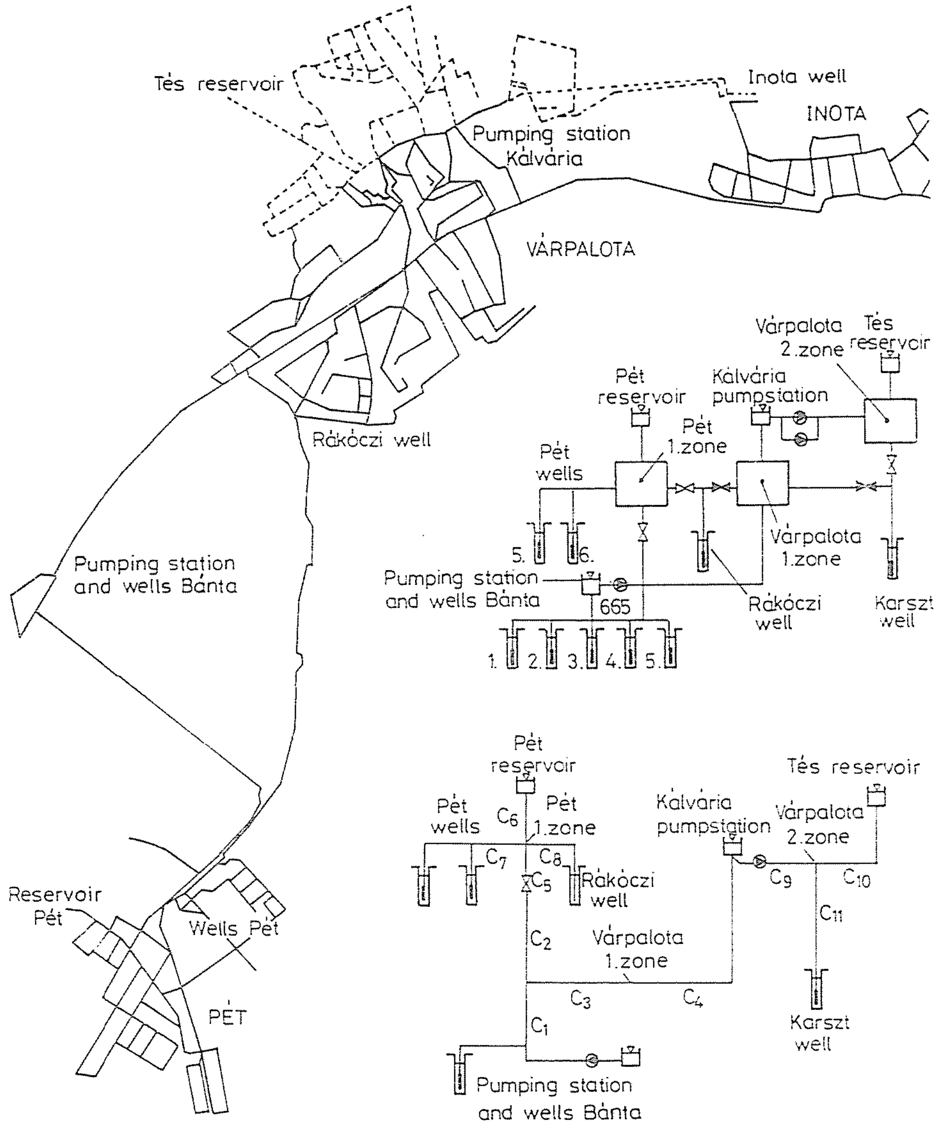

Fig. 1.

ple. Pressure and delivery data of the feeding points, reservoir levels, water delivery and consumption data of different operation states are determined by hydraulic calculations made on the detailed model. The unknown loss factors C_i of the substituting branches are calculated from the equations below, according to the 2nd law of Kirchoff:

$$H_{BA'} - C_1(Q_{BA'} + Q_{B5}) - C_3(Q_{BA'} + Q_{B5} - Q_{9tz}) + C_4(Q_{KM} - Q_{KA'}) = H_{KM}$$

$$H_{1.9tz} + C_2 Q_{9tz} - C_3(Q_{BA'} + Q_{B5} - Q_{9tz}) + C_4(Q_{KM} - Q_{KA'}) = H_{KM},$$

$$H_{PK} - C_7(Q_{P5} + Q_{P6}) - C_6 Q_{PM} = H_{PM},$$

$$H_{2.9tz} - C_5 Q_{9tz} - C_6 Q_{PM} = H_{PM},$$

$$H_{RK} - C_8 Q_{RK} - C_6 Q_{PM} = H_{PM},$$

$$H_{KA'} - C_9 Q_{KA'} + C_{10} Q_{TM} = H_{TM},$$

$$H_{KK} - C_{11} Q_{KK} + C_{10} Q_{TM} = H_{TM},$$

where:
$H_{BA'}$ -Bánta pumping station, output absolute pressure
$Q_{BA'}$ -Bánta pumping station, discharge
Q_{B5} -Bánta well No.5., discharge
$H_{1.9tz}$ -Slide valve No.9, absolute pressure on the side of Bánta
$H_{2.9tz}$ -Slide valve No.9, absolute pressure on the side of Pét
Q_{9tz} -Slide valve No.9, discharge
H_{KM} -Kálvária reservoir, absolute level
Q_{KM} -Kálvária reservoir, discharge
$H_{KA'}$ -Kálvária pumping station, output absolute pressure
$Q_{KA'}$ -Kálvária pumping station, discharge
H_{TM}-Tés reservoir, absolute level
Q_{TM} -Tés reservoir, discharge
H_{KK} -Inota well, output absolute pressure
Q_{KK} -Inota well, discharge
H_{PM} -Pét reservoir, absolute level
Q_{PM} -Pét reservoir, discharge
H_{PK} -Pét wells, output absolute pressure
Q_{P5} -Pét well No.5., discharge
Q_{P6} -Pét well No.6., discharge
H_{RK} -Rákóczi well, output absolute pressure
Q_{RK} -Rákóczi well, discharge
The unknown loss factors were determined by linear regression method of several variables.

Identification of the Model

The feeding points of the distribution system are defined by their real physical characteristics in substituting models. Accordingly, the most proper way to identify substituting models is the comparison of typical characteristic curves. Appropriate is the comparison of the curves bordering the operation zone from below and above.

The characteristic curves are usually determined by calculation in the process of network analysis. For these calculations the identified, detailed model is used.

The characteristic curves of the feeding points calculated by the substituting model and by the detailed model are described in *Fig.2*.

Notation:

MOP - Measured operating point
DML - Detailed model, the lower bordering characteristic curve
DMH - Detailed model, the upper bordering characteristic curve
SML - Substituting model, the lower bordering characteristic curve
SMH - Substituting model, the upper bordering characteristic curve.

The identification can be continued by the comparison of results of simulation, made on the detailed and on the substituting model. Considering the limited extent of this paper we not go into details about the results of these calculations, but we note that no significant difference between the calculations was found either in level of reservoirs or in water delivery of feeding points.

Authenticity of Substituting Models, Limits of Applicability

For the application of identified substituting models, data measured in the real system are required. All data which are significant in creation and maintenance of the parameters of substituting models must be known. Supposing operation management, also measuring and registering of data are indispensable. By the process of identification it can be determined whether the shape and the physical behaviour of the substituting model conforms to the real system to a satisfying degree.

In the course of operation management there may be some structural changes in the real water distribution system, which are not significant but permanent (for example new connections, change of consumption routine, etc.). These changes may gradually modify the behaviour of the real system concerning the original state, which formed the basis of the identification.

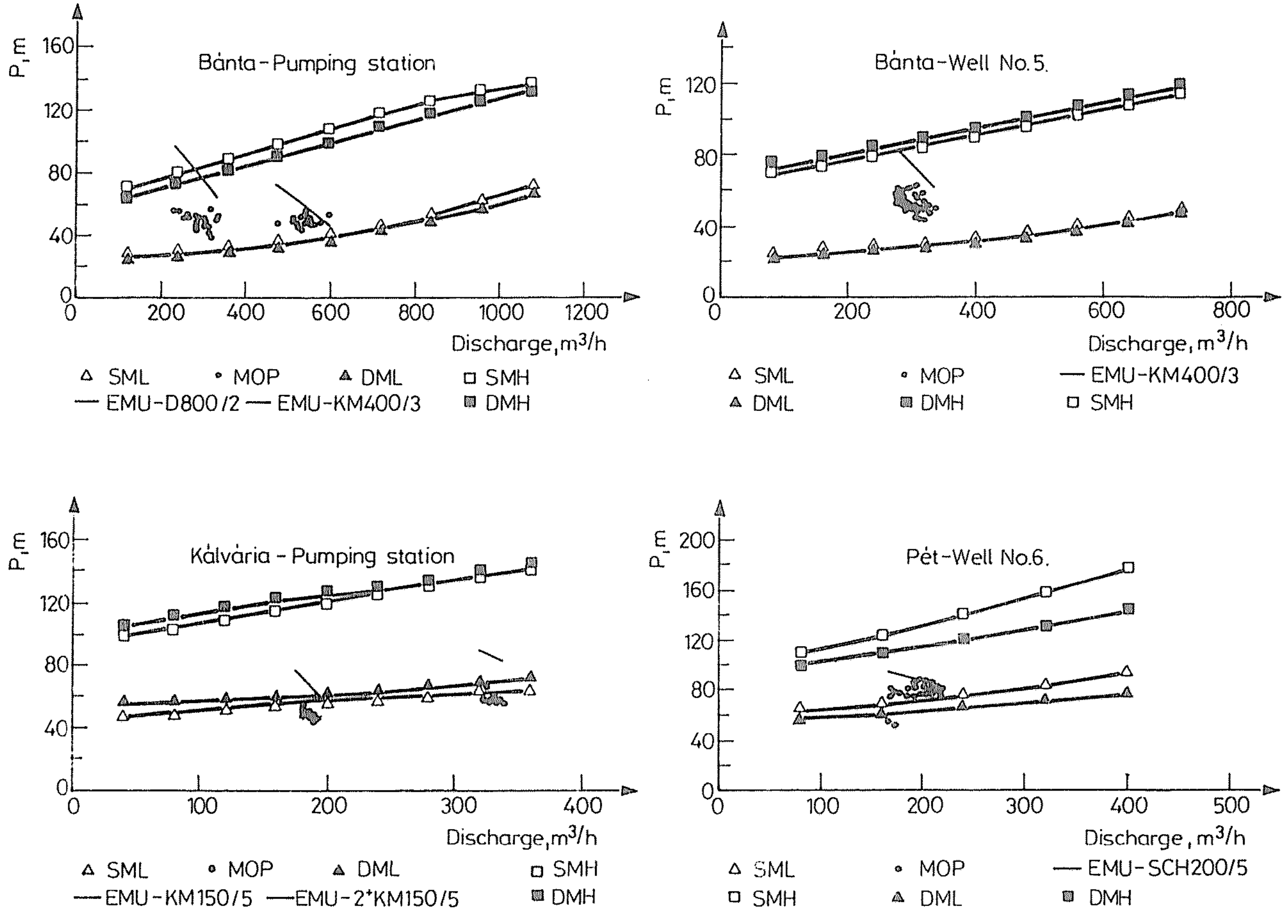
Bánta-Pumping station
P, m
160
120
80
40
0
0
200
400
600
800
1000
1200
Discharge, m3/h
△ SML • MOP ▲ DML □ SMH
— EMU-D800/2 — EMU-KM400/3 ■ DMH
Bánta-Well No.5.
P, m
120
80
40
0
0
200
400
600
800
Discharge, m3/h
△ SML • MOP — EMU-KM400/3
▲ DML ■ DMH □ SMH
Kálvária-Pumping station
P, m
160
120
80
40
0
0
100
200
300
400
Discharge, m3/h
△ SML • MOP ▲ DML □ SMH
— EMU-KM150/5 — EMU-2*KM150/5 ■ DMH
Pét-Well No.6.
P, m
200
160
120
80
40
0
0
100
200
300
400
500
Discharge, m3/h
△ SML • MOP — EMU-SCH200/5
□ SMH ▲ DML ■ DMH

Fig. 2.

Therefore the parameters of substituting models must be maintained according to the measured data. In recent computer management systems recursive, parameter estimating algorithms can be applied for this job.

Each structural change of the system, for example, construction of new main pipes, new feedings, new reservoirs, requires different sorts of solution. In each case, it must be examined whether the structure of substituting model should be changed or not. If a rectification is necessary, a new substituting model must be developed and identified, as it was presented above.

The described substituting models, arising from the generation of the parameters by regression method, minimize the effects of the random errors of the measured data, during the maintenance of the parameters (supposing normal distribution of errors). However, the permanent errors of the measured data must be detected and cleared separately. In recent computer management systems this problem is solved by credibility tests of the measured data. Besides tests, verifying hydraulic investigations of the detailed model can also help to detect errors.

Another fundamental point of the application of substituting models is the definition of consumption. It can be fixed that the simpler the model is, the less problem the definition causes; therefore the developing of simple models is required in this respect, too.

Summary

Substituting models give an opportunity for the fast control and planning of operation. The radical increase of the execution velocity of the simulation program can be achieved by drastic decrease of the model extent. Simplified, substituting models can be applied without having considerable inaccuracy in estimation, concerning the elements of the system that are essential in operation.

References

FÁY, CS. (1982): AIRTF - Felszínalatti vízkészletből táplált vízművek technológiai folyamatai automatikus irányítási rendszerének tervezési ajánlásai (Aspects of Planning the Automatic Controlling Systems of Technological Processes, Operating in Water-works Supplied by Subsurface Water Resources). *Vízügyi Műszaki Gazdasági Tájékoztató,* 136.sz., VIZDOK, Budapest, 1982. (in Hungarian).

BOZÓKY-SZESZICH, K. - DELI, M. (1980): A vízelosztás rekonstrukciója tervezésének néhány matematikai alapja (Some Mathematical Bases of Planning the Reconstruction of Water distribution). MHT. Víz- és Csatornaművek Rekonstrukciója c. szeminárium. Budapest, 1980. (in Hungarian).

BOZÓKY-SZESZICH, K. – DELI, M. – DARABOS, P. (1983): Kistérségi vízművek tervezésének és üzemeltetésének néhány kérdése (Some Questions of Planning and Running Small Regional Water Works). MHT. 4. Országos Vándorgyűlés. Győr, 1983. (in Hungarian).

BOZÓKY-SZESZICH, K. - DELI, M. - DARABOS, P. (1986): Vízellátó rendszerek ellenőrzése és tervezése üzemszimulációval (Planning and Controlling Water Supply Networks by Operation Simulation). MHT. 6. Országos Vándorgyűlés. Hévíz, 1986 (in Hungarian).

DEMOYER, R. – HOROWITZ, L.B. (1975): Macroscopic Distribution System Modelling. American Water Works Association, July 1975.

MÉSZÁROS, G. (1982): Vízellátó hálózatok üzemeltetésének optimalizálása (Optimization of the Operation of Water Supply Networks). Kutatási jelentés (Research report). BME VVI. Vízellátás - Csatornázás Tanszék, 1982. (in Hungarian).

SHAMIR, U.F. – HOWARD, C. (1977): Engineering Analysis of Water Distribution Systems. American Water Works Association September 1977.

Address:

Péter DARABOS and Ferenc GÖCZE
Department of Water Supply and Sewerage
Technical University, H-1521 Budapest, Hungary