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MODELLING OF WATER DISTRIBUTION SYSTEMS USING EPANET 2.2 SOFTWARE

INTRODUCTION AND SET OF EXERCISES

Bialystok 2021

Bialystok University
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ISSUE I

Publisher:
Agencja Wydawnicza Ekopress

eISBN:
978-83-962816-3-0

NARODOWA AGENCJA
WYMIANY AKADEMICKIEJ

Project financed by the National Agency for Academic Exchange
as part of the Academic International Partnerships Program

FOREWORD

This script is intended for students of courses which cover the material on computer simulation of water distribution systems. The set of exercises is intended to assist in acquiring the skills of building the model in the EPANET software, while entering the necessary data and evaluating the obtained calculation results. It was not intended to be another version of the EPANET program manual. The book covers the most important, practical information on computer simulation of water distribution systems, principles of performing basic operations in the program and exercises at a basic level for those who are new to the EPANET software. Each exercise includes a discussion of the problem, offers a method of implementation and presents the scope of the report.

In order to use this script, you must have the working knowledge of hydraulic calculations, which are covered in many available textbooks.

We are pleased to present you with the first edition of the script. Please, take our apologies for any errors that may occur. Also, we would be grateful for any comments and suggestions so that we can improve future editions of this book (j.dawidowicz@pb.edu.pl).

Authors

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1. INTRODUCTION

The water supply system is one of the most important elements of the technical infrastructure of urban and rural areas. It should ensure water supply in appropriate quantity and quality, under required pressure at any time convenient for the recipient. Water supply requires the proper design of individual components of the system, which is associated with the performance of calculations, whose purpose is to determine the flow rate through individual water pipes, the selection of pipe diameters, the calculation of pressure losses in pipelines and the amount of pressure in the network nodes. Another important task is to design the right layout of pressure zones and the right location of e.g. zone pumping stations, pressure control valves and possibly water tanks. Numerical models and related hydraulic calculations are one of many steps in the process of designing, development or operation of water supply systems. Computer modelling of water supply systems allows to improve the structure of the water supply network, ensure appropriate pressure, abandon inappropriate investments, and optimize the operation of water supply pumping stations. The results of the hydraulic analysis performed with the help of numerical models are increasingly used by water supply companies in order to support pre-design and operational decisions.

2. ORGANIZATION OF THE BOOK AND DESIGNATIONS

The The first part of the book contains basic information on the numerical modelling of water distribution systems. It describes the methodology of representing the structure of the water supply network in numerical calculations and the principles of calculating water supply networks with ring structure. It also covers the most important assumptions for hydraulic calculations of the water distribution system. Then, it provides basic information on the EPANET software.

The next part includes a set of exercises on modelling water distribution systems using the EPANET program, which are addressed to students of various technical faculties, with particular emphasis on environmental engineering. The manual contains a set of elementary exercises for people who are taking their first steps with the program.

This booklet focuses on the design of new water distribution systems and addresses the basic issues of modelling the existing systems. Building a model of the existing water distribution system necessitates obtaining situational-elevation plans of the area with the routed network of pipes, disposal of data on the daily amount of water supplied to the system, the location of water intakes by recipients, the characteristics of water intake variability in individual nodes of the network, the flow through selected water supply pipes and the amount of pressure in the nodes necessary for the model calibration. These issues are beyond the scope of the present study.

The following designations are used in the script:

L – length of the water pipe design section [m],

D_{in} – internal cross-sectional diameter of the water pipe [mm],

DN – nominal diameter of the water pipe [mm]

Δh_{lin} – height of linear pressure loss [m],

Δh_{loc} – height of local pressure loss [m],

V_{ave} – average jet velocity in the cross section of the pipe [m/s],

Q_S – efficiency of the water supply source [m^3/h; l/s],

Q_i – inflow and/or outflow rate from the node [l/s],

Q_r – design flow rate [l/s],

q_n – demand (+) or supply (-) rate at a network node [l/s],

e_l – network graph arc, pipe section of a water supply network,

π – pi,

N_n – number of nodes in the water network model,

N_k – number of design sections of the water network,

N_r – number of rings in the water network model,

ZN_i – sets of pipes connected at individual nodes of the water network model,

ZP_r – sets of pipes forming elementary rings in the water network model,

S1, S2 – designations of water supply sources,

i, j – indicators of water network nodes,

k, l – design section indices for water networks,

H_n – pressure height at the node [m].

Extremely important information that will prevent a calculation error, often difficult to trace

Important information to bear in mind that will save a lot of time or make work with the model easier

3. FUNDAMENTALS OF NUMERICAL MODELLING OF WATER DISTRIBUTION SYSTEMS

Computer technology has been used for many years in the calculation of water distribution systems, mainly because of their considerable complexity and the increase in requirements regarding the quality and lead time of design studies. The first computer programs appeared in the second half of the 20th century (Adams, 1961; Epp & Fowler, 1970; Hoag & Weinberg, 1957; Ormsbee, 2006). Since then, there have been noticeable advances in the technical capabilities and facilities of the latest water distribution system calculation programs (Rossman, 2000), which increasingly make use of GIS (Kwietniewski, 2013; Shamshi, 2005; Taher & Labadie, 1996) and CAD (Walski et al., 2003) capabilities. However, this does not change the fact that the correct implementation of calculations requires a sound knowledge of theoretical issues, which are at the core of algorithms used in calculation programs, a thorough evaluation of the obtained results and the correctness of the applied technical solutions. Currently, a very popular program for the calculation of distribution systems is EPANET (Rossman, 2000).

3.1. MAPPING OF THE WATER DISTRIBUTION SYSTEM STRUCTURE FOR NUMERICAL CALCULATIONS

The simplest way to represent the structure of water supply system is the graphical scheme showing the location of water pipes, water reservoirs, pumping stations, water tanks and other objects (Fig. 1). Unfortunately, the above method does not suffice to represent the structure of water supply system in numerical calculations.

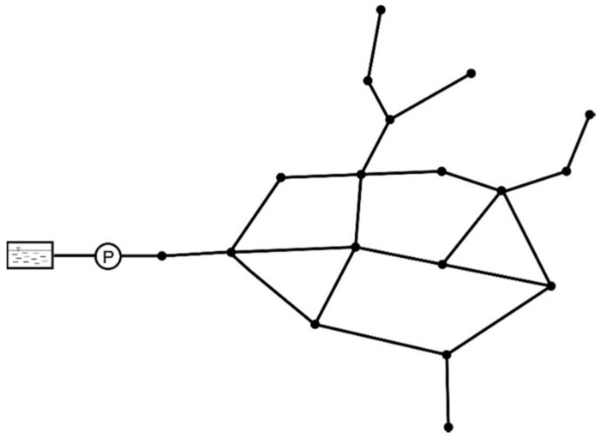


Fig. 1. Mapping the structure of a water supply system by means of a scheme

Numerical calculations of water distribution systems require the representation of the geometric structure of the network in the computer's internal memory. For this purpose, graph theory is commonly used (Deo, 2017; Boulos, 1991; Chandarshekar & Kesavan, 1972). A water distribution system is understood as a set of graph arcs corresponding to water supply network pipes and other elements described by a linear object (e.g. in EPANET these are water supply pumping stations, control valves), and graph nodes describing terminations and connections of linear objects. The nodes in the model can act as water intake or storage points. The graph makes it possible to reproduce the structure of the water supply network in a way that makes it possible to perform numerical operations on them (Fig. 2).

Graph G is defined as follows:

- a graph is a set G consisting of two subsets V (vertices or nodes) and E (edges)

$$G = \{V,E\}$$

- $V = \{v_1,...,v_n\}$ is a finite subset of all the nodes of the graph $v_1,...,v_n$
- $E = \{e_l = <v_i,v_j>, l = 1,...m\}$ is a finite subset containing pairs of $<v_i,v_j>$ of all arcs v_l connecting the nodes of the graph.

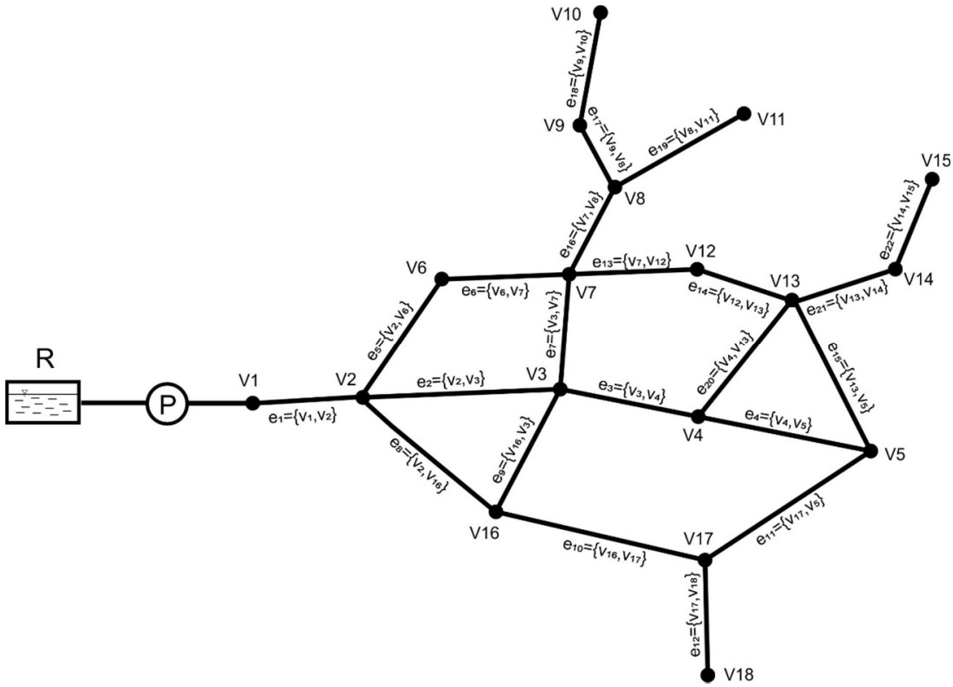


Fig. 2. Mapping the structure of a water supply system using a graph

Accordingly, the dataset for hydraulic calculations and the obtained results consists of two tables containing information on nodal and linear objects. The vertices of the graph correspond to water network nodes (Junctions), water supply sources (Reservoirs) and storage objects (Tanks), and the arcs of the graph to the pipes (Pipes), water supply pumping stations (Pumps) or control valves (Valves). The nodes are usually identified by their assigned numbers or names, linear objects are described by the identifiers of the two nodes that delimit them.

3.2. MATHEMATICAL MODEL OF THE WATER DISTRIBUTION SYSTEM

Water distribution systems for hydraulic analysis are described by a mathematical model in the form of a system of non-linear equations derived from two basic laws of hydraulics: mass balance in the nodes and energy balance in the rings (Bhave i Gupta, 2006; Lansey i Mays, 2000).

Hydraulic calculations of water supply systems are performed under the following assumptions:

- intakes at connection points are replaced by concentrated intakes at network nodes,
- for specific demand conditions, the network operates under steady-state conditions.

The following assumptions are made for the established conditions in order to perform the hydraulic calculation of water distribution systems:

- the flow rate along the design section between the restriction nodes is constant,
- the average flow velocity along the design section is constant,
- the diameter of the water pipe within the design section does not change,
- the roughness coefficient is constant over the design section.

The laws of mass balance at nodes and energy balance at rings, which are the basis for modelling water distribution systems, are as follows:

- **law I**, the so-called continuity condition for the network nodes says that the algebraic sum of inflows, outflows and water intakes for each node is equal to zero, i.e:

$$\sum_{e \in ZN_i} Q_i + q_n = 0 \tag{1}$$

- **law II** says that the algebraic sum of pressure losses in each closed ring is equal to zero; it is assumed that the positive sign is taken by hydraulic losses in sections where the flow direction is consistent with the adopted direction of circulation in the ring, the negative sign by the opposite direction of flow:

$$\sum_{e_l \in ZP_r} \Delta h = 0 \tag{2}$$

where: Δh is the number of pressure losses in the pipeline u_l belonging to the given ring ZP_r.

The mathematical model of a water distribution system with a ring structure is a system of nonlinear equations that consists of (Biedugnis, 1998):

- $\mathbf{N_n}$ – l equations for the nodes resulting from continuity conditions at the nodes,
- $\mathbf{N_r}$ equations for the rings resulting from equilibrium conditions in rings.

Based on the laws of mass balance in nodes and energy balance in rings, two additional equilibrium conditions apply to water networks:

- **condition of equality of supply and intake** says that the algebraic sum of all nodal demands q_n in the network and the inflow rate from all supply sources is equal to zero, assuming that the inflows to the network are taken into account with a minus sign:

$$\sum q_n + \sum Q_S = 0 \tag{3}$$

- **condition of interoperability of sources** says that the difference in elevations of the pressure lines of the two supply sources Δh_{S1-S2} is equal to the sum of the pressure drops in the network pipes forming part of any path connecting these sources:

$$\Delta h_{S1-S2} - \sum_{S1}^{S2} \Delta h = 0 \tag{4}$$

In equation (4) a drop in pressure height Δh for individual sections S1 to S2 is designated with {+}, if the flow in the pipe u_l is in the corresponding direction, or {-} when in the opposite direction from S1 to S2. It is assumed that the reservoir S1 has a higher elevation of the pressure line than the reservoir S2.

There are many methods that are used for calculating the system of equations describing multi-ring water distribution systems. The computational process referred to as hydraulic balancing is based on an iterative search for a solution that satisfies the equilibrium laws for the nodes and rings of the network. The first and the most important method is the one developed by Hardy Cross in 1936 (Cross, 1936). Subsequent work brought the gradient method (Todini & Pilati, 1987), the hybrid method (Hamam & Brameller, 1971) and a method referred to as the "Newton Loop-Node Method" (Osiadacz, 1987). In EPANET, Todini's gradient method was used.

3.3. WAYS OF CALCULATING WATER DISTRIBUTION SYSTEMS

In the EPANET program, computer simulations can be carried out in two ways: for one selected time interval, the so-called Single Period Analysis, and over a longer period of time, i.e. the Extended Period Analysis.

The single-period analysis is most often conducted for the operating conditions of the water distribution system, which are the basis for dimensioning the diameters of water supply pipes, i.e. the hours of maximum water demand. These may also be other distribution conditions, e.g. for maximum water transit to the tank, for minimum water demands. Accordingly, the values of water demands at the nodes should correspond to the calculated ones for the analyzed conditions, as they are not corrected by the multiplier from the water intake histogram in the settlement unit.

Extended Period Analysis simulations are usually run for one day with varying water demands at nodes, parameters of pumps or valves, and taking into account the filling or emptying of water from tanks. If the analysis of tank cooperation with the water supply network is to be made, it is more beneficial to apply simulations longer than one day. The time steps used in an extended period analysis can be set by the user, but a typical step length is one hour.

4. BASIC INFORMATION ON THE EPANET SOFTWARE

EPANET a computer program for simulating water distribution systems, is available on the U.S. Environmental Protection Agency (EPA) website at https://www.epa.gov/water-research/epanet. EPANET is free software that can be freely copied and distributed.

The EPANET program is designed to be run in the Windows environment. Instructions for the program can be found on the EPA website, which provides information on installing, running, building the model, and simulating water distribution systems (Rossman, 2000). EPANET allows to work on one water distribution system model at a time.

In EPANET, we use a full stop, not a **comma**, to separate the whole number from the fraction.

4.1. EPANET PROGRAM AFTER START-UP

After starting the EPANET program, the following elements are displayed on the screen (Fig. 3):

- a bar at the top with the name and version of the program on the left (e.g. EPANET 2.2) and icons to close, minimize and maximize the window on the right,
- a menu bar containing a system of drop-down options allowing access to the majority of the program's functions,
- a toolbar containing icons associated with the most frequently used program functions (Fig. 4),
- work area with two windows:
  - Network Map – the main model editing window, which allows to create a design and view the data of objects that make up the network model,
  - Browser – a window consisting of two tabs:

- Data – allows select and view individual objects in the model (Fig. 5a),
- Map – allows to view the computed results in the Network Map window displayed next to the individual model objects. Moreover, individual model objects can be marked with colors depending on defined value ranges and corresponding colors (Fig. 5b).

- status bar – containing information on the method for inserting the length of linear model objects, the adopted flow units and the current state of the simulation.

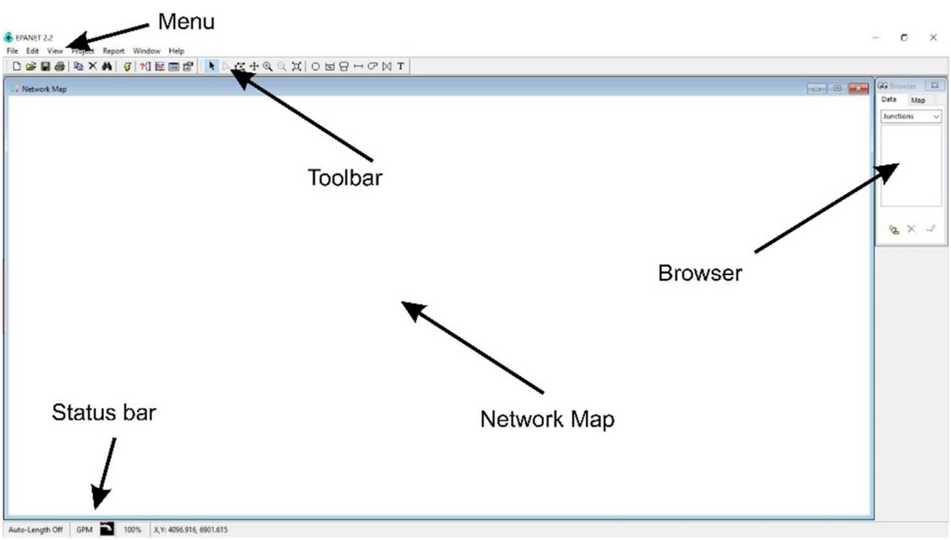


Fig. 3. View of EPANET program after start-up

The toolbar (Fig. 4) contains icons for numerical model objects that are not available in the program menu.

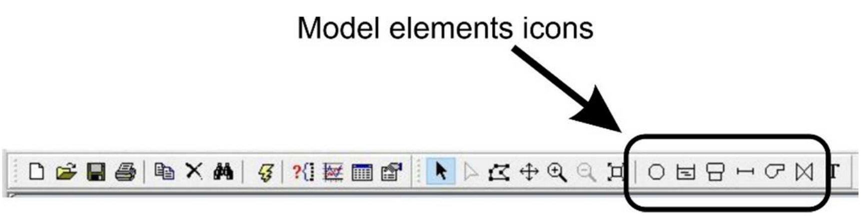
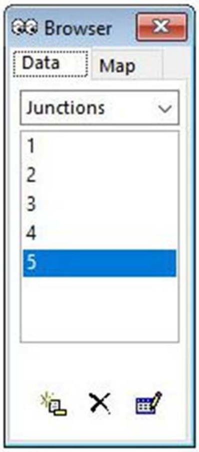


Fig. 4. Toolbar with marked icons of EPANET model objects

a) 

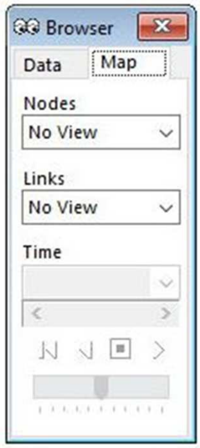
b) 

Fig. 5. Browser window for searching model objects and displaying the results on a map a) Data tab; b) Map bar

4.2. EPANET MODEL OBJECTS

Physical model objects in EPANET are inserted into the Network Map using the following toolbar icons:

 nodes, pipe junctions points in the network that connect linear objects, which may be water pipes, pumps or control valves; nodes are points of concentration of water intakes by the users of the water distribution system (BaseDemand),

 reservoirs, facilities supplying unlimited quantities of water to the water distribution network,

 tanks, they have an internal capacity and fill up at the pump capacity higher than the demands in the nodes, they return water to the network at demands in the nodes higher than the supply from the pump, during operation the water level in the tank also changes,

 pipes, elements for the distribution of water through the water supply area,

 pumps,

valves (control valves), there are several types of valves in the program. It should be noted that the above option is not used for inserting pipeline valves used for closing water pipes and non-return valves, which are included in the water pipe properties.

4.3. UNITS OF MEASUREMENT AND DEFAULT PARAMETERS FOR CALCULATIONS

A new project should begin with establishing the units of measurement, the formula used to calculate linear pressure losses and the default values for the parameters of the model objects.

Units of measurement are determined by the following steps:

1. In the program menu select Project >> Defaults... (Fig. 6):

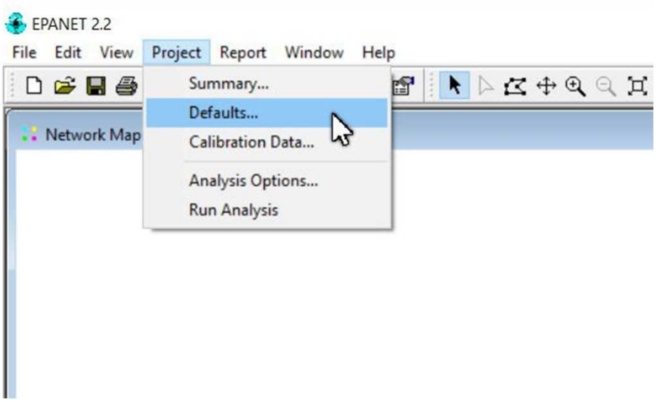


Fig. 6. Selection of options Project >> Defaults....

2. After selecting the menu option Defaults a window with three tabs is displayed:
   - **ID Label** – prefixing model object identifiers,
   - **Properties** – assigning default values to parameters of model objects,
   - **Hydraulics** – determining, inter alia, units of measurement and a formula for computing linear pressure losses.

3. In the window Defaults select the tab Hydraulics, next change the option Flow Units into LPS and Headloss Formula into D-W (*Darcy-Weisbach* formula) (Fig. 7).

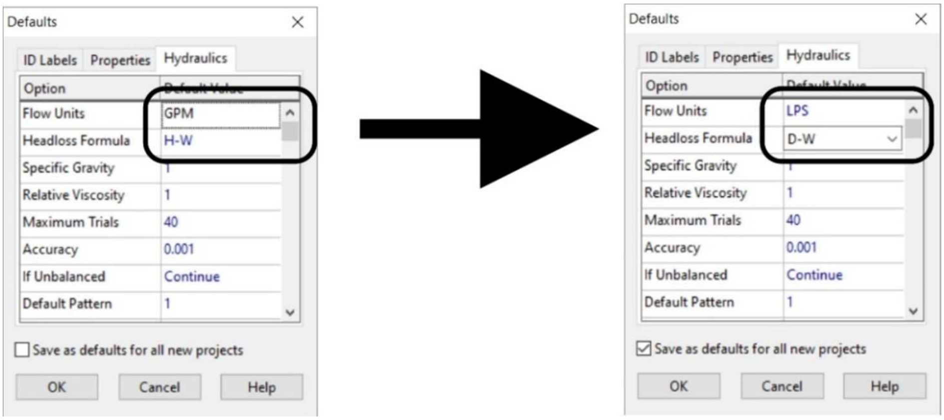


Fig. 7. Determining units of measurement and the formula for calculating linear pressure losses

By default, EPANET is set to American units of measurement, i.e. flow rate is expressed in gallons per minute (GPM), length in feet (ft), water pipe diameter in inches (in), and pressure in pounds per square inch (psi). By changing the flow rate unit to liters per second (LPS), all other units are changed to metric, i.e. individual variables are expressed in the following units: pressure – msw (meters sea water), diameter – mm, length – m, height – m (m.a.s.l.).

Three formulas are available in EPANET for computing linear pressure losses. In this script, the Darcy-Weisbach formula is used.

After changing the units of measurement to metric, it is worth modifying the values of the default parameters. The default parameters are adjusted to US units. For example, the default diameter of a water pipe in the US version is 12 inches. After changing the units to metric, the program will read this value as 12 mm diameter, which will certainly result in calculation errors. It advisable to insert a default diameter value, e.g. 110 mm. It is also crucial to change the roughness of the pipe if you intend to carry out calculations using the Darcy-Weisbach formula. Default parameters can be changed in settings Project >> Defaults in the tab Properties (Fig. 8).

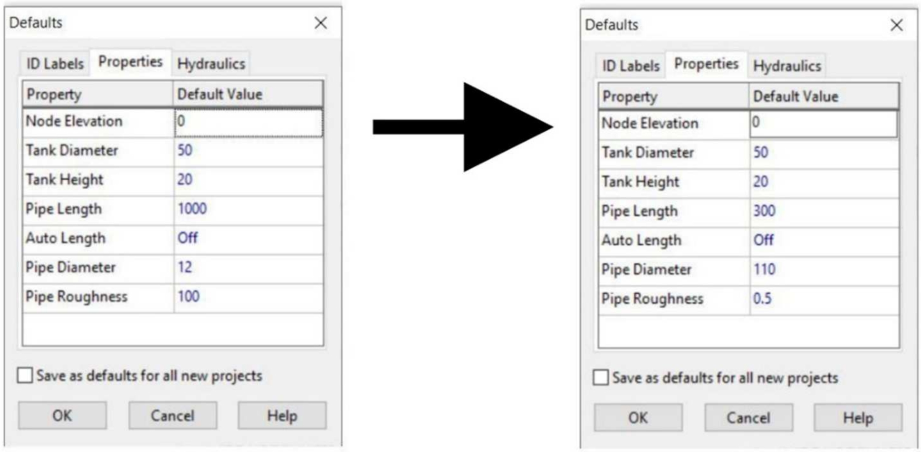


Fig. 8. Setting default parameters of model objects

After installation, EPANET uses numerical identifiers, but model object designations can be alphanumeric. It is a good practice to use identifiers that specify the type of object by its name. This makes the model more readable. In the design settings Project >> Defaults the ID Labels tab, you can define proper prefixes for the corresponding element types (Fig. 9).

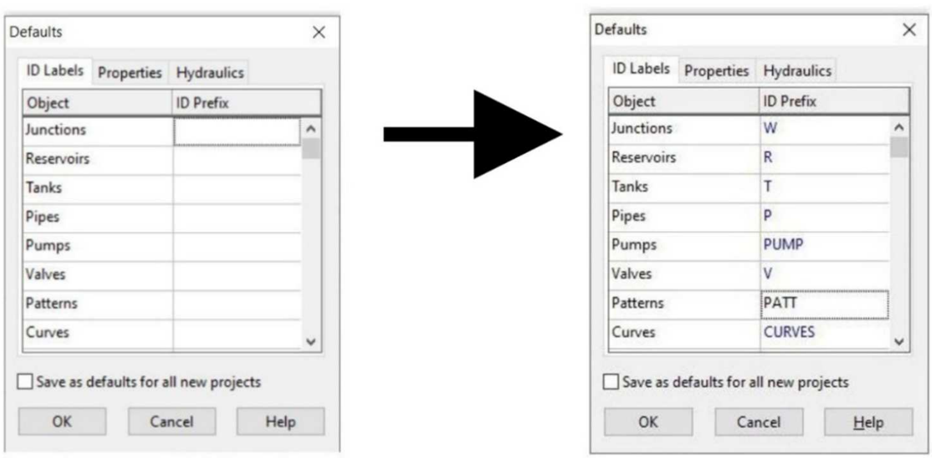


Fig. 9. Setting prefixes of model object identifiers

4.4. REPEATABLE AND OPERATION-FACILITATING ACTIVITIES

4.4.1. Recording of computation results using functions Edit >> Copy To...

The results of computations in EPANET are not automatically saved in dedicated files. After the simulation has been run, the form and scope of the results to be saved must be defined before drawing up the tables.

The results can be saved for the whole network separately for nodes and linear objects, e.g. water pipes, but for a selected time step. Another form is to save results for one selected object but for all time steps. This makes it possible to analyze the operation of an object during the whole simulation period, usually a day.

The results are put in a tabular form by selecting the menu option Raport >> Table or by clicking the toolbar icon .

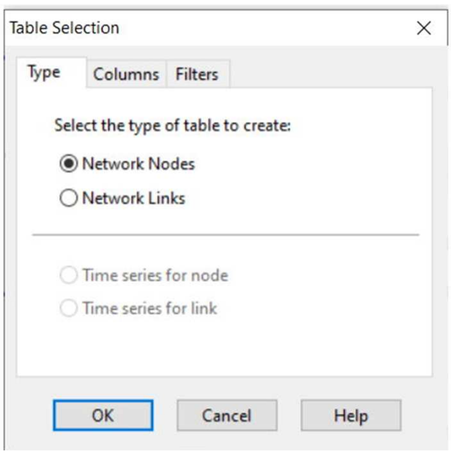


Fig. 10. Okno wyboru typu i zakresu tabeli z wynikami

In the Type tab of the Table Selection window, choose in the upper part of the window whether you want to make a table for nodes or for linear objects. In the lower part of the window, you can make a table for one object, but for the whole simulation period. This option is active if simulations have been carried out over a longer period of time.

In the Columns tab of the Table Selection window, define which parameters of the results should appear in the table (Fig. 11).

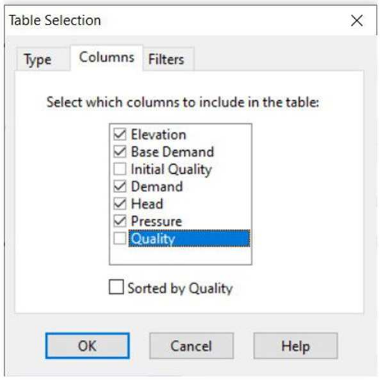
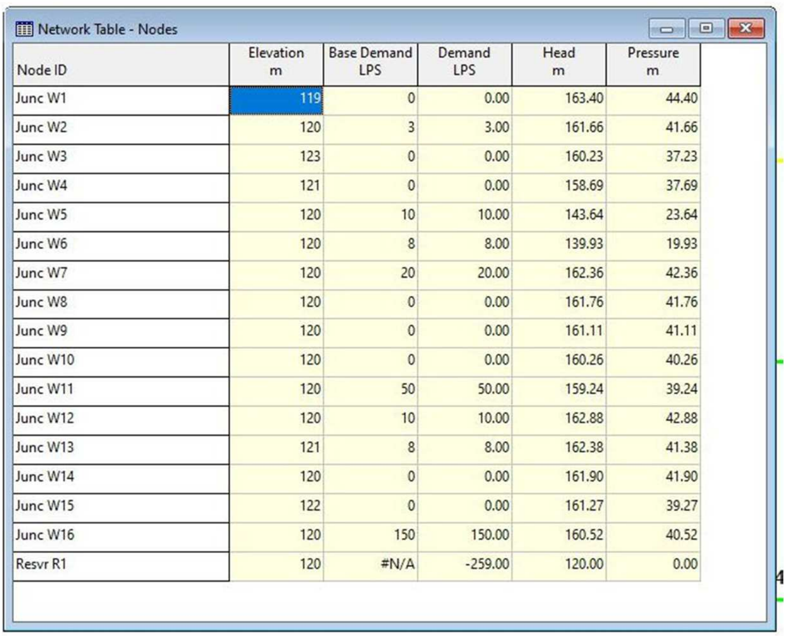


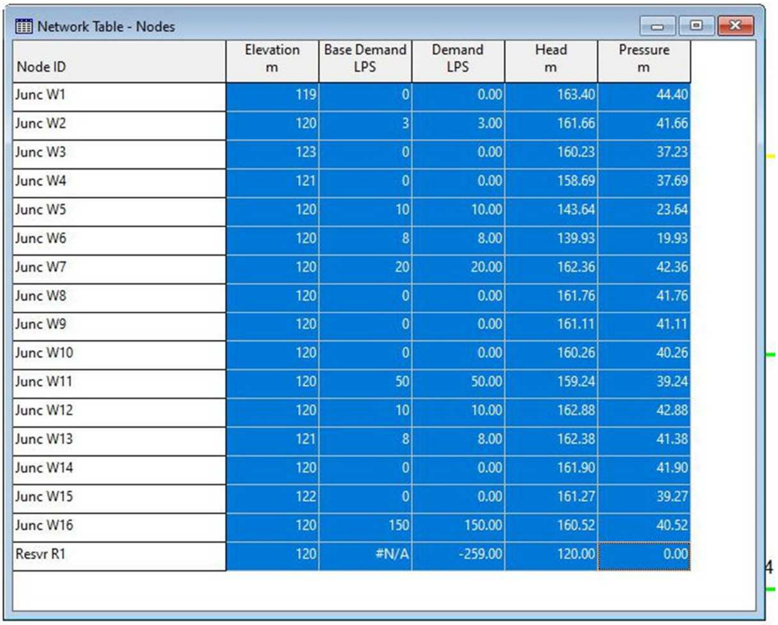
Fig. 11. Selection of columns in the results table

After accepting the table type and the list of columns, the window with the computation results appears as shown in Fig. 12. The results in the table are saved by copying them to the clipboard or to a text file. The table cells marked in blue are copied, therefore in order to save the whole sheet with the results, click on the cell with the inscription Node ID or in the case of linear objects – Link ID. By this means, the whole table with the results will be selected (Fig. 13).



Node ID	Elevation m	Base Demand LPS	Demand LPS	Head m	Pressure m
Junc W1	119	0	0.00	163.40	44.40
Junc W2	120	3	3.00	161.66	41.66
Junc W3	123	0	0.00	160.23	37.23
Junc W4	121	0	0.00	158.69	37.69
Junc W5	120	10	10.00	143.64	23.64
Junc W6	120	8	8.00	139.93	19.93
Junc W7	120	20	20.00	162.36	42.36
Junc W8	120	0	0.00	161.76	41.76
Junc W9	120	0	0.00	161.11	41.11
Junc W10	120	0	0.00	160.26	40.26
Junc W11	120	50	50.00	159.24	39.24
Junc W12	120	10	10.00	162.88	42.88
Junc W13	121	8	8.00	162.38	41.38
Junc W14	120	0	0.00	161.90	41.90
Junc W15	122	0	0.00	161.27	39.27
Junc W16	120	150	150.00	160.52	40.52
Resvr R1	120	#N/A	-259.00	120.00	0.00

Fig. 12. Table with a node score worksheet



Node ID	Elevation m	Base Demand LPS	Demand LPS	Head m	Pressure m
Junc W1	119	0	0.00	163.40	44.40
Junc W2	120	3	3.00	161.66	41.66
Junc W3	123	0	0.00	160.23	37.23
Junc W4	121	0	0.00	158.69	37.69
Junc W5	120	10	10.00	143.64	23.64
Junc W6	120	8	8.00	139.93	19.93
Junc W7	120	20	20.00	162.36	42.36
Junc W8	120	0	0.00	161.76	41.76
Junc W9	120	0	0.00	161.11	41.11
Junc W10	120	0	0.00	160.26	40.26
Junc W11	120	50	50.00	159.24	39.24
Junc W12	120	10	10.00	162.88	42.88
Junc W13	121	8	8.00	162.38	41.38
Junc W14	120	0	0.00	161.90	41.90
Junc W15	122	0	0.00	161.27	39.27
Junc W16	120	150	150.00	160.52	40.52
Resvr R1	120	#N/A	-259.00	120.00	0.00

Fig. 13. Table with all worksheet cells to be copied

After selecting the cells to be copied in the results table, choose the option Edit >> Copy To..., in the menu, which opens a window for selecting the place where the cells should be copied (**Fig. 14**).

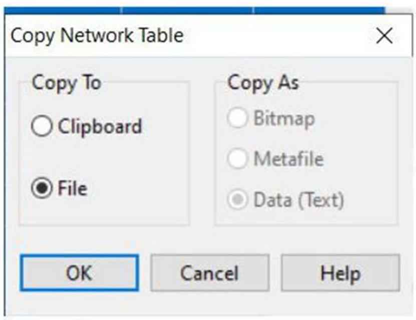


Fig. 14. Selecting the destination for copying results from the table

If you select a text file on disk, a standard Windows window opens for saving files (**Fig. 15**).

The Filters tab of the Table Selection window allows to define rows in the results table according to the criteria that the selected output variables must meet.

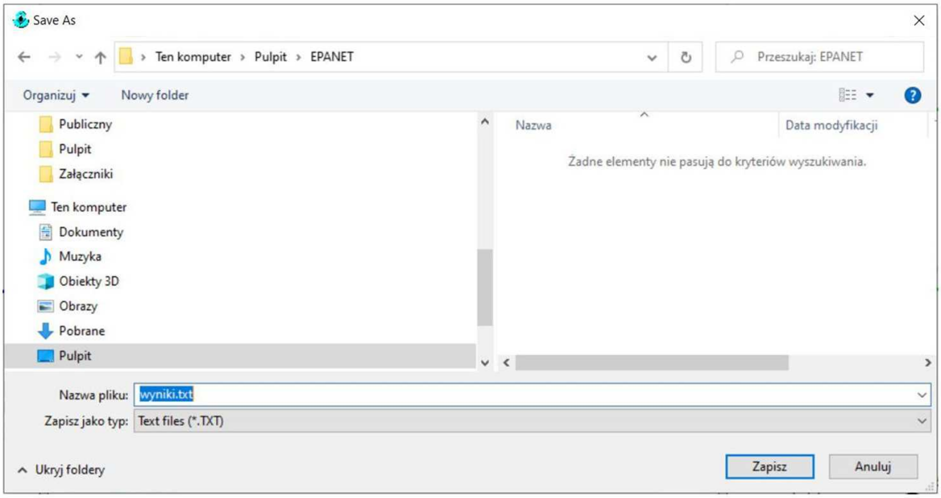


Fig. 15. Windows window for saving files to disk

When creating a table of linear objects, proceed in the same way as for nodes.

4.4.2. Recording drawings with functions Edit >> Copy To...

The diagrams from the Network Map window, as well as all diagrams produced as results, can be saved to the clipboard or to a graphic file on disk. Two file types are available in EPANET: Bitmap and Metafile. The window from which you want to save the drawing must be active. Then select the menu option Edit >> Copy To... (Fig. 16).

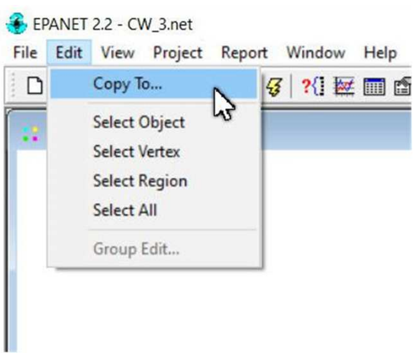


Fig. 16. Select Edit => Copy To... to save the computation results

This opens a window to select where the drawing is to be saved and the file format (Fig. 17). If a file is selected, the standard Windows window for saving files opens.

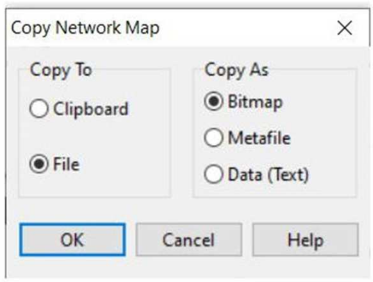


Fig. 17. Selection of options

4.4.3. Changing the map display parameters

In order to facilitate the handling of objects in the Network Map window, you can enlarge the nodes using Map Options. To do this, select the View >> Options... menu option and the Nodes tab. Increase the size of the displayed node objects (Fig. 18).

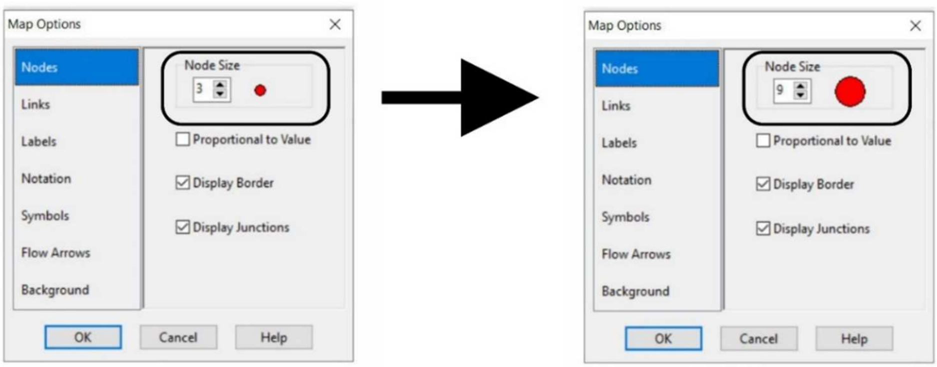


Fig. 18. Enlarging node size in map display options

Next, in the Map Options window, select the Links tab and increase the thickness of the displayed linear objects (Fig. 19).

After selecting the Notation tab, choose options for displaying node and link identifiers and increase the font for the displayed identifiers (Fig. 20).

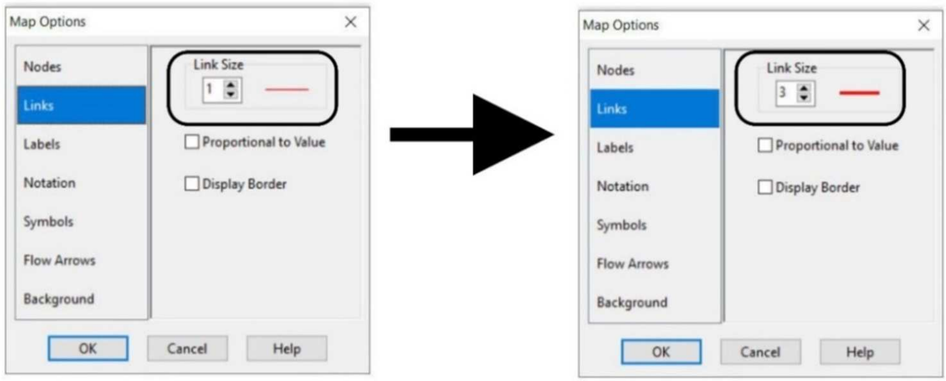


Fig. 19. Increasing thickness of linear objects in map display options

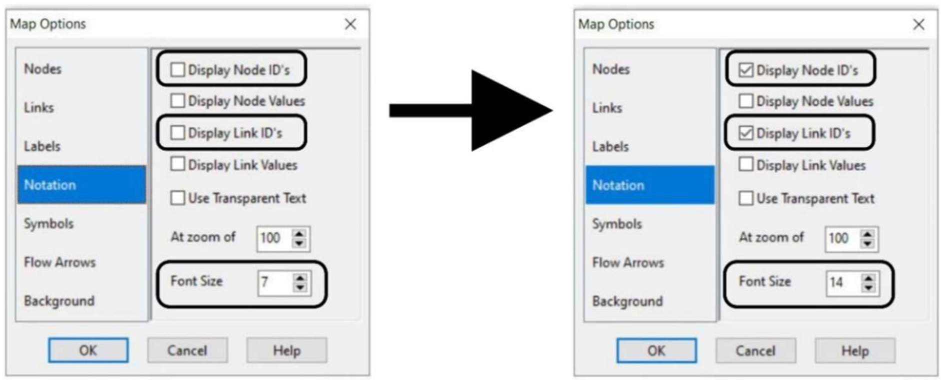


Fig. 20. Options for displaying node and link identifiers and increasing the font of the displayed identifiers

4.4.4. Editing the parameters of the selected object group

If you want to change the same input parameters in more objects of the same type, you can use the group editing function. You can select the whole Select All area in the Network Map window, or a part by clicking Select Region (**Fig. 21**). After the area is selected, the Group Edit... option is activated, which opens the window where it is possible to change parameters for a bigger number of junctions (**Fig. 22**) and linear objects (**Fig. 23**).

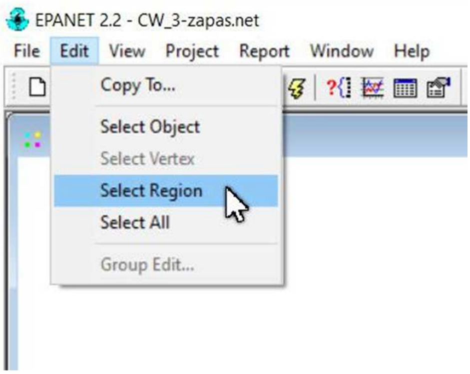


Fig. 21. Options for selecting the area for joint editing of objects

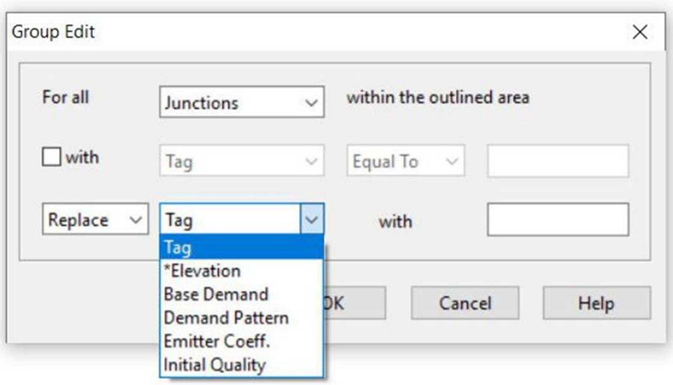


Fig. 22. Selection of the parameter to be jointly edited for the selected junctions

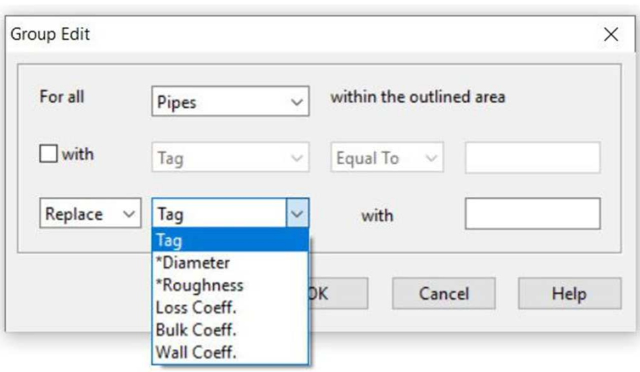


Fig. 23. Selection of the parameter to be jointly edited for the selected pipes

5. PRACTICAL EXERCISES IN THE EPANET PROGRAM

5.1. INSERTING OBJECTS AND COMPLETING THE PARAMETERS OF THE WATER DISTRIBUTION SYSTEM MODEL

5.1.1. Introduction to the exercise

The first exercise is dedicated to beginners in EPANET. The construction of the model starts with placing the required objects in the Network Map window. The model consists of nodal and linear elements. Nodal objects are inserted first, as linear objects are always bounded by two node elements. The next step is to fill in the corresponding parameter values in the individual objects. A sample water supply system will be created, which will be used in the following exercises.

5.1.2. Implementation of the exercise

In order to carry out the exercise, the following steps should be followed:

1. **Setting the display of objects and model identifiers**

The method for displaying objects on the map and identifiers is determined according to the methodology described in chapter 4.4.3.

2. **Insertion of water supply wodę**

To do this, click the icon on the toolbar Reservoir (Fig. 24).

Fig. 24. Inserting a Reservoir object

When the Reservoir icon is selected, the cursor changes to the viewfinder to indicate the location of the object (Fig. 25).

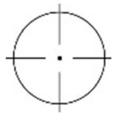


Fig. 25. Pointing cursor for inserting objects Reservoir and Junction

Use the pointing cursor in the Network Map window to indicate the location of the water source and then insert the object by single-clicking the left mouse button. Be careful not to insert multiple objects in one place by clicking the mouse button repeatedly. They often overlap, which is difficult to see in the Network Map window, and redundant objects generate data errors.

There is no Undo. function in EPANET. If you accidentally insert objects that are not required, you must delete them. To do this, they can be highlighted on the map or selected in the Browser window. It is good practice to save the project file under a new name after several steps of the task have been completed, and especially when making major adjustments to the model. Project versions can be saved as: Project v.1.1, Project v.1.2, etc. This will allow, in the case of an error, to quickly return to the previous stage by loading the previously saved file.

 If you do not want to insert any more objects, it is most convenient to select the following icon on the toolbar Select Object.

3. Inserting nodes

To do this, select the icon in the toolbar Junction (Fig. 26)

Fig. 26. Inserting the Junction object

Using the cursor in the shape of a viewfinder (Fig. 25), indicate the locations of the nodes in the Network Map. window. In the exercise you should insert 16 nodes forming a branched network with three parallel routes of water pipes: one initial node acting as a branch and three branches of 5 nodes each. In the Network Map window you should get the effect shown in Fig. 27.

> If the node is in the wrong place, it can be moved by selecting it with a single mouse click and moving it while holding down the left mouse button.

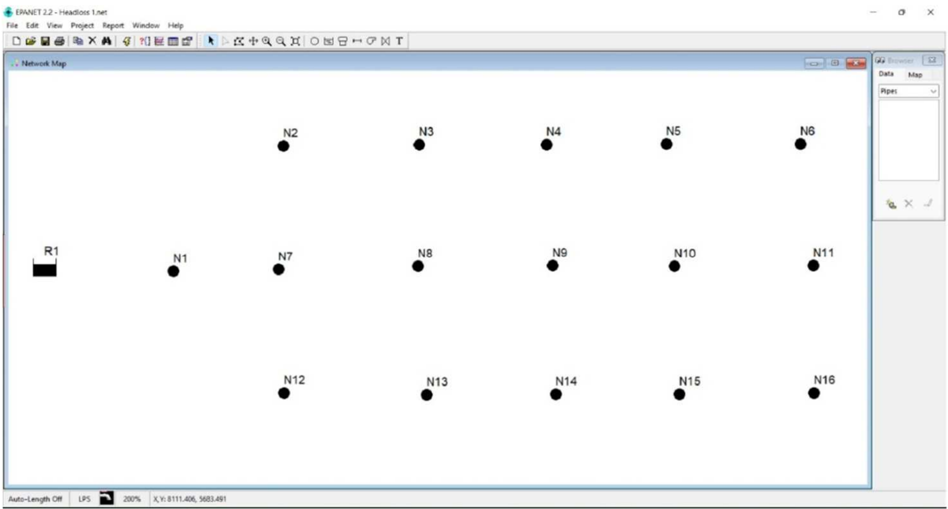


Fig. 27. The reservoir and nodes of the example water supply network model with set map display options

> The numbers of nodes and other objects in each category depend on the order of insertion into the model.

4. Inserting pumping stations

To insert a pumping station, click on the icon in the toolbar Pumps (Fig. 28).

Fig. 28. Selecting the Pumps icon on the toolbar

The cursor turns into a cross +. Select the starting node with the cursor, which in this example is the water supply source Reservoir.

The cursor then turns into a pencil connected to the starting node by a dashed line (Fig. 29). Point the pencil to the target node and insert the pump by single-clicking on the node.

> When inserting pumping stations into the model, it is essential to maintain the correct order of the selected limiting nodes. The first node must always be a water supply source or a network node connected with the source.

Fig. 29. Inserting a pump into a model

The inserted pump must point with its outlet in the direction of the pumping of the water in the system (Fig. 30).

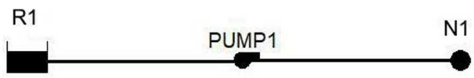


Fig. 30. Inserted pumping station between the reservoir R1 and the node N1

After inserting the pump, you will get the network diagram shown in Fig. 31.

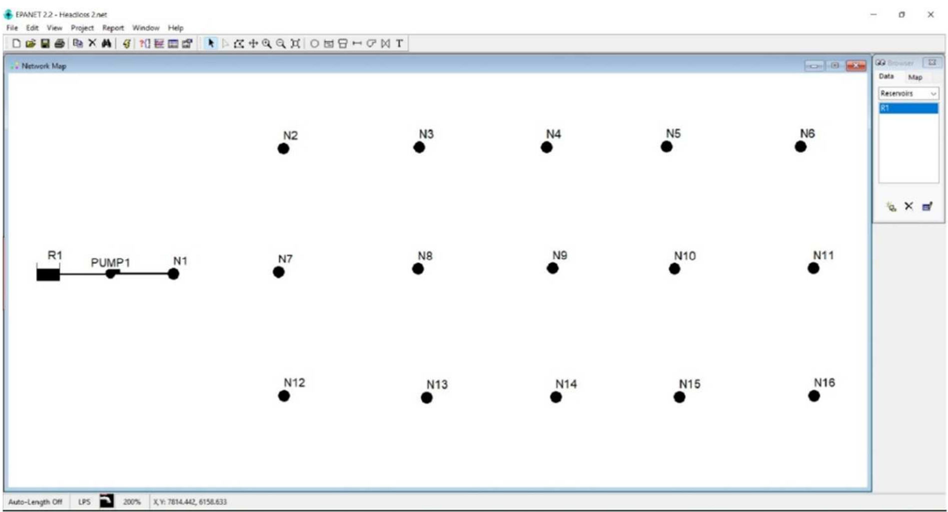


Fig. 31. Network model with PUMP1 pumping station inserted between R1 and N1 nodes

5. Inserting water pipes

To do this, click the icon on the toolbar Pipe (Fig. 32)

Fig. 32. Inserting water pipes

The cursor turns into a cross +, which is used to select the starting node. The cursor then turns into a pencil connected to the starting node by a dashed line, in the same way as when inserting a pump (Fig. 29). Point the pencil to the target node and insert the water pipe by single-clicking on the node. When inserting water pipes, the order of the nodes is arbitrary. The exceptions are pipes with a non-return valve, where the flow can only take place from the start node to the end node. Insert the water pipes so that you get the network diagram as shown in the Fig. 33.

! When inserting water pipes, the order of node selection is arbitrary. An exception are pipes with a non-return valve, where the flow can only take place from the start node to the end node. The non-return valve is inserted in the Initial Status parameter in the water pipe data.

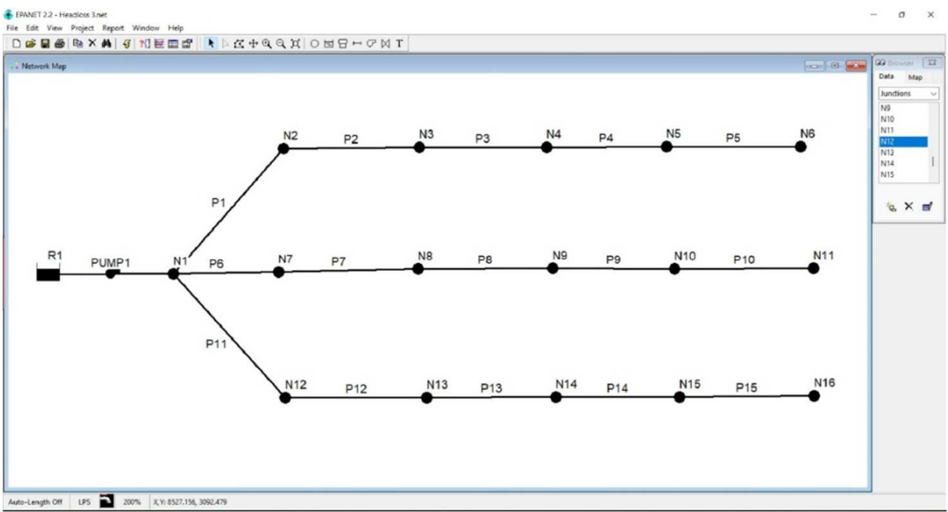


Fig. 33. Diagram of an example water supply system

6. Creating pump characteristics

The pump model requires an assignment of pump characteristics, which must be created. To do this, in the Browser window, on the Data tab, select Curves in the drop-down box (Fig. 34). Select the button at the bottom of the window to add new objects, in this case pump characteristics. This will display the pump curve editor window (Curve Edytor) (Fig. 35).

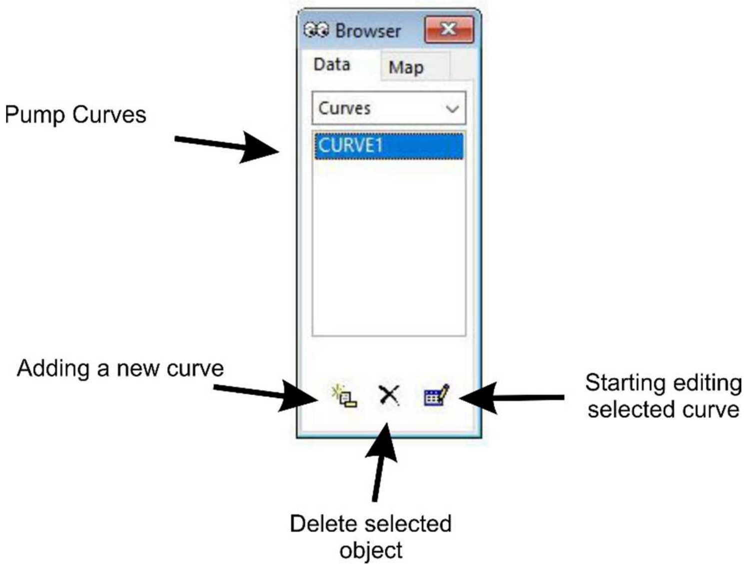


Fig. 34. The Browser window with a displayed tab for creating and viewing the pump curve

In the pump curve editor in the spreadsheet on the left hand side of the window, enter the pump capacity Flow and the Head. Create the curve based on one nominal point of the pump. This point is located in the middle of the curve. After entering the data into the worksheet, click on the line below, as this will generate the formula and graph of the characteristic. If these two elements are not present, the computations will not be performed. Initially, insert Flow = 100 l/s, Head = 40 m.

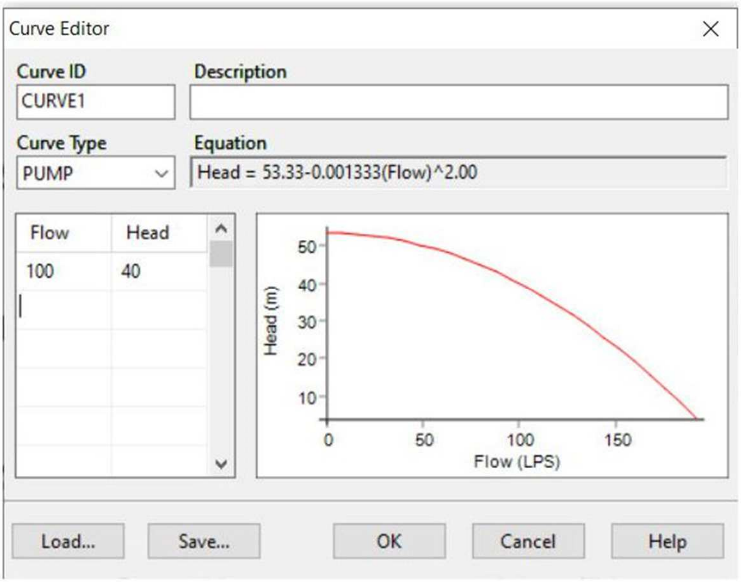


Fig. 35. Pump curve editor

7. Adding a pump curve to a pump object

The created pump characteristic CURVE1 must be assigned to the pump object. To do this, open the Edit Pump Data window. Double-click the pump on the diagram in the Network Map window. The Edit Pump Parameters window will open (Fig. 36). The names of the parameters are listed on the left and the values on the right. Under Pump Curve enter the name of the pump curve you created earlier.

The name of the pump curve must be case-sensitive, e.g. CURVE1 and Curve1 are different characteristics.

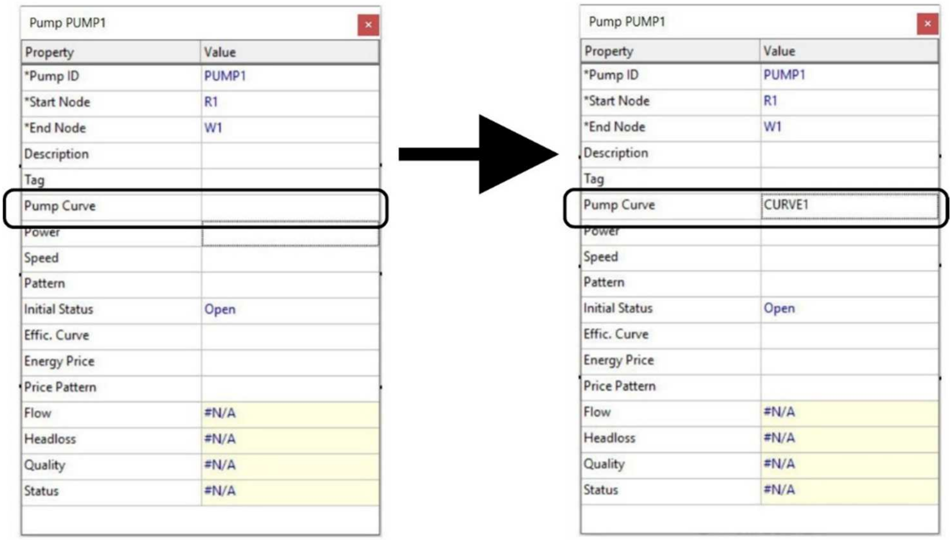


Fig. 36. Pump data editor – inserted pump curves

The lower part of the object data editor window contains the parameters calculated by the program. If simulation calculations have not been performed in this part, the parameters are assigned a mark #N/A.

8. Editing node data

At this stage, some node data have no values, some are filled with default values set in the Defaults option. The data of each node must be adjusted to the conditions resulting from the project conditions. To do so, open the Junction data editor window. This is done by double-clicking with the left mouse button on a selected node. If the data edit window is already open for another object, the edited object is changed by a single left click on the new object. The names of the parameters are listed on the left-hand side of the editing window, and the values on the right-hand side. In this exercise, the terrain elevation of 120 m.a.s.l. is to be inserted into all nodes (Fig. 37). The above can be done by selecting each node separately and changing the terrain elevation value or by editing a group of nodes described in chapter 4.4.4.

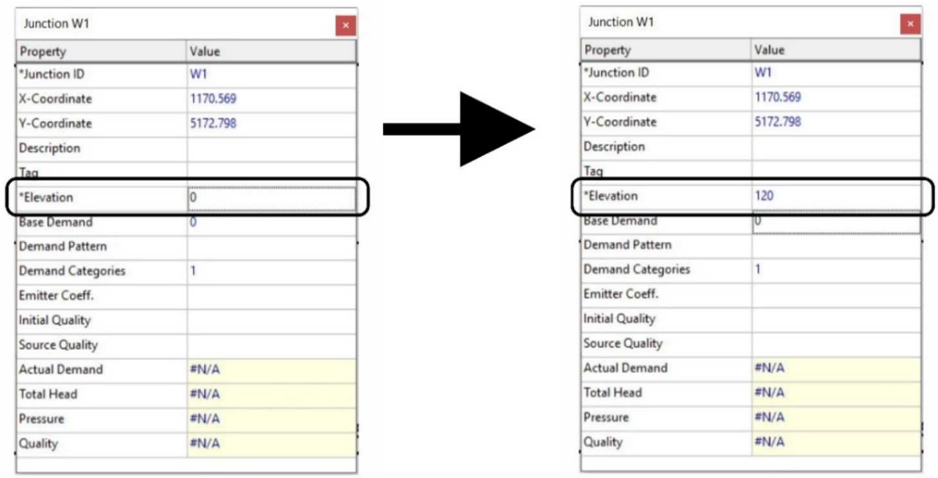


Fig. 37. Junction data editor – insert terrain elevation

If a parameter name starts with an asterisk, such as Elevation, it means that the value is required, although it may be 0 in some cases.

The data and results of the node are as follows:

- **Input parameters:**

  Junction ID – node identifier;

  X-Coordinate – horizontal position of the node on the map, measured in map distance units;

  Y - Coordinate – vertical position of the node on the map, measured in map distance units;

  Description – textual description of the node;

  Tag – a label allowing objects to be grouped, e.g. for editing;

  Elevation – terrain elevation at the junction, measured in m.a.s.l.;

  Base Demand – average or nominal water demand (depending on the type of computation), a negative value serves to indicate the external water supply, measured in l/s;

  Demand Pattern – identifier of the water intake distribution, i.e. the table of multipliers enabling the conversion of the average water demand (Base Demand) into values per time step, most frequently hours of the day;

  Demand Categories – number of water consumption categories assigned to a given node. One node can be assigned more categories of water recipients, each with a different water demand (Demand

Pattern). If there is a greater number of recipients in a given node, in the Base Demand field, the value assigned to the main recipient is displayed, i.e. the one entered in the first row of the table of the recipient category group;
Emitter Coeff. – coefficient of performance of the emitter (sprinkler or nozzle),
Initial Quality – initial water quality (unit of measurement depends on selected calculation option);
Source Quality – water quality where the node is a water source.

- **Calculated parameters** (values for the current time step):
  Actual Demand – current water intake;
  Total Head – elevation of the pressure line, measured in m.a.s.l.;
  Pressure – pressure, measured in m;
  Quality – water quality (unit of measurement depends on selected calculation option).

9. Editing water pipe data

The parameters of the water pipes required in the exercise are described with default values. Change the default diameters for sections P1, P6, P11 from the value 110 to 315 (Fig. 38). Perform actions analogically to editing nodes. In the open window of water pipe data editor, change the diameter.

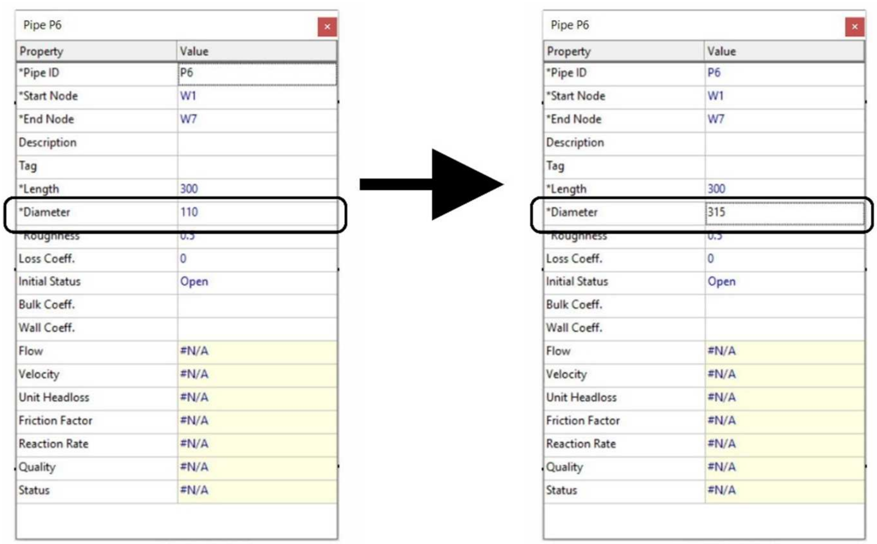


Fig. 38. Water pipe data editor – diameter correction

The data and results of the water pipe are as follows:

- **Input parameters:**
  Pipe ID – section identifier;
  Start Node – identifier of the node where the pipe starts;
  End Node – identifier of the node where the pipe ends;
  Description – textual description of the pipe;
  Tag – a label allowing objects to be grouped, e.g. for editing;
  Length – length of the pipe, measured in m;
  Roughness – pipe roughness coefficient, for the *Darcy-Weisbach* formula expressed in mm, for the *Hazen-Williams and Chezy-Manning* formula – dimensionless quantity;
  Loss Coefficient – local loss coefficient;
  Initial Status – determines whether the pipe is initially open, closed or contains a non-return valve. If a non-return valve is specified, the flow in the pipe must be from the start node to the end node;
  Bulk Coefficient – volumetric response coefficient, a coefficient taken into account in the qualitative model;
  Wall Coefficient – wall reaction coefficient, a coefficient included in the quality model.
- **Calculated parameters** (values for the current time step):
  Flow – flow rate, l/s;
  Velocity – velocity, m/s;
  Unit Headloss – unit pressure loss, m/km;
  Friction Factor – friction coefficient;
  Quality – quality (unit of measurement depends on the chosen calculation option);
  Status – status.

10. Editing reservoir data

In the reservoir data editor window, the Total Head parameter should be changed from 0 to 120 m.a.s.l. (Fig. 39). Total Head, , i.e. total height, is the sum of the altitude in m.a.s.l. and the pressure altitude in m. In the exercise the source of water is considered open, hence the Total Head parameter is interpreted as the elevation of the water table in the reservoir.

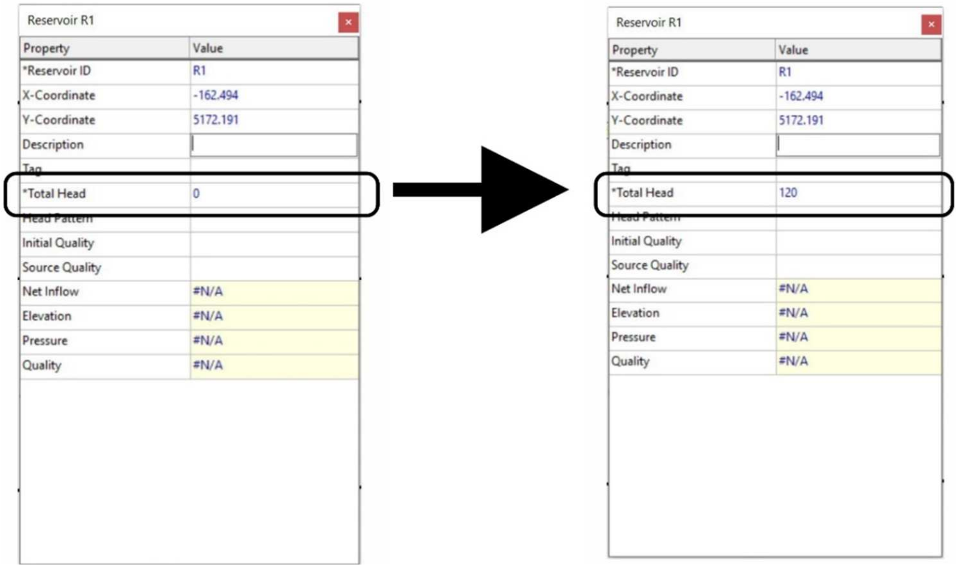


Fig. 39. Water pipe data editor – diameter correction

5.1.3. Report on the exercise

In the exercise report, a copy of the Network Map window should be included with the schematic diagram of the sample water supply network and the elevations of nodes and diameters of water pipes (**Fig. 40**).

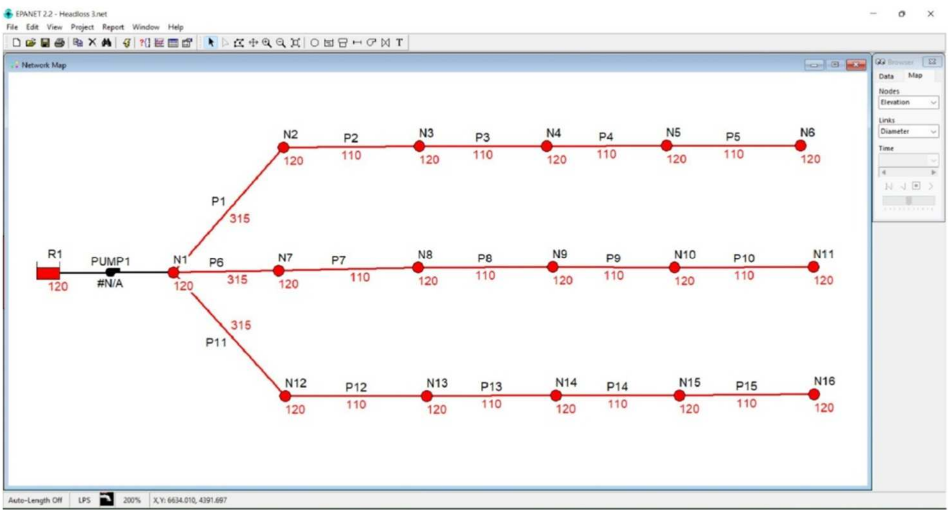


Fig. 40. System map diagram for the report on exercise 1

Set the display of junction and pipe identifiers according to the rules described in chapter 4.4.3. Display the values of junction parameters using the functions in the Browser window on the Map tab.

5.2. SELECTION OF DIAMETERS FOR WATER PIPES

5.2.1. Introduction to the exercise

The basic criterion for the selection of pipe diameters is the water flow velocity. The approximate inside diameter can be calculated using formula (5), based on the representative flow for the most unfavourable conditions and assumed velocity:

$$D_{in} = \sqrt{\frac{4Q_r}{\pi V_{ave}}} \tag{5}$$

Knowledge of the formula and the principles for the selection of pipe diameters is necessary, but in the case of a large water supply system this method is problematic in application. Calculated selection of diameters is particularly troublesome in case of analysing various variants of a ring network, where flows can significantly change in individual calculation sections of water supply pipes. This exercise will provide a selection of diameters for water pipes using the possibilities of the EPANET program.

The recommended flow velocities in water pipes are:

- in the distribution water supply network: 0.5-1.0 m/s,
- in the main and transit water supply network: 1.3-3.0 m/s.

However, it should be borne in mind that extreme flow velocities in water supply networks range from 0.2 to 3.0 m/s. Particularly in water supply networks that must meet the conditions for water supply for fire-fighting purposes, it may be difficult or impossible to maintain higher velocities than 0.5 m/s for household flows.

Proper selection of pipe diameters is extremely important for the operation of the water supply system and for operating costs. Higher flow velocities cause significant pressure losses, which results in higher water pumping costs and can cause water hammer. Too low flow velocities are conducive to the formation of deposits on the walls of the pipes and result in long periods of water stoppage in the pipes.

In exercise 2, pipe diameters should be selected, assuming recommended flow velocities in water pipes. The minimum pipe diameter is DN110 mm. The diameter range of HDPE pipes is as follows: DN110, DN160, DN225, DN250, DN280, DN315, DN400, DN450, DN500, DN630. The roughness coefficient for HDPE pipes should be k = 0.01 mm.

> For the purpose of the exercise, the nominal diameters of the DN pipes will be used, i.e. in the case of HDPE pipes these are the outside diameters. It must be noted, however, that the actual calculations must be made using the inside diameters of the pipes. This has a significant influence on the amount of pressure loss in the pipes.

5.2.2. Implementation of the exercise

In Exercise 2 the water supply network diagram drawn up in Exercise 1 will be used. The project file is loaded and the map display options are set according to the rules described in chapter 4.4.

In order to carry out the exercise, the following steps should be followed:

1. Insert Base Demand **of nodes in an example water supply network**

The values to be inserted in the individual nodes are shown in Fig. 41. The values of the nodal demands will generate flows in different ranges in individual water pipes, used for the selection of diameters from the entire series of types. Node N1, a distribution point into three branches of the system, remains without the nodal demand.

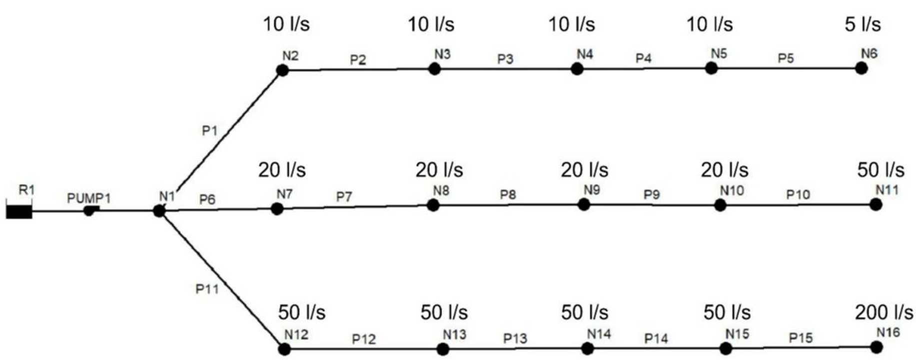


Fig. 41. „BaseDemand" node demand values

To enter demands, open the junction data editor by double-clicking the node (Fig. 42). If the editor window is open, the other nodes only need to be clicked once to display the data of the selected node. Complete the Base Demand parameter with the values from the diagram in Fig. 41.

Fig. 42. Junction data editor – inserting "Base Demand" water intakes

2. Select the pump

Use the Browser window to open the curves editor (Fig. 43) and adjust the pump parameters. Take the flow as the sum of the flows from all the nodes in the example water supply system, Head being 40 m. The Flow value can be slightly rounded up.

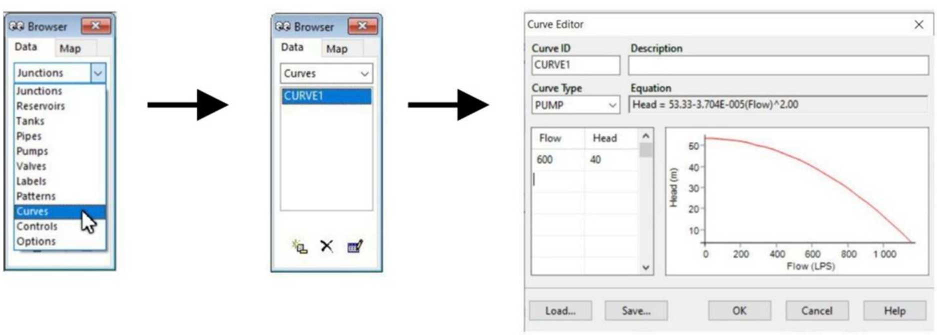


Fig. 43. Selecting and editing pump curves

3. Initial start of calculations

By selecting the menu option Project >> Run Analysis or the icon start the computation of the water distribution system. After the first run, if the water pipes have default values of DN110, very high pressure losses will occur. This will result in a warning message (Fig. 44), and then a Status Report window with negative pressure information (Fig. 45).

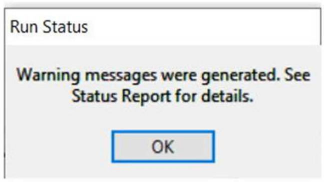


Fig. 44. Run Status – Warning messages

The warning "Negative pressures" indicates that the elevations of the pressure lines are lower than the elevation of the terrain. This is caused by a high pressure line drop. To solve this problem, you need to make the correct selection of pipe diameters.

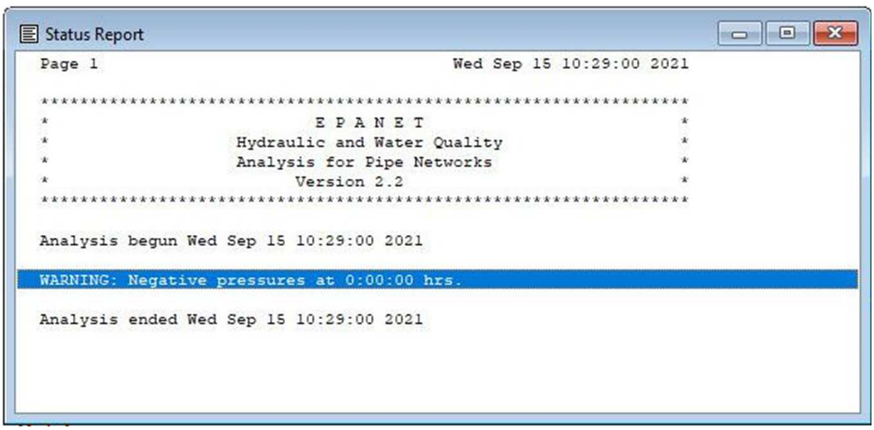


Fig. 45. Status Report – Warning "Negative pressures"

4. Select pipe diameters in the Map Network window using the options in the Map tab of the Browser window

In order to use the selection of diameters using the Map Network window, the display of parameters for pipes must be selected in the Map Options. Fig. 46 shows the identifiers and parameters for nodes and linear objects.

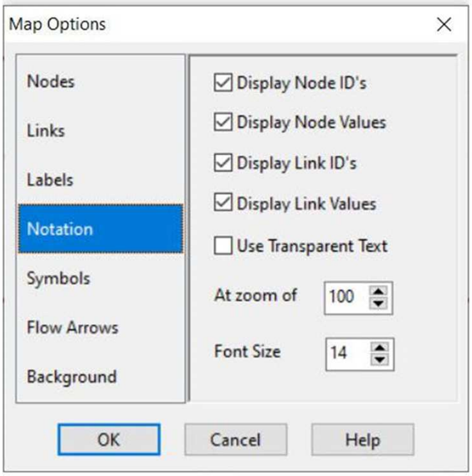


Fig. 46. Setting the display of identifiers and parameter values of nodes and linear objects

Next, in the Map tab of the Browser window, set the Velocity parameter, i.e. the speed, displayed in the Map Network window next to linear objects (Fig. 47).

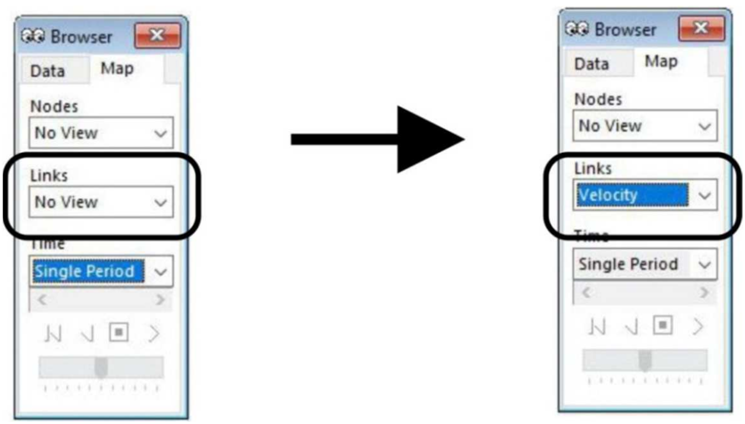


Fig. 47. Setting the velocity display in water pipes

The diagram of the water distribution system in the Map Network window should look like the one in Fig. 48. It shows that the flow velocities in most of the pipes are far too high. In sections W1-W2 and W5-W6 the velocities are correct, so the diameters on these pipes do not need to be corrected. The window also displays a legend with velocity ranges assigned to the colours with which the water pipes are marked.

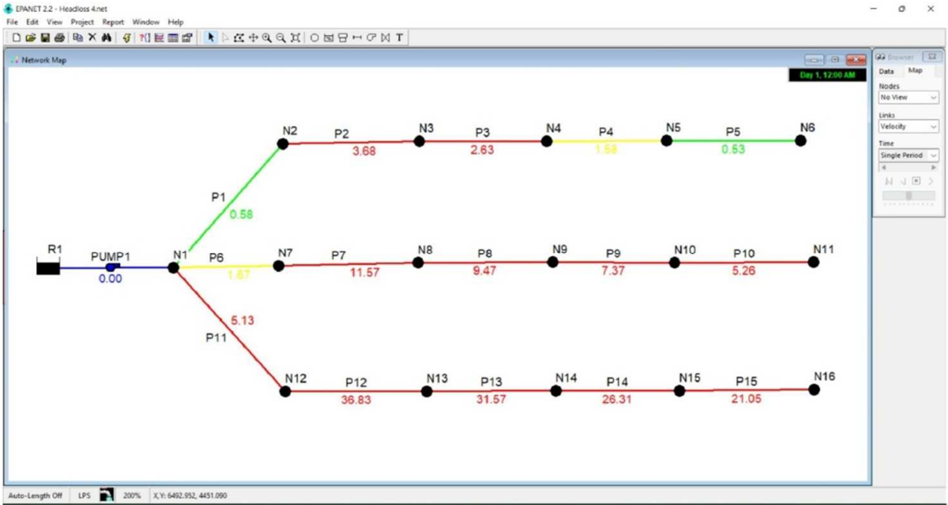


Fig. 48. Scheme of the water distribution system with flow velocities in water pipes before adjusting the diameters

Using the pipe data editor, increase the diameters in pipes where the velocities are too high. Before each adjustment of diameters, it is worth saving the project in a new file under a new name, so that in the event of a mistake you can easily return to the previous variant of diameters.

5. Subsequent start of calculations

After adjusting the diameters, the following calculations are performed . Again, display a diagram of the water distribution system with the flow velocities in the water pipes. Repeat the process until you obtain pipe diameters that provide the recommended flow velocities.

5.2.3. Report on the exercise

In the report on exercise 2, include two diagrams of an example water distribution system:

1. Diagram with flow velocity values in water pipes;
2. Diagram with selected diameters in water pipes.

Save the diagrams from the Network Map window using the Edit >> Copy To... option described in chapter 4.4.2.

5.3. COMPUTATION OF PRESSURE LOSSES IN WATER PIPES

5.3.1. Introduction to the exercise

A water supply system consists of pipes carrying water from the source to consumers together with the necessary fittings. During water flow along the length of a water supply system, there occur resistances caused by the friction of the flowing liquid against the walls of the system and the friction inside the liquid. The amount of friction against pipe walls depends on the roughness of the walls, while the amount of internal friction depends on the fluid viscosity. The value of the kinematic viscosity coefficient ν depends on the temperature. It is assumed that the temperature in water pipes is 10°C. The measure of the roughness of the pipe wall is the diameter of sand grains used to coat the inner surface of the pipes in experiments conducted by Nikuradse – this is the absolute roughness, denoted by *k* (Mielcarzewicz, 2000).

One of the dependencies for the computation of linear pressure losses Δh_l is *Darcy-Weisbach's* formula expressed as:

$$\Delta h_{lin} = \lambda \cdot \frac{L}{D_{in}} \cdot \frac{V_{ave}^2}{2g} \qquad (6)$$

The absolute roughness coefficient k is used in the calculation of the linear resistance coefficient λ. The roughness coefficient *k*, depending on the material and the age of the pipes, takes on values in a very large range from 0.001 mm to several tens of mm, so in computations the value of this variable, which has a decisive influence on λ, should be evaluated very carefully.

In the calculation of water pipes, it is not necessary to consider local losses as significantly less than the pressure losses along the length of the pipe. Local losses must be taken into account when calculating short pipe lengths with a large number of fittings and fixtures, e.g. in pumping stations.

5.3.2. Implementation of the exercise

The aim of this exercise is to calculate pressure losses for water pipes of an example water supply network for different values of the absolute roughness *k*. Exercise 3 will use the diagram of a water supply network drawn up in Exercise 2. Load a file with the project and set the options of map display according to the rules described in chapter 4.4.3.

In order to carry out the exercise, the following steps should be followed:

1. **Enter the parameters of the water distribution system model for pressure loss calculations**

The values to be entered for the individual nodes and water pipes are shown in Fig. 49.

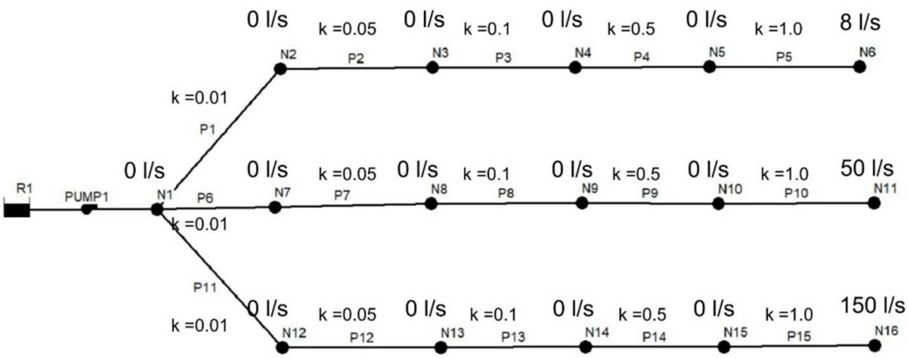


Fig. 49. Diagram of the water distribution system

In each branch, water intakes will come from the terminal nodes only. This will ensure a constant flow through the pipes and uniform diameters in the system branches. The length of the pipes will also be the same in all branches of the system, equal to 300 m. The individual branches of the system will differ in the value of the absolute roughness coefficient *k*.

2. **Run the calculations**

By selecting the menu option Project >> Run Analysis or the icon , launch the computation of the water distribution system.

3. **Obtain calculation results for water pipes**

Make a table of results for all water pipes and save it in a text file according to the rules described in chapter 4.4.1. In the table take into account the following variables: length, diameter, roughness, flow, velocity and unit headloss (Fig. 50). Draw a diagram of the water distribution system with unit pressure losses assigned to the water pipes (Fig. 51).

Link ID	Length m	Diameter mm	Roughness mm	Flow LPS	Velocity m/s	Unit Headloss m/km
Pipe P1	300	110	0.01	8.00	0.84	6.15
Pipe P2	300	110	0.05	8.00	0.84	6.72
Pipe P3	300	110	0.1	8.00	0.84	7.30
Pipe P4	300	110	0.5	8.00	0.84	10.13
Pipe P5	300	110	1.0	8.00	0.84	12.37
Pipe P6	300	280	0.01	50.00	0.81	1.87
Pipe P7	300	280	0.05	50.00	0.81	2.01
Pipe P8	300	280	0.1	50.00	0.81	2.15
Pipe P9	300	280	0.5	50.00	0.81	2.85
Pipe P10	300	280	1.0	50.00	0.81	3.38
Pipe P11	300	450	0.01	150.00	0.94	1.39
Pipe P12	300	450	0.05	150.00	0.94	1.50
Pipe P13	300	450	0.1	150.00	0.94	1.61
Pipe P14	300	450	0.5	150.00	0.94	2.11
Pipe P15	300	450	1.0	150.00	0.94	2.48
Pump PUMP1	#N/A	#N/A	#N/A	208.00	0.00	-46.92

Fig. 50. Calculation results for water pipes, taking into account unit pressure losses

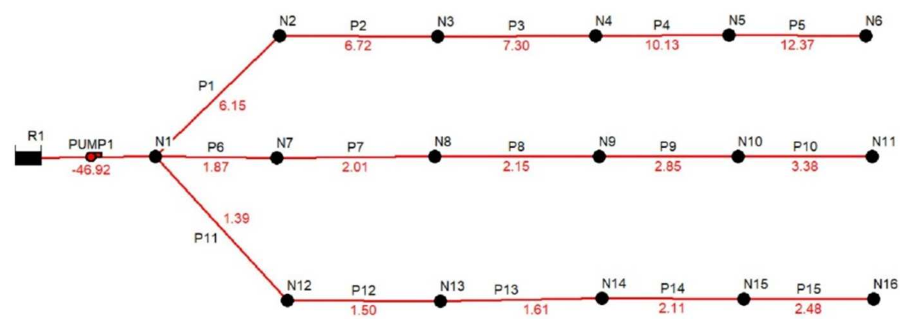


Fig. 51. System diagram with unit pressure loss values

4. Draw up unit pressure loss diagrams for individual pipe diameters

Using a spreadsheet, draw graphs of unit pressure losses for specific nominal diameters of the pipes and the absolute roughness coefficient k according to the formula in **(Fig. 52)**.

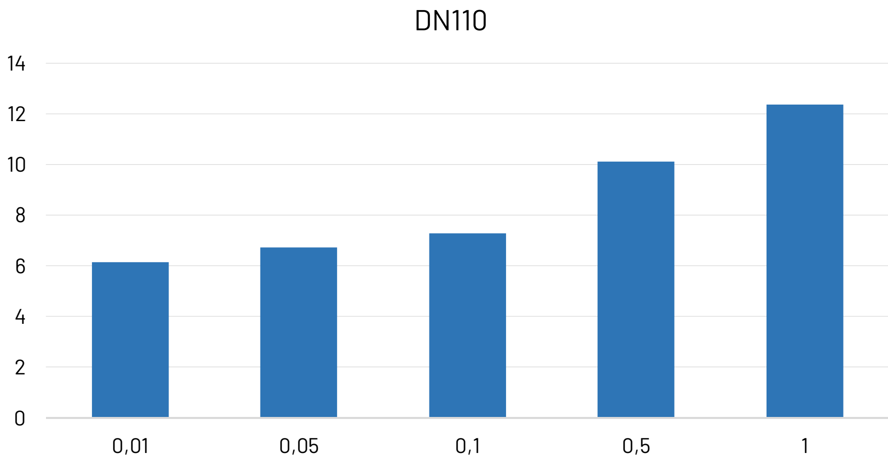


Fig. 52. Unit pressure loss for diameter DN110 for roughness coefficients *k* ranging from 0.01 to 1.0 mm

5.3.3. Report on the exercise

In the report on exercise 3, include two diagrams of an example water distribution system:

1. Diagram with roughness values for water pipes;
2. Diagram with values for specific pressure losses in water pipes.

In addition, the report should include a table with the results of the water pipe calculations and diagrams of specific pressure losses for each branch of the system:

3. Table with results for water pipes;
4. Graphs of specific pressure losses for pipes in each branch of the system separately.

Save the diagrams from the Network Map window using the Edit => Copy To... option described in chapter 4.4.2.

5.4. LOADING OF THE NUMERICAL BASE, ROUTING OF THE WATER SUPPLY NETWORK, SIMULATIONS OVER A LONGER PERIOD OF TIME

5.4.1. Introduction to the exercise

The design of a water distribution system can be reduced to the following steps:

- drawing up a water demand balance for the settlement unit,
- designing the network layout in the plan (network routing),
- determining nodal demands,
- determining flows in individual sections of the water supply network,
- selecting pipe diameters,
- calculating pressure losses,
- establishing pressure lines and checking whether the calculated pressure line provides the necessary economic and fire pressure everywhere,
- adjustment of diameters, recalculation of losses in case of insufficient pressure,
- final determination of pressure lines.

In order to carry out network routing, which consists in giving the network a geometrical shape depending on the transport route system and the lie of the land, a contour plan of the city, housing estate, or district in a scale from 1:10,000 to 1:1,000 is required, with 1:5,000 being the most convenient scale. The choice of scale depends on the area to be designed. Network routing is carried out by drawing lines marking pipes along traffic routes and streets. The pipes should be routed in a manner ensuring delivery of the largest quantities of water along the shortest route. In addition to the city plan with contours and the network of existing and planned streets, a spatial development plan is necessary indicating the type of development in individual city zones.

First of all, the water demand in the whole settlement unit should be calculated, taking into account different categories of users and water losses in the water supply network. Due to the variability of water consumption several characteristic quantities are distinguished:

- Q_{AWD} – predicted annual water demand by all water consumers in the settlement unit, measured in m^3/a,
- Q_{ADD} –average daily water demand (Daily Average Water Demand) expressed as, measured in m^3/d:

$$Q_{ADD} = \frac{Q_{AWD}}{365} \quad (7)$$

- Q_{MDD} – the maximum daily demand (Maximum Day Water Demand), measured in m^3/d, which represents water demand on the maximum consumption day of the year; it is determined by multiplying the average daily water demand Q_{ADD} by the daily irregularity coefficient N_D, expressed as:

$$Q_{MDD} = Q_{ADD} \cdot N_D \quad (8)$$

- Q_{AHD} – average hourly water demand on the maximum consumption day, measured in m^3/h

$$Q_{AHD} = \frac{Q_{MDD}}{24} \quad (9)$$

- Q_{MHD} – the maximum hourly water demand on the maximum demand day; it can be calculated by multiplying the average hourly water demand Q_{AHD} by the coefficient of hourly irregularity on the maximum consumption day N_H:

$$Q_{MHD} = Q_{AHD} \cdot N_H \quad (10)$$

In the practice of designing water supply systems, the decisive figure for dimensioning pipes is most often expressed by the maximum hourly water demand Q_{MHD} on a day with maximum daily demand Q_{MDD}. However, it should be borne in mind that this does not correspond to the demand in the maximum hour of the whole year Q_{PHD} (Peak Hour Water Demand), which may occur on a day other than Q_{MDD}. In most water supply systems there is an hour with demand greater than the maximum hourly $Q_{PHD} > Q_{MDD}$. In many countries the value Q_{PHD} is the authoritative value for the dimensioning of water supply networks.

The irregularity coefficients in formulae (8) and (10) are defined as follows:

$$N_D = \frac{Q_{MDD}}{Q_{ADD}} \quad (11)$$

$$N_H = \frac{Q_{MHD}}{Q_{AHD}} \quad (12)$$

The amount of water demand is calculated using unit water demand indicators, which determine the amount of water in relation to one inhabitant in the city and a unit of time, l/M·d. This exercise will use the integrated water demand indicators for different groups (categories) of consumers in the settlement unit, per capita in the city. The size of the indicators changes with the size of the settlement unit expressed by the number of inhabitants.

These unit water demand indicators for different customer groups are used to calculate the average Q_{AHD} and maximum daily water demand Q_{MDD} in the settlement unit. The maximum daily water demand is calculated as the sum of the products of the average daily water demand of the individual customer categories multiplied by the corresponding daily irregularity coefficient:

$$Q_{MDD} = \sum_{i=1}^{n} Q_{ADD(i)} \cdot N_{D(i)} \ \ \mathrm{m^3/} \tag{13}$$

$$Q_{ADD(i)} = q_i \cdot L_{NI} \ \ \mathrm{m^3/d} \tag{14}$$

where:
$Q_{ADD(i)}$ – average daily demand of the i-th consumer category,
q_i – water demand unit indicator for the i-th customer category,
L_{NI} – number of inhabitants in the settlement unit,
$N_{D(i)}$ – coefficient of daily irregularity of the i-th category of users,
n – number of recipient categories

Maximum hourly water demand Q_{MHD} on the day Q_{MDD} is calculated taking into account the variation of demand by different categories of users during the day. However, it is not sufficient to multiply the average hourly values $Q_{AHD(i)}$ for the different customer categories by the corresponding coefficient values $N_{H(i)}$, since the maximum values for the different categories may occur at different times of the day.

For this purpose, hourly distributions of water demand by each category of users during a 24-hour period shall be established and, on the basis of these distributions, water demand volumes for each hour of that 24-hour period shall be calculated as the sum of the demands of all categories of users. The maximum hourly value Q_{MHD} for the entire settlement unit is the value at the hour in which the sum $Q_{MHD(i)}$ for all categories is the highest.

Within cities and urban settlements, several groups of tap water consumers can be distinguished. In the reports of companies operating water supply systems, the number of recipients is often limited to three:

- households,
- industry,
- services.

In the EPANET program, in order to calculate Q_{MHD}, hourly water demand distributions for different categories of users are used.

5.4.2. Implementation of the exercise

Start the exercise by loading a sample (didactic) design with the layout of traffic routes and description of buildings (Fig. 54). In this exercise, carry out calculations in a longer time horizon of 1 day, with a time step of 1 hour. Residential areas are divided into two subcategories with multi-family housing – 30% and single-family housing – 70% of the settlement unit population. Hence, hourly water consumption distributions will be introduced for the four categories: MF – multi-family housing, SF – single-family housing, IA – industrial areas, SP – service-provision area (Tab. 1).

Tab. 1. Hourly schedules of water demands and multipliers for the categories ZW, ZJ, U and TP

Hour	Consumption ZW %	Multiplier ZW	Consumption ZJ %	Multiplier ZJ	Consumption U %	Multiplier U	Consumption TP %	Multiplier TP
1	1.50	0.4	0.50	0.1	2.40	0.6	5.10	1.2
2	1.50	0.4	0.50	0.1	2.25	0.5	5.10	1.2
3	1.50	0.4	0.50	0.1	2.85	0.7	5.00	1.2
4	1.50	0.4	1.50	0.4	2.45	0.6	4.85	1.2
5	2.50	0.6	2.50	0.6	2.45	0.6	3.80	0.9
6	3.50	0.8	3.50	0.8	3.45	0.8	1.35	0.3
7	4.50	1.1	5.00	1.2	5.00	1.2	1.95	0.5
8	5.50	1.3	6.50	1.6	4.25	1.0	6.20	1.5
9	6.25	1.5	7.00	1.7	4.70	1.1	6.35	1.5
10	6.25	1.5	7.00	1.7	4.70	1.1	6.40	1.5
11	6.25	1.5	7.00	1.7	4.30	1.0	7.25	1.7
12	6.25	1.5	6.25	1.5	5.90	1.4	6.40	1.5
13	5.50	1.3	4.00	1.0	4.40	1.1	5.70	1.4
14	5.50	1.3	4.00	1.0	6.10	1.5	6.90	1.7
15	6.00	1.4	6.00	1.4	4.90	1.2	4.30	1.0

Hour	Consumption ZW %	Multiplier ZW	Consumption ZJ %	Multiplier ZJ	Consumption U %	Multiplier U	Consumption TP %	Multiplier TP
16	6.00	1.4	7.00	1.7	5.60	1.3	2.10	0.5
17	6.50	1.6	7.00	1.7	4.80	1.2	3.05	0.7
18	6.50	1.6	6.25	1.5	4.30	1.0	1.90	0.5
19	6.00	1.4	6.00	1.4	4.20	1.0	2.60	0.6
20	4.00	1.0	4.50	1.1	5.35	1.3	2.40	0.6
21	3.00	0.7	4.00	1.0	4.45	1.1	2.60	0.6
22	1.50	0.4	2.00	0.5	5.55	1.3	2.70	0.6
23	1.50	0.4	1.00	0.2	3.15	0.8	2.25	0.5
24	1.00	0.2	0.50	0.1	2.50	0.6	3.75	0.9
	100.00	**24.0**	**100.00**	**24.0**	**100.00**	**24.0**	**100.00**	**24.0**

Assume that the settlement unit has 15,000 inhabitants. Unit average daily water demand q_i for individual categories of consumers and daily irregularity coefficients N_d are:

- multi-family housing: q_i = 140 l/M·d, N_D = 1.3
- single-family housing: q_i = 100 l/M·d, N_D = 1.5
- industrial areas: q_i = 80 l/ M·d, N_D = 1.2
- service-provision areas: q_i = 60 l/ M·d, N_D = 1.3.

Losses in the water supply network due to leakage were set at 10% of Q_{ADD}, which are distributed evenly over all hours of the day.

The roughness coefficient for HDPE pipes is k = 0.01 mm.

The exercise is carried out in the following steps:

1. Load the base map for water pipe routing

The map is loaded into the program via View >> Backdrop >> Load... (Fig. 53).

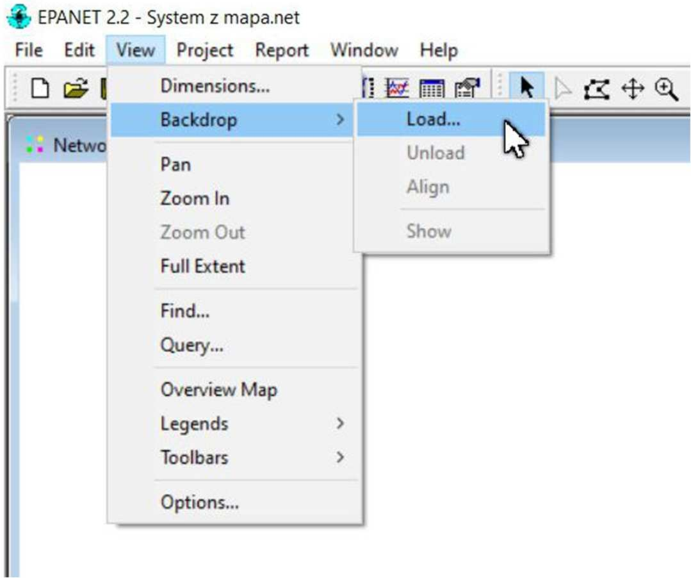


Fig. 53. Loading a design map

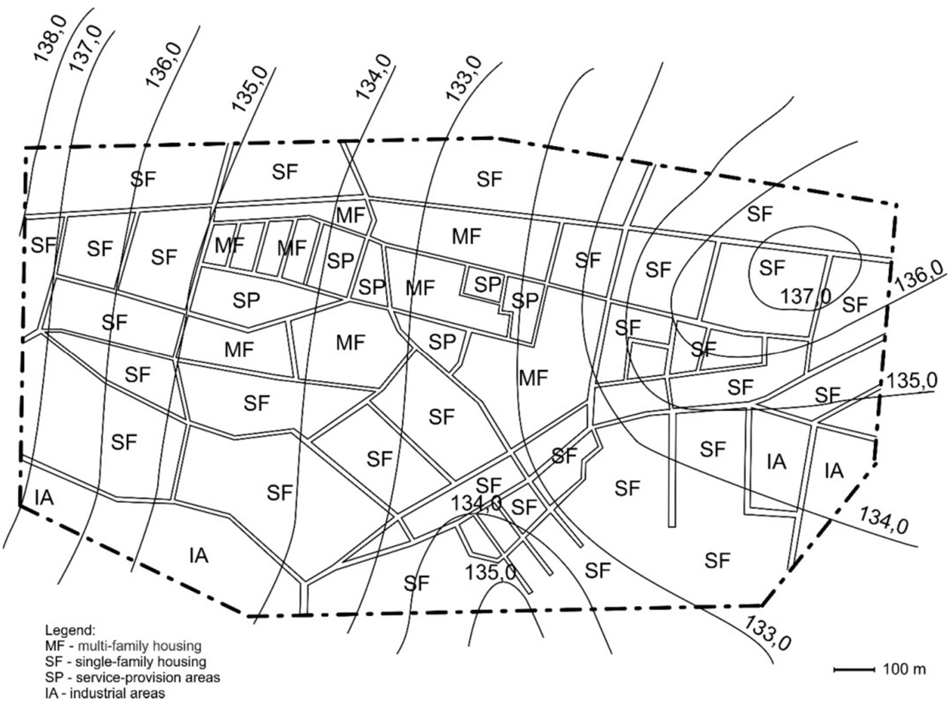


Fig. 54. Scheme map of the settlement unit used for classes

2. **Enter data for hourly water consumption** (Demand Pattern)

The hourly schedules of water consumption are entered by choosing the Patterns option in the Browser window in the Data tab (Fig. 55). Clicking the Add icon in the lower part of the window will activate the pattern editor (Fig. 56). The default name of the pattern identifier is changed to the abbreviation of the recipient category from the example, e.g. ZW. In the Multiplier line enter the values of the multiplier in particular time steps from Table 1. Four patterns for each category of water recipients are created.

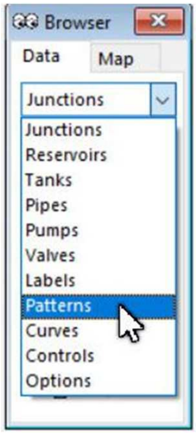


Fig. 55. Launch the template editor

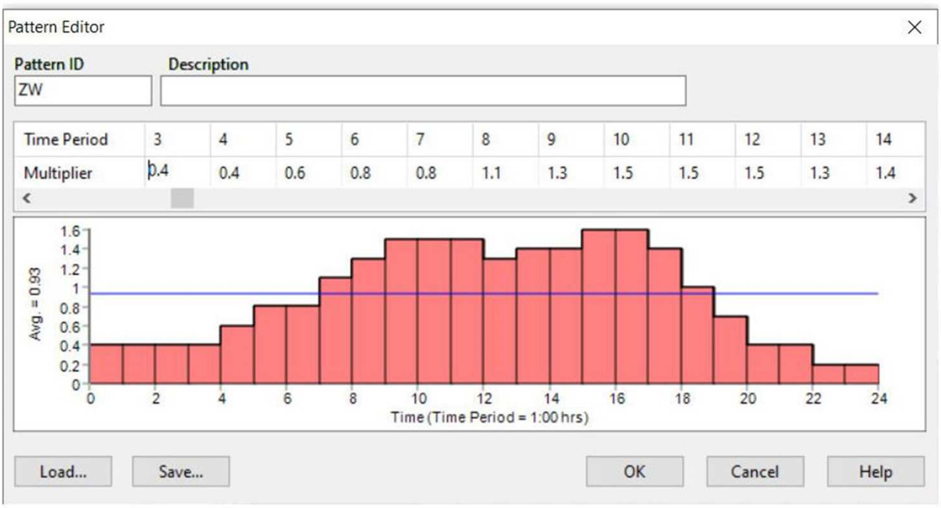


Fig. 56. Editor of water consumption patterns

In EPANET, we use a full stop, not a **comma**, as a separator to separate the whole number from the fraction.

3. Insert a water supply source, nodes and pipes

Using the information from the previous exercises, insert nodal and linear objects. A supply source has been inserted at the boundary of the settlement unit, in a place where the ground elevations are lower. It is assumed that it is a clean water reservoir behind the water treatment plant operating at atmospheric pressure.

Nodes have been placed at road junctions and at the ends of the water distribution networks. Water pipes are routed in traffic routes.

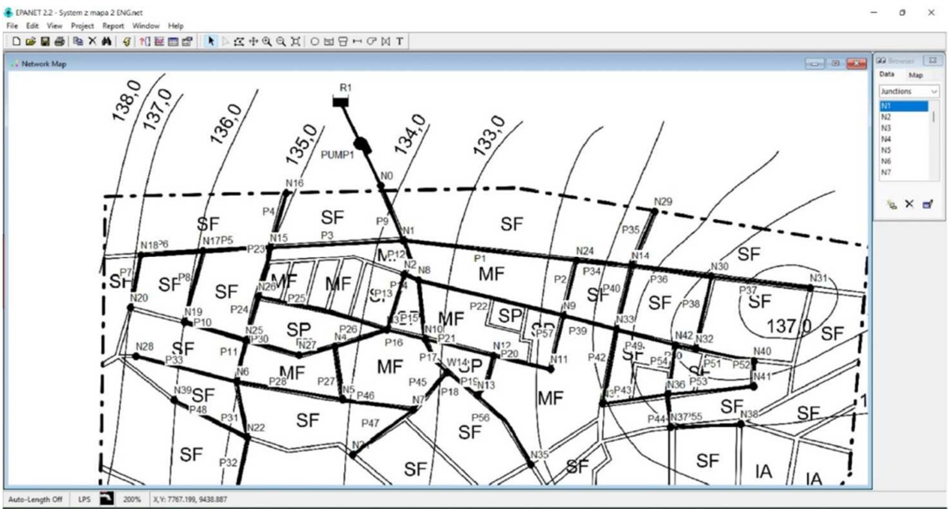


Fig. 57. Routing water distribution networks on a map

4. Complete model objects with required data

Complete the entered model objects with the data discussed in the previous exercises. Next, enter the average hourly demand Q_{AHD} (Base Demand) expressed in l/s, which should be distributed in nodes, taking into account the type of development adjacent to the node. The sum of water demands for single-family and multi-family buildings, respectively, in nodes should be equal to the values calculated in the balance taking into account water losses. In addition, identifiers of water demand patterns for individual categories of buildings adjacent to the node should be entered in the nodes (Fig. 58).

In the “Base Demand” junction intake exercise, enter it indicatively, bearing in mind that this is a teaching project aimed at familiarizing with the basic functions of the EPANET program. In reality, this is an extremely important and complex task.

The junction data editor for two categories of recipients is presented in Fig. 58. In the case of a greater number of recipient categories assigned to the node, the junction editor displays the data of the first recipient, but the number of water recipients is given underneath (Fig. 59).

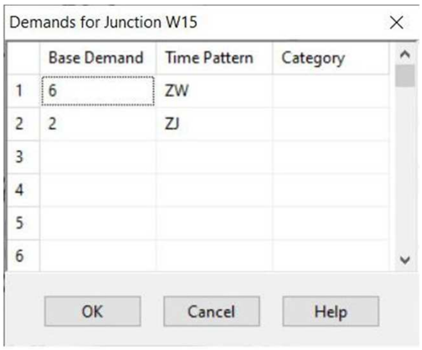


Fig. 58. Completion of data on average water consumption “Base Demand” and water consumption distributions “Demand Pattern” for several consumers in a node

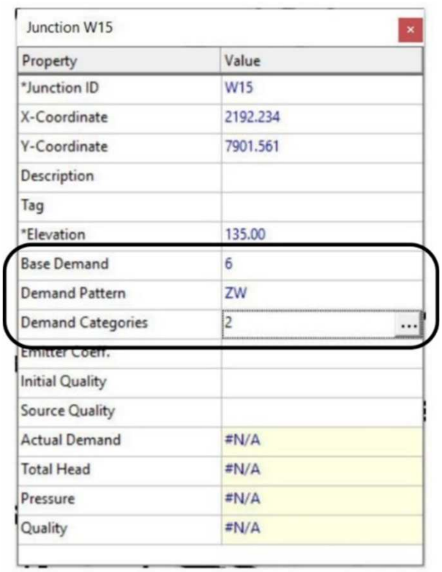


Fig. 59. Junction data for two categories of recipients

5. Set calculation options for the long term

Longer-term calculations require setting the number of simulation steps. For this purpose, in the Browser window, select Options (Fig. 60), and then Times (Fig. 61). In the Times Option window, set the Total Duration parameter to 24 hours (Fig. 62).

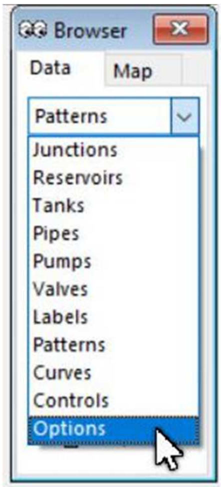


Fig. 60. Launch the editor for calculation options

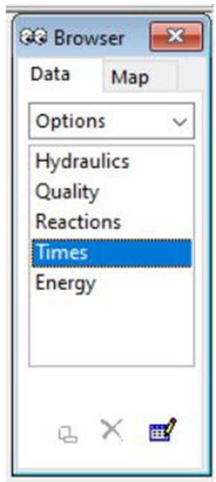
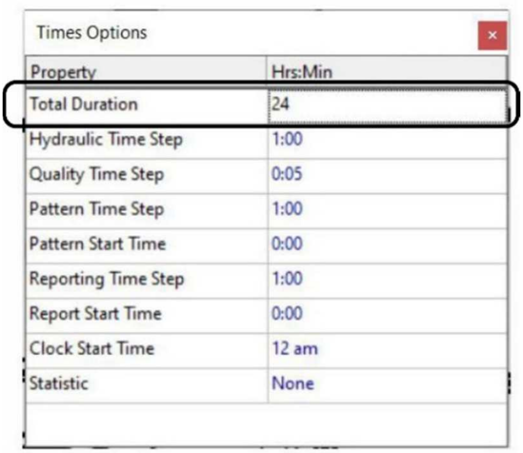


Fig. 61. Selection of options for setting the calculation time



Times Options

Property	Hrs:Min
Total Duration	24
Hydraulic Time Step	1:00
Quality Time Step	0:05
Pattern Time Step	1:00
Pattern Start Time	0:00
Reporting Time Step	1:00
Report Start Time	0:00
Clock Start Time	12 am
Statistic	None

Fig. 62. Select options for setting the calculation time

6. Perform hydraulic simulations

Perform initial hydraulic simulations for 24 hours, following the principles discussed in earlier exercises. “Negative pressure” warnings may appear for a bigger number of hours. Correct the diameters or check the capacity of the pumping station.

7. Set the hour Q_{MHD} for the water distribution system

Assume that the hour Q_{MHD} will occur at the maximum capacity of the pumping station. In order to determine this hour, draw up a chart of the variation in the daily capacity of the pumping station.

Select the pump in the Network Map, window, then create a graph by selecting the icon . The Graph Selection (Fig. 63) window opens, where you select the graph type Time Series, parameter Flow, while Object Type and Links to Graph should appear automatically after selecting the pump on the map.

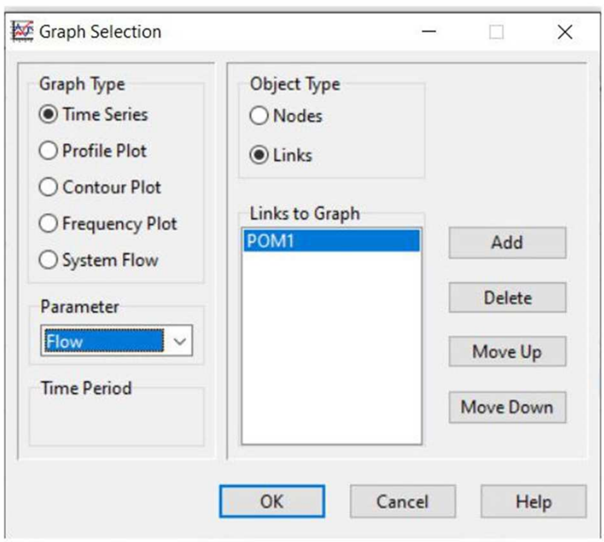


Fig. 63. Window for selecting chart type and drawing parameters

You will obtain the graph shown in Fig. 64, where the hour of maximum water demand in the system is determined. In this example it is 4 p.m.

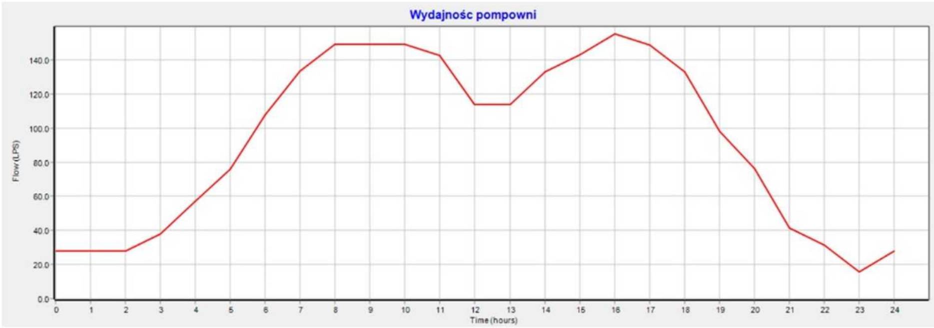


Fig. 64. Pump station capacity variation per day y

8. Compile the results of the calculations

Perform hydraulic simulations again for 24 hours. “Negative pressure” warnings may appear for a bigger number of hours. Correct the diameters for the hour Q_{MHD} or check the capacity of the pumping station.

Draw up the calculation results for the hour Q_{MHD} for junctions and linear objects according to the principles described in section 4.4.1. Correct the diameters.

5.4.3. Report on the exercise

The report should include:

- Network Map window with the routed water distribution system,
- diagram of pumping station capacity per day,
- results of hydraulic calculations for the maximum hourly demand Q_{MHD} for nodes and water pipes.

6. SUMMARY

The script contains basic information on modelling of water distribution systems, methodology of network structure representation for numerical modelling by means of graphs, general principles of building a numerical model of a water distribution system. The practical part includes a detailed description of the implementation of exercises in modelling water distribution systems at the basic level.

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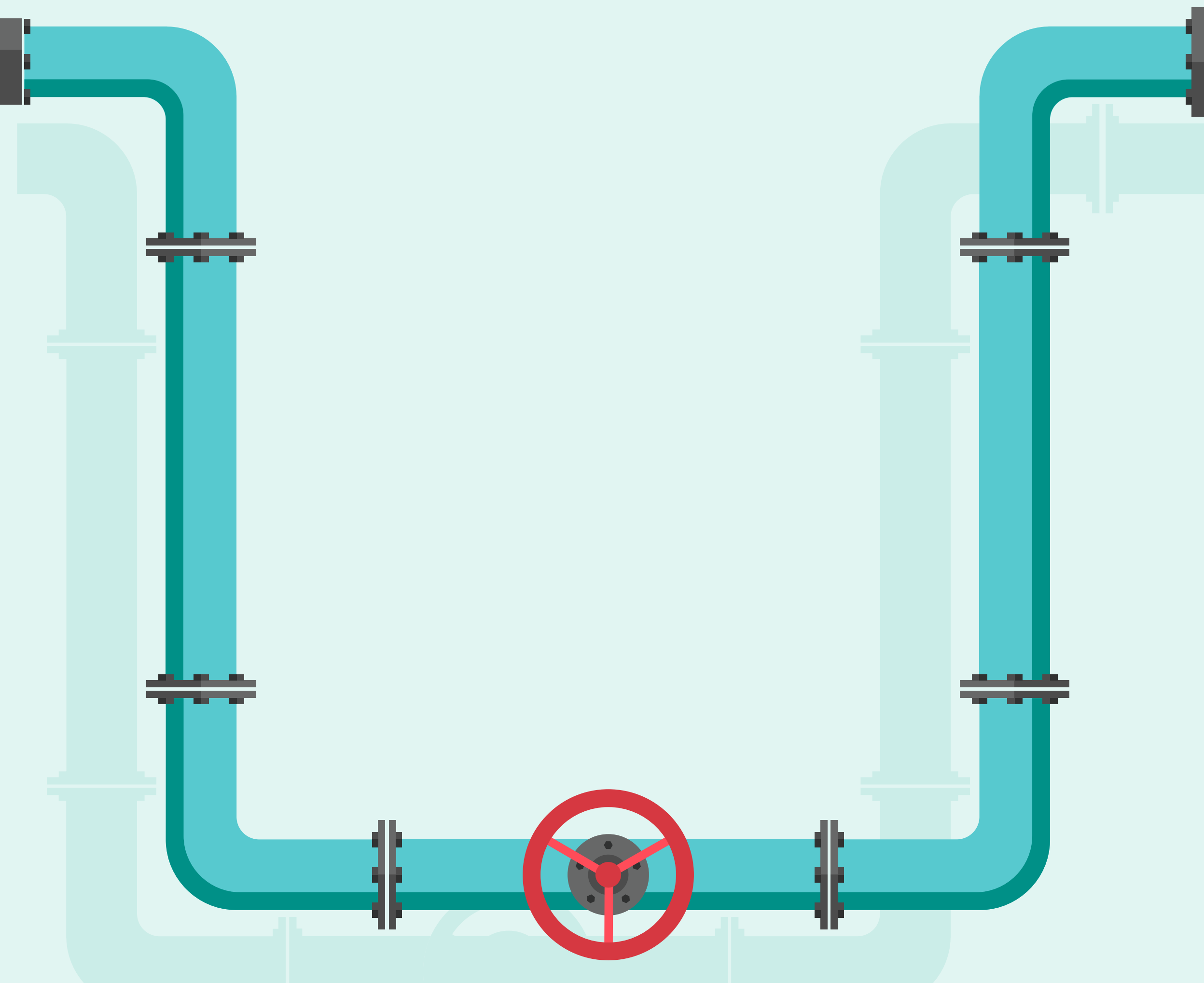

eISBN 978-83-962816-3-0