1. Epanet – EasySketch (EES)

Addendum to D6.6

1.1 Description

The access to the modelling platform of WP4 and the use of the tools of this platform is only possible for water companies, who already have a model of the pipeline network. As a platform for pipeline network calculations the public domain EPANET is frequently used. To apply the tools of the WP4 Risk Analysis and Evaluation Toolkit (RAET), an EPANET-file of the model (EPANET_INP_FILE) must be created and uploaded to the RAET.

In case that a water company has no pipeline network model, the Epanet – EasySketch (EES) tool is used to generate a simplified hydraulic model of a pipeline network with the open source software EPANET.

All information on required system components for model creation is clearly presented in tabular form. The manual effort for model creation is reduced significantly. The tool is particularly useful for small networks and schematically simplified models (< 1000 network components).

The Tool is based on EXCEL, which is widespread and may be used even by inexperienced staff. The tool enables an user who is not familiar with EPANET to create an EPANET-file without using the software EPANET. The tool may be used everywhere in STOP-IT, where

- calculations based on an EPANET model are performed,
- a calibrated hydraulic network model is not available
- the typical setup of a hydraulic model is too sophisticated for the desired results,
- the water supply company has not the skilled and trained staff,
- rough estimations are sufficient.

1.1.1 Functional goals

The tool has the main goal to generate a simplified EPANET model of the water supply system.

Two sub-functions are implemented in EES which are explained below:

- Specification of necessary information
- Automated assignment of coordinates and generation of EPANET_INP_FILES

1.1.2 Specification of necessary information

For an inexperienced user, it is unclear what information about the water network is actually needed to create a computable hydraulic network model. Furthermore, it may be questionable even for an experienced user, which model complexity is necessary.

Approach: The EES specifies what data is needed to create an EPANET input file. Only parameters which are absolutely necessary are used. This necessary information can be entered using the predefined EXCEL-table “EES.xlsm”. Existing information (e.g., from a network information system) can be entered in the input sheet “Input” of the table in a user-

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friendly manner. The tool provides additional information on features of water networks (e.g., literature values for friction factors of pipes). A calibration of the model and the determination of friction factors of pipes may be added later, but is not substantial to the quick estimation the calculation is aiming for. However, elevation data of the system components is necessary.

1.1.3 Automated generation of EPANET_INP_FILES

In some cases there is no or inaccurate information about the location (exact geographical coordinates) of network components. True coordinates are stored in different necessarily compatible or accessible datasets and have to be converted for further processing. In general, manual entry of network information in EPANET is time consuming, inconvenient and in some cases not even necessary.

Approach: According to existing information about the water distribution system the user has to make a simple sketch of his supply system. In this sketch he has to define nodes, tanks, reservoirs, pumps, valves and pipes (Table 1).

Table 1: Network Components

	Description	Characteristics	For modelling …	Reference EPANET USERS MANUEL [1]
Nodetypes				
Junction	Start and / or Endnode of Linkobjects	Elevation [m], demand of water consumed (+) / supplied (-) [m³/h]	Consumer, Supplier (e.g. Waterworks)	Page 68; Table 6.1
Reservoir	Nodes that represents an infinite external source or sink.	Elevation [m], hydraulic head [m]	Well[1], Reservoir Supplier	Page 69; Table 6.2
Tank	Nodes with storage capacity.	Volume [m³], initial volume	Water storage tank	Page 69; Table 6.3

[1] Wells are modelled due combination of:

- Reservoir + pipe + Flow Control Valve OR
- Reservoir in dynamic level + pipe + pump OR
- Junction with total head and negative demand

For further Information see EPANET USERS MANUEL [1, p. 131].

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		[m³], elevation [m]		
Linkobjects				
Pipe	Pipes are links that convey water from one point in the network to another.	Length [m], diameter [mm], roughness [mm]	Pipes	Page 71; Table 6.4
Valve	Valves are links that limit the pressure or flow at a specific point in the network.	Diameter [mm], Type, Setting (pressure [m] or volume flow [m³/h]), Elevation [m]	Control valve for specifying setpoints	Page 73; Table 6.6
Pump	Pumps are links that impart energy to a fluid thereby raising its hydraulic head.	Curve (X [m³/h], Y [m])	Pumps	Page 72; Table 6.5

Geographic coordinates are not needed. Thus, a computational model is created partially automated (Figure 1). Individual nodes no longer have to be manually inserted into EPANET and connected to each other individually.

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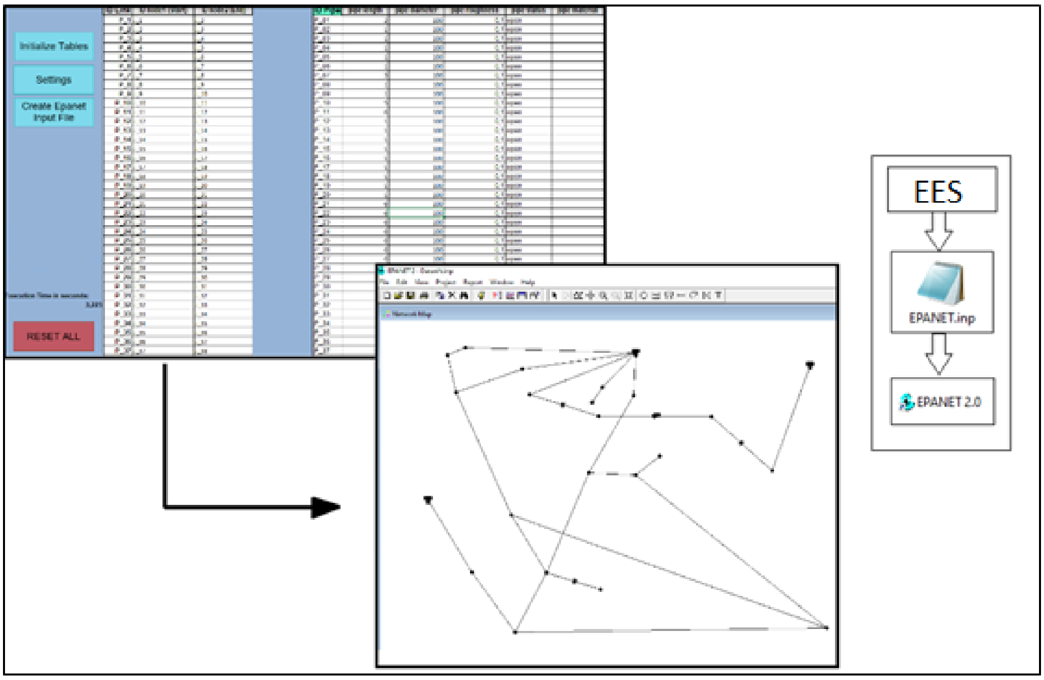

Figure 1: **EXCEL-based input of necessary data, generation of an EPANET-INPUT-File**

The model is visualized by loading the generated input file in EPANET. The position of the system components is assigned automatically by the EES - tool. This means that the graphical output of the EES-tool may differ from the actual position of the individual elements in the original sketch. (Figure 2). This is only a matter of visualization and has no effect on the calculation result, if all topological network information has been entered correctly.

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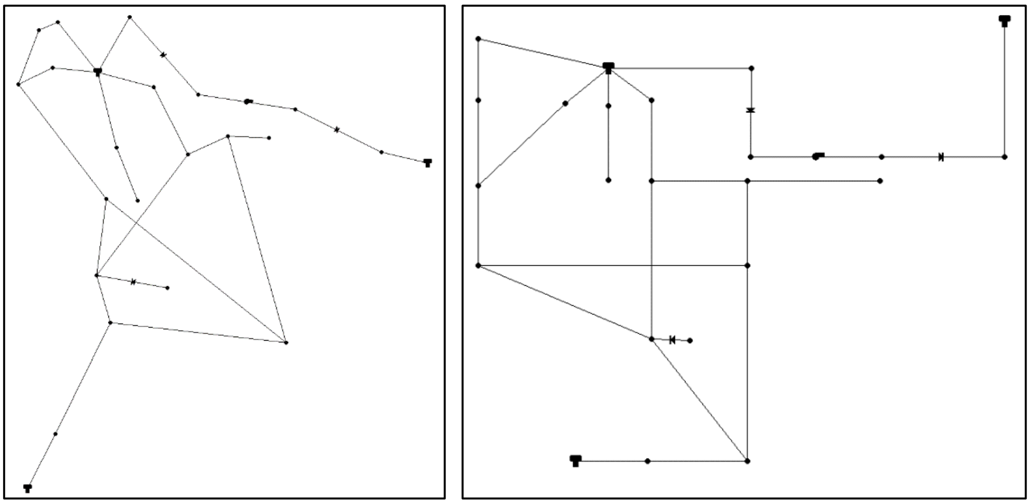

Figure 2: Visualisation in EPANET - Left: Automatically generated model. Right: Same model after manual adjustment. The model properties remain unaffected (same calculation result)

1.2 Description of the EES EXCEL file

This tool simplifies the process of creating an input file for EPANET. That is achieved by allowing to copy and paste network data in the corresponding columns of the EES EXCEL input sheet and automatically generating an EPANET input file in the correct format.

In case the user is able to operate EPANET, the visualisation may be changed in the EPANET software after uploading the EPANET input file. The EES EXCEL file “EES.xlsm” contains the following sheets:

Input

This sheet defines the fields for entering the properties of the model objects. The buttons for setting options and network generation can also be found in this sheet.

EPANET_inp

In this sheet, the entered properties of the network elements are transformed into the format of an EPANET-INPUT file. The user does not have to make any entries in this sheet.

README

This sheet contains a quick guide (step-by-step) for using EES.

About

Information and Links about the STOP-IT-Project and EPANET.

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Input_Example_1

This sheets contain completed tables in the same format as the input sheet. This enables the user to understand the correct entry of information and use of EES.

The generation of *Input_Example_1* is described in chapter 1.3.

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1.3 Network Creation - Step By Step

The following example shows how to create an EPANET input file. The example can be found in the tool's EXCEL sheet named *Input_Example_1*.

Figure 3 shows the sketch of a water supply system for which the input file is created. The supply system consists of two catchment areas and one drinking water treatment plant, five supply areas, three drinking water storage tanks and two pumping stations. The drinking water pumps of the treatment plant are represented by the Pumping Station_1. The valves allow the operation of the Supply_Areas 1 and 2 in a circular, consecutive, or individual mode.

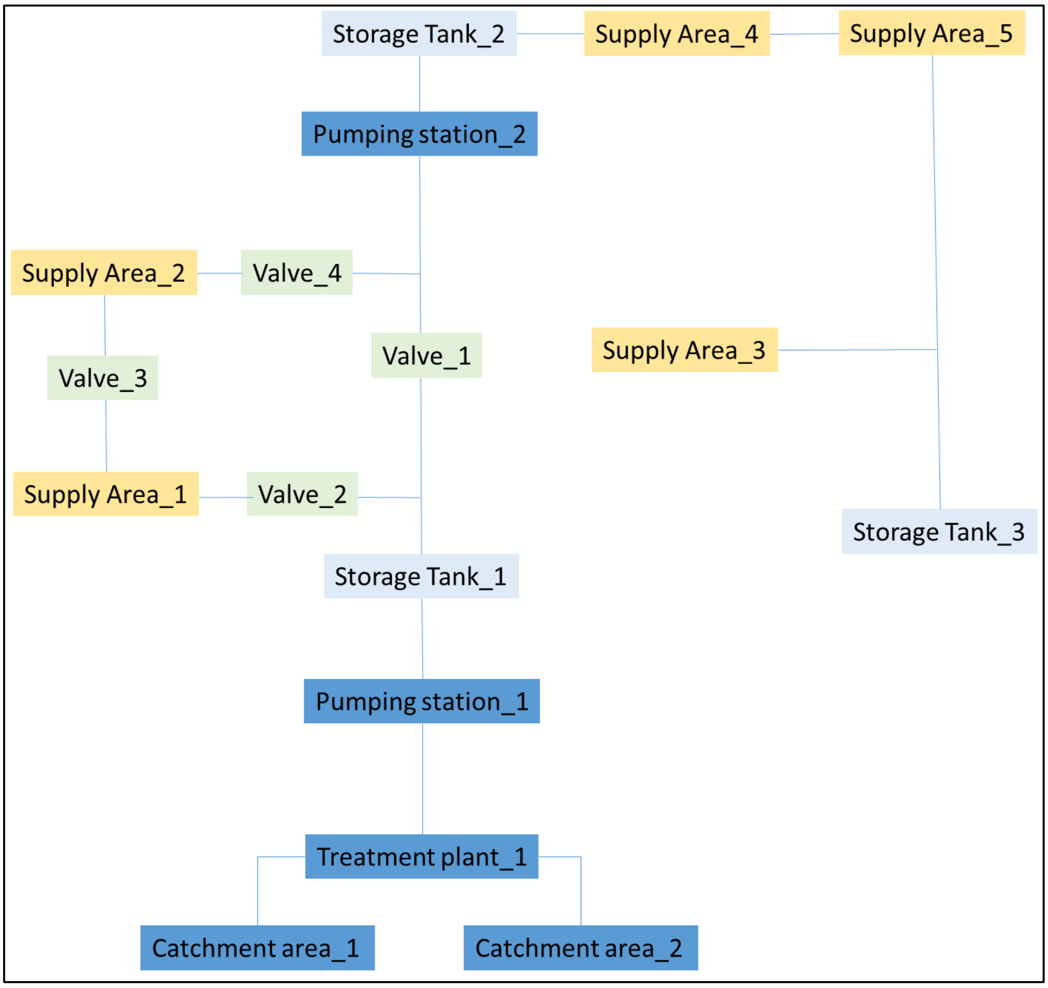

Figure 3: Scheme of the supply system

In the following, the input to the EXCEL-sheet "*Input_Example*_1" according to the example is described step by step.

The input starts with entries in the first column from left to right. The entries must follow the corresponding syntax.

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1.3.1 Enter information about how elements in the network are connected into columns.

Linkobjects are

- Pipes: P_<unique name or id>
- Valves: V_<unique name or id>
- Pumps: PP_<unique name or id>

Nodetypes are:

- Junction: J_<unique name or id>
- Tank: T_<unique name or id>
- Reservoir: R_<unique name or id>

For every object type <unique name or id> corresponds to a unique identifier within that object type. Therefore, allowed names are for example P_1, P_one and P_main, although it is recommended to use numeric, increasing ID´s of the form P_1, P_2, P_3, etc.

Please name all objects of your network as seen in Figure 4 and enter topological information in columns B to D of the EXCEL-input-sheet.

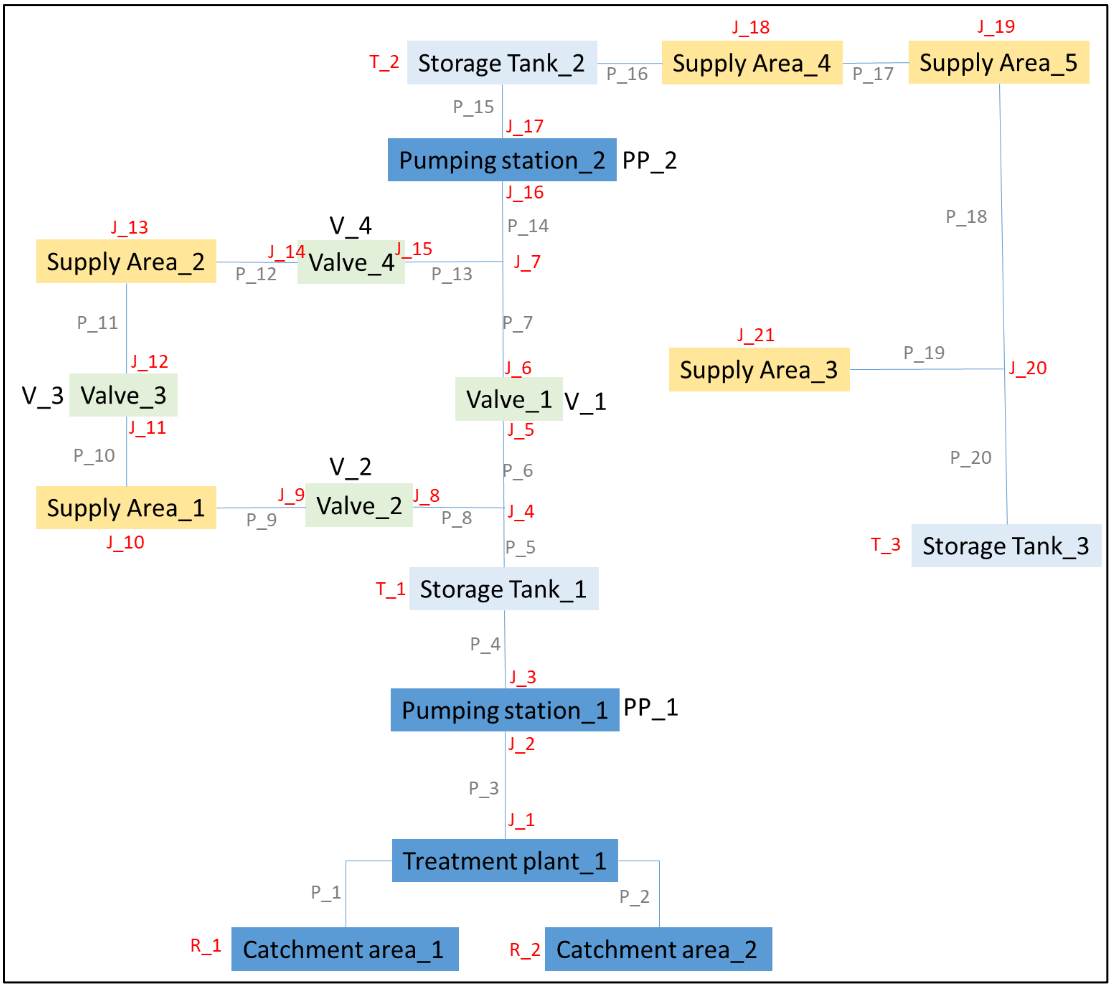

Figure 4: Labeling of the model elements

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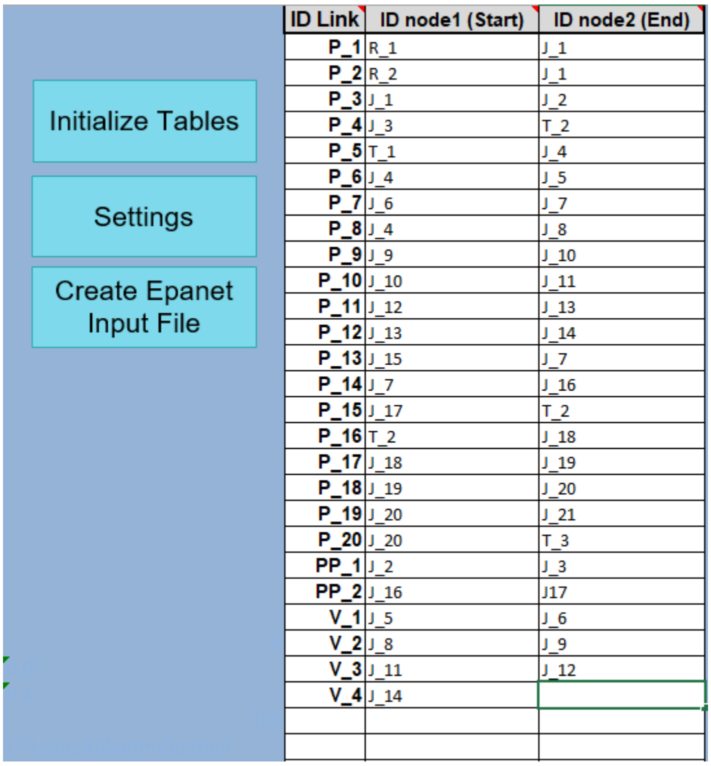
The Catchment areas are mapped as reservoir (R_1 and R_2). Tanks are described as node objects with T_. The Supply areas are node objects (J_). Additional nodes are required at all pipeline intersections. Pumps and Valves are links, which means they have a start and end point (J_). The drinking water treatment plant is not explicitly considered, because it has no effect on the hydraulic model. Figure 5 shows how to enter the model elements according to the sketch. The entry is made from left to right. Accordingly, a start and end point is defined for each link object.



ID Link	ID node1 (Start)	ID node2 (End)
P_1	R_1	J_1
P_2	R_2	J_1
P_3	J_1	J_2
P_4	J_3	T_2
P_5	T_1	J_4
P_6	J_4	J_5
P_7	J_6	J_7
P_8	J_4	J_8
P_9	J_9	J_10
P_10	J_10	J_11
P_11	J_12	J_13
P_12	J_13	J_14
P_13	J_15	J_7
P_14	J_7	J_16
P_15	J_17	T_2
P_16	T_2	J_18
P_17	J_18	J_19
P_18	J_19	J_20
P_19	J_20	J_21
P_20	J_20	T_3
PP_1	J_2	J_3
PP_2	J_16	J17
V_1	J_5	J_6
V_2	J_8	J_9
V_3	J_11	J_12
V_4	J_14	

Figure 5: Enter of the model elements according to the sketch

1.3.2 Press Initialize Tables button to create entries in the remaining tables

In the next step, the entered elements are distributed to the descriptive tables. To do this, press the button *Initialize Tables* (Figure 6).

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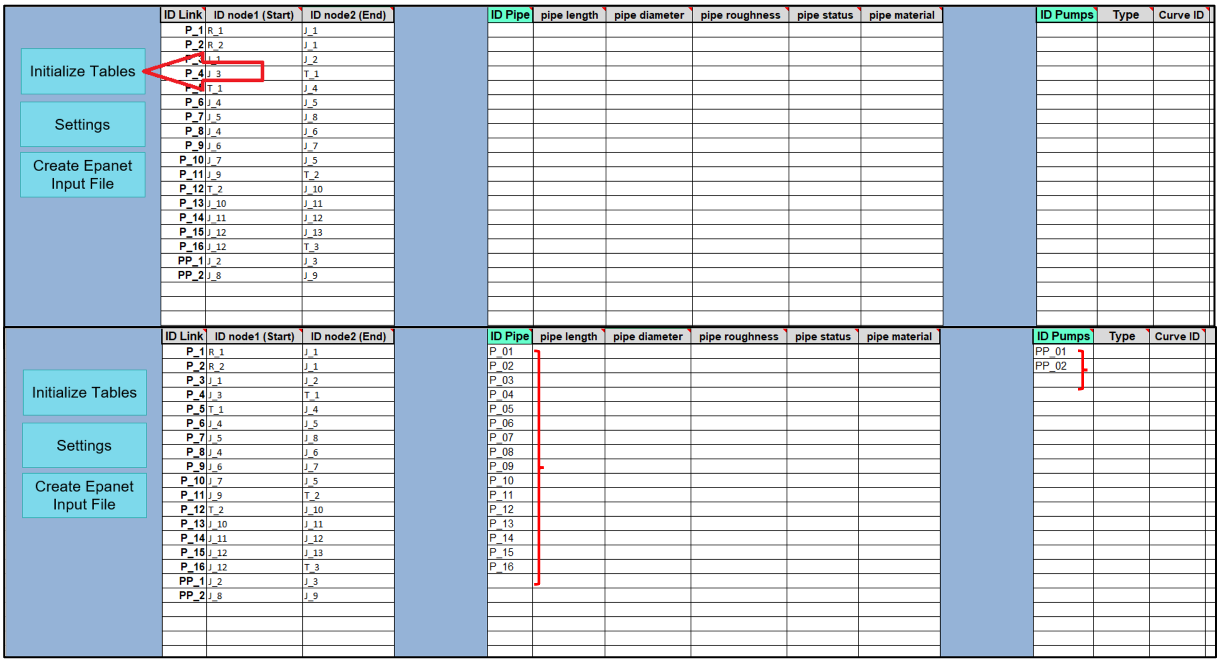

Figure 6: Button Initialize Tables

1.3.3 Enter detailed information on all network elements in the initialized tables (Columns F to AR)

The tables can now be filled in for all elements. For a short description of a network element's properties hover your mouse over the column's header (Figure 7).

Pipes

For the pipes, the length [m], diameter [mm], roughness and pipe status (Open / Closed / CV = check valve) must be specified. Additionally (informative), the material can be specified (Figure 7).

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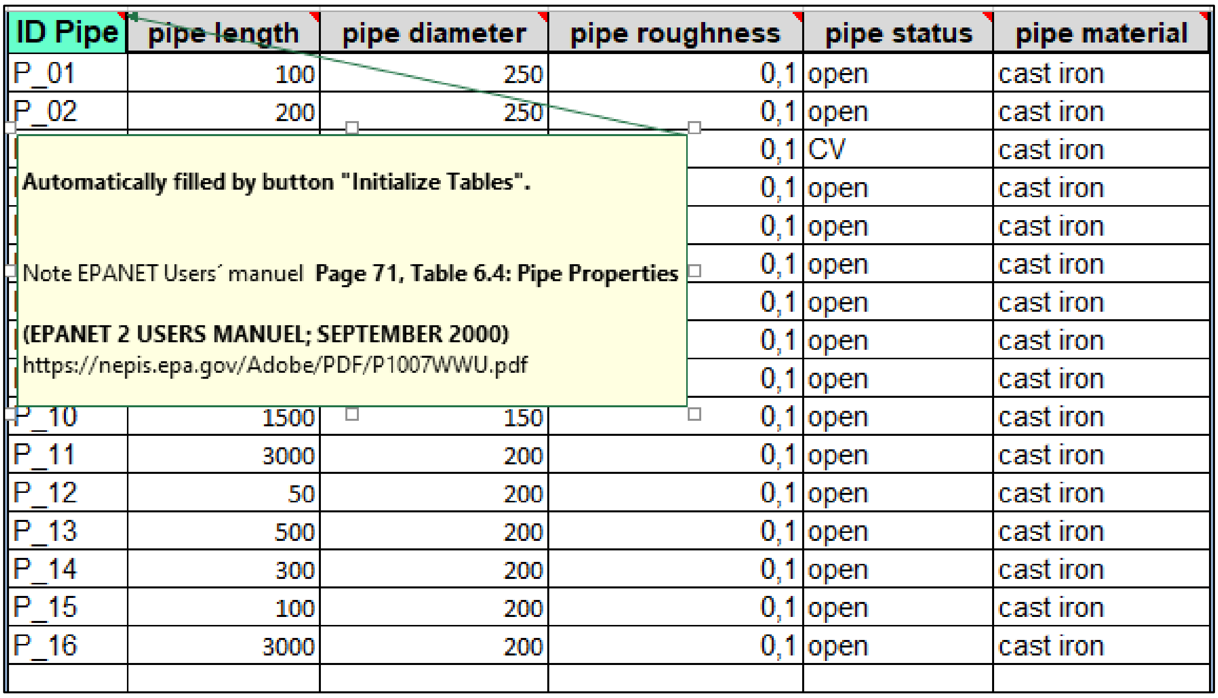


ID Pipe	pipe length	pipe diameter	pipe roughness	pipe status	pipe material
P_01	100	250	0,1	open	cast iron
P_02	200	250	0,1	open	cast iron
			0,1	CV	cast iron
			0,1	open	cast iron
			0,1	open	cast iron
			0,1	open	cast iron
			0,1	open	cast iron
			0,1	open	cast iron
			0,1	open	cast iron
P_10	1500	150	0,1	open	cast iron
P_11	3000	200	0,1	open	cast iron
P_12	50	200	0,1	open	cast iron
P_13	500	200	0,1	open	cast iron
P_14	300	200	0,1	open	cast iron
P_15	100	200	0,1	open	cast iron
P_16	3000	200	0,1	open	cast iron

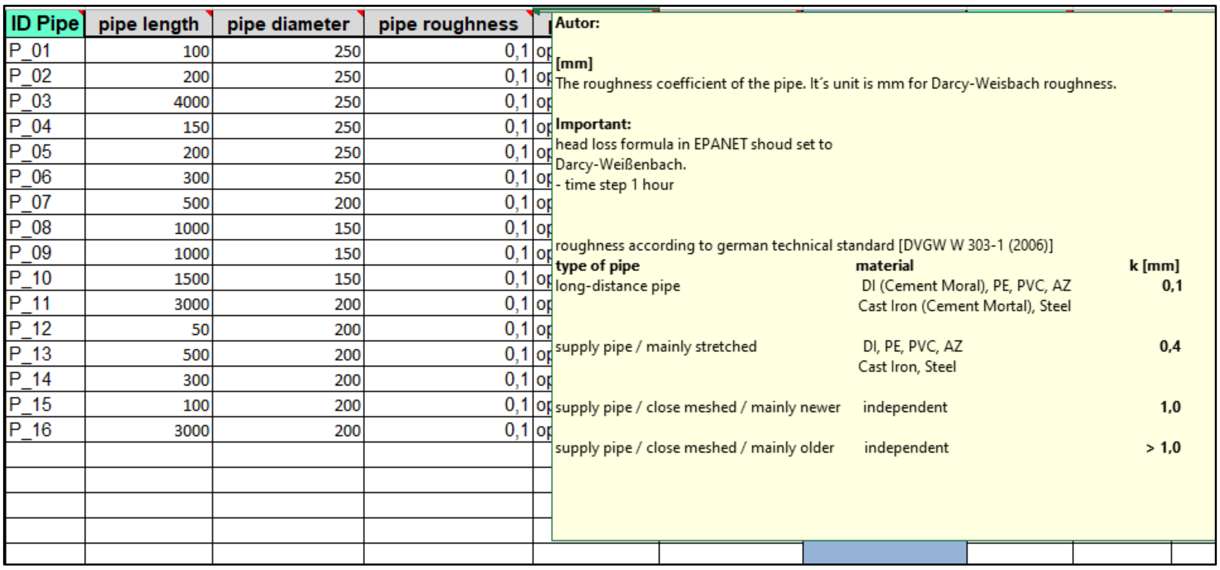
Automatically filled by button "Initialize Tables".

Note EPANET Users´ manuel **Page 71, Table 6.4: Pipe Properties**

(EPANET 2 USERS MANUEL; SEPTEMBER 2000)
https://nepis.epa.gov/Adobe/PDF/P1007WWU.pdf

Figure 7: Pipe Specifications (units are specified in the EXCEL sheet)

If the roughness of the pipes is not known, default values may be used, which are defined as recommendations in the German Technical Standard DVGW W 303 [2] (Figure 8).



ID Pipe	pipe length	pipe diameter	pipe roughness	
P_01	100	250	0,1	op
P_02	200	250	0,1	op
P_03	4000	250	0,1	op
P_04	150	250	0,1	op
P_05	200	250	0,1	op
P_06	300	250	0,1	op
P_07	500	200	0,1	op
P_08	1000	150	0,1	op
P_09	1000	150	0,1	op
P_10	1500	150	0,1	op
P_11	3000	200	0,1	op
P_12	50	200	0,1	op
P_13	500	200	0,1	op
P_14	300	200	0,1	op
P_15	100	200	0,1	op
P_16	3000	200	0,1	op

Autor:

[mm]
The roughness coefficient of the pipe. It´s unit is mm for Darcy-Weisbach roughness.

Important:
head loss formula in EPANET shoud set to Darcy-Weißenbach.
- time step 1 hour

roughness according to german technical standard [DVGW W 303-1 (2006)]

type of pipe	material	k [mm]
long-distance pipe	DI (Cement Moral), PE, PVC, AZ Cast Iron (Cement Mortal), Steel	0,1
supply pipe / mainly stretched	DI, PE, PVC, AZ Cast Iron, Steel	0,4
supply pipe / close meshed / mainly newer	independent	1,0
supply pipe / close meshed / mainly older	independent	> 1,0

Figure 8: Pipe Roughness (units are specified in the EXCEL sheet)

Additional information on pipes can be found in EPANET Users' manual [1] Page 71, Table 6.4: Pipe Properties.

Pumps

Initially, the pump types must be defined. If a pump curve is known, select HEAD. An ID must

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be assigned to a pump curve that can be used for other pumps as well if they share the same curve. At least one pair of values for flow rate [m³/h] and pressure [m] (X and Y) must be specified, which is later used to compute a characteristic curve in EPANET. If known, additional pairs of values can be added in EPANET. Choose type POWER only if no pump curve is known and enter the power supplied by the pump in kilowatts (kW). In this case it is assumed that the pump supplies the same amount of energy no matter what the flow is. (Figure 9)

ID Pumps	Type	Curve ID	X	Y
PP_01	HEAD	1	2160	60
PP_02	HEAD	2	1500	120

Figure 9: Pumps Specifications (units are specified in the EXCEL sheet)

Additional information on pumps can be found under EPANET Users' manual Page 72, Table 6.5: Pump Properties [1].

Valves

The diameter [mm], type, type settings and height must be defined as properties (Figure 10).

ID Valve	Diameter	Type	Setting	elevation
V_01	250	FCV	100	80
V_02	250	FCV	90	70
V_03	250	FCV	40	75
V_04	250	FCV	0	55

Figure 10: Valves Specifications (units are specified in the EXCEL sheet)

The different types of valves included in EPANET are:

- Pressure Reducing Valve (PRV)
- Pressure Sustaining Valve (PSV)
- Pressure Breaker Valve (PBV)
- Flow Control Valve (FCV)
- Throttle Control Valve (TCV)
- General Purpose Valve (GPV).

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PRVs limit the pressure at a point in the pipe network. PSVs maintain a set pressure at a specific point in the pipe network. PBVs force a specified pressure loss to occur across the valve. Flow through the valve can be in either direction. PBV's are not true physical devices but can be used to model situations where a particular pressure drop is known to exist. FCVs limit the flow to a specified amount. The program produces a warning message if this flow cannot be maintained without having to add additional head at the valve (i.e., the flow cannot be maintained even with the valve fully open). TCVs simulate a partially closed valve by adjusting the minor head loss coefficient of the valve. GPVs are used to represent a link where the user supplies a special flow - head loss relationship instead of following one of the standard hydraulic formulas. They can be used to model turbines, well draw-down or reduced-flow backflow prevention valves. Each type of valve has a different type of setting parameter that describes its operating point (pressure for PRVs, PSVs, and PBVs; flow for FCVs; loss coefficient for TCVs, and head loss curve for GPVs). [1]

For additional information on valves, see EPANET Users' manual page 73, Table 6.6: Valve Properties [1].

Tanks

Tanks are modeled as node objects with storage function. Tanks decouple the network hydraulically and specify the pressure level in the downstream network according to their filling level. For tanks, the elevation [m], the initial level of the water level, the minimum level (will not fall below in operation) and the maximum level (will not be exceeded during filling) must be specified (Figure 11). Furthermore the diameter and optionally the parameters MinVol and volumecurv are to be defined. Volumecurv is only used if the relation between level and storage volume is not linear.

ID TANKS	Elevation	InitLevel	MinLevel	MaxLevel	Diameter	MinVol	volumecurv
T_01	150	3	1	5	30		
T_02	95	2	1	4	50		
T_03	85	3	1	4	40		

Figure 11: Tank Specification (units are specified in the EXCEL sheet)

Additional information on tanks can be found in the EPANET Users' manual page 69, Table 6.3: Tank Properties [1].

Reservoirs

Reservoirs are nodes that represent an infinite external source or sink of water to the network. They are used to model such things as lakes, rivers, groundwater aquifers, water wells, and tie-ins to other systems. Reservoirs can also serve as water quality source points. The primary input properties for a reservoir is its hydraulic head (equal to the water surface elevation if the reservoir is not under pressure). Because a reservoir is a boundary point to a

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network, its head cannot be affected by what happens within the network. Therefore it has no computed output properties. However its head can be made to vary with time by assigning a time pattern to it, which reflects changes in groundwater table or reservoir level (Figure 12).

ID reservoirs	head	pattern	elevation
R_01	145		140
R_02	145		140

Figure 12: Reservoirs Specification (units are specified in the EXCEL sheet)

Additional information on reservoirs can be found in EPANET Users' manual Page 69, Table 6.2: Reservoir Properties [1].

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Junctions

Junctions are used to display branches or connection points; accordingly, each junction must be assigned an elevation. Junctions are used to model the water demand by the consumers. A demand [m^3/h] is assigned to each junction. A negative demand value is used to indicate an external source of flow into the junction. If there are no consumptions or feeds, then 0 should be entered. (Figure 13).

ID Junctions	elevation	demand
J_01	130	0
J_02	130	0
J_03	130	0
J_04	140	0
J_05	80	0
J_06	80	0
J_08	80	0
J_09	70	0
J_10	70	50
J_11	70	0
J_12	75	0
J_13	75	40
J_14	75	0
J_15	55	0
J_16	55	0
J_07	50	0
J_17	50	0
J_18	50	30
J_19	50	50
J_20	50	0
J_21	40	20

Figure 13: Junctions Specifications (units are specified in the EXCEL sheet)

Additional information on reservoirs can be found in EPANET Users' manual Page 68, Table 6.1: Junction Properties [1].

All the necessary properties were thus defined for the model.

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1.3.4 Press Settings to choose an output location.

Pressing the *Settings* chooses the default location which corresponds to the current folder. If you choose to change the advanced settings please refer to the section Advanced Settings below (Figure 14).

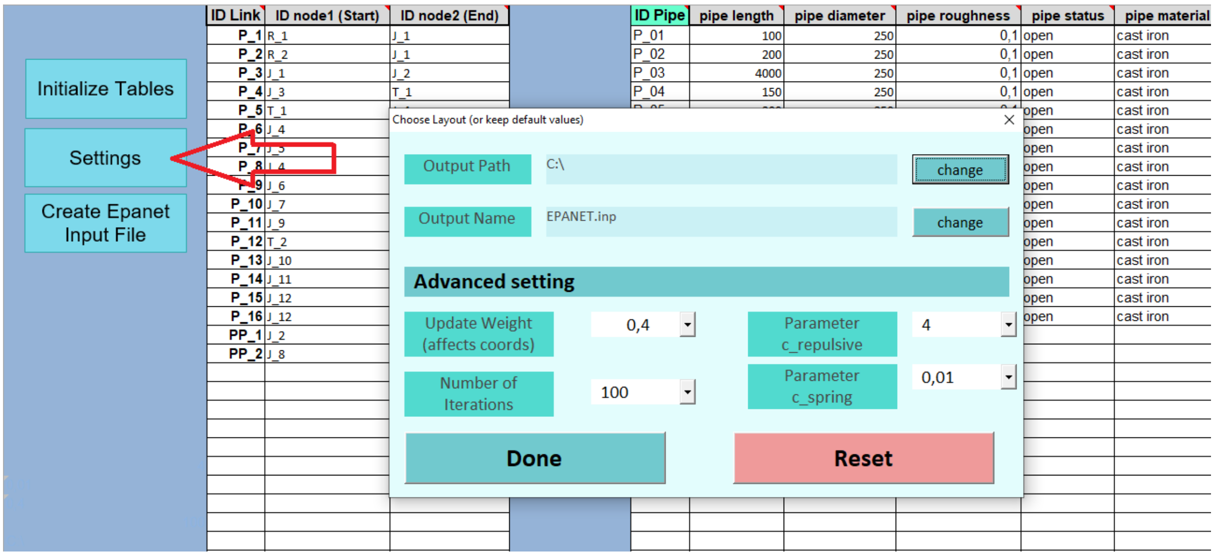

Figure 14: Folder of the file

1.3.5 Press Create Epanet Input File.

Note: If this step consumes a large amount of time (e.g. 10min+), please consider changing the iterations parameter (see section Advanced Settings).

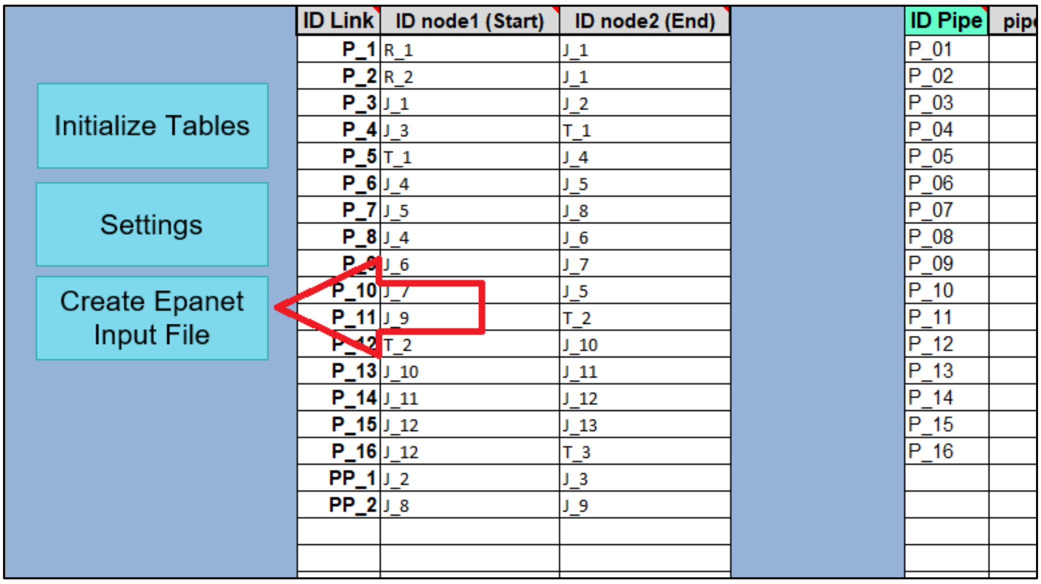

Figure 15: Create EPANET File

Since the model creation is not georeferenced, the position of the point objects (junctions,

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tanks and reservoirs) is calculated according to the number of links and the pipeline length.

This generates a user interface in EPANET without additional effort. Options available in EPANET, such as the graphical output of hydraulic parameters (pressure, flow velocity, etc.) can be traced. The generated model can still be modified with little effort, e.g. to adapt it to an existing sketch / scheme.

The type of automatic assignment of the position is described in more detail under *Advanced Settings*.

1.3.6 Import Network into EPANET and do computations

When loading the file, make sure to select INP as file type. See Figure 16.

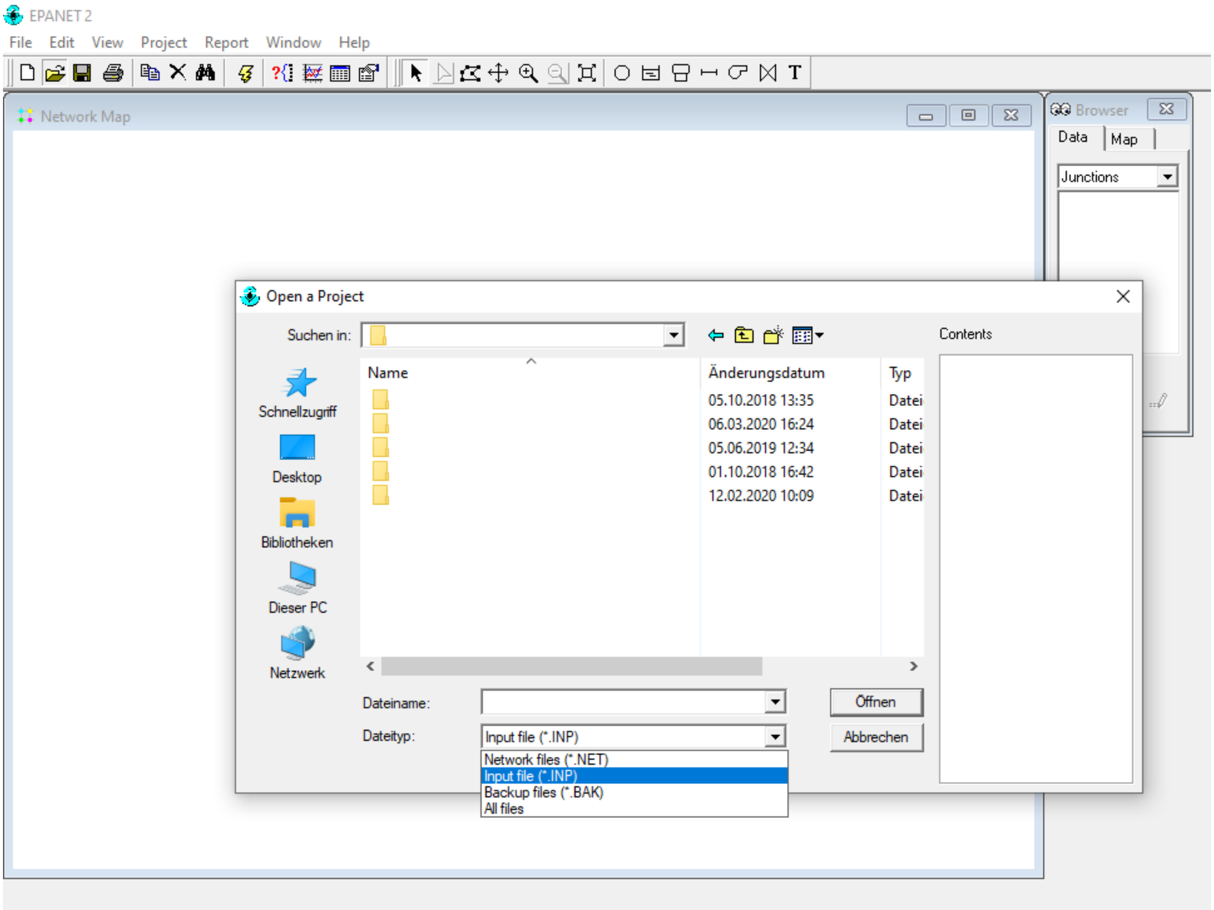

Figure 16: Choose INP

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The generated model is shown in Figure 17.

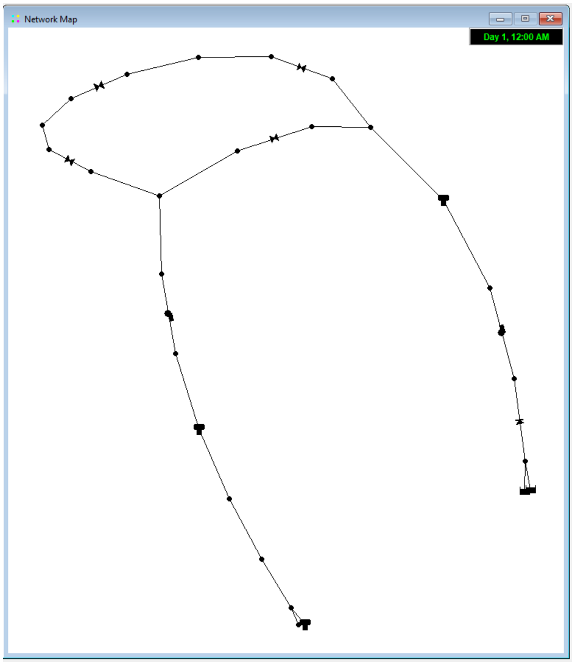

Figure 17: Generated EPANET Model according to sketch shown in Figure 3

Calculation results can be displayed graphically in EPANET (Figure 18).

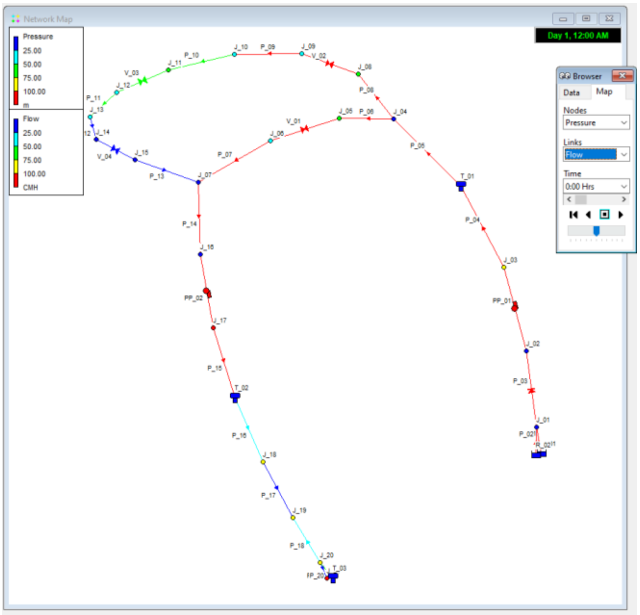

Figure 18: Generated EPANET Model – with calculation results

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1.4 Remarks

- For a short description of a network element's properties hover your mouse over the column's header
- For a detailed description of a network element's properties please refer to the EPANET users´s manual [1] chapter 6.4 (download: https://www.epa.gov/water-research/epanet)
- The advanced settings can help in controlling the computation time and network layout (x,y coordinates in EPANET) although it is recommended to keep the default settings if everything works fine.
- Changing the advanced settings may lead to errors during the creation of the EPANET input file.
- The generated model and all properties can be modified and complemented in EPANET.
- The computation of the x and y coordinates for the network layout works well for smaller networks (< 1000 network components).

1.5 Limitations

- Every Curve ID (Column O in Excel file “EES”, sheet “Input”) must correspond to exactly one pump, not multiple pumps. There may however be multiple entries of the same curve ID and the same pump with differing x and y values
- In every table (e.g. columns B to D) entries must be continuous, entries that follow an empty line are disregarded
- Changing the Advanced Setting (see below) may cause overflow errors.

1.6 Advanced Settings

The layout of the resulting network is computed with a spring embedder algorithm [3] and its performance is controlled by four parameters (Figure 19). As changing the parameters may lead to unexpected behaviour, it is recommended to keep the default parameters unless either the computation time is too long or the network layout (when loaded into EPANET) is unusable. For more than 1000 nodes with the iterations parameter set to 100, a computation time of 10+ minutes is not unusual. The computation time can be largely reduced by setting iterations to 1, although the visual representation of the network in EPANET will suffer.

- **Iterations**: Number of iterations for the algorithm to compute appropriate coordinates. More iterations cause longer computation times but more appealing network layouts.
- **Update weight**: Controls by how much every coordinate is updated after each iteration. A higher update weight may lead to a more appealing network layout after less iterations.
- **c_repulsive:** A (spring) constant that indicates the force with which the network’s nodes are pulled together. In theory, large values cause a tighter network.
- **c_spring**: A (spring) constant that indicates the force with which the network’s nodes are pushed apart. In theory, large values cause a more expanded network.

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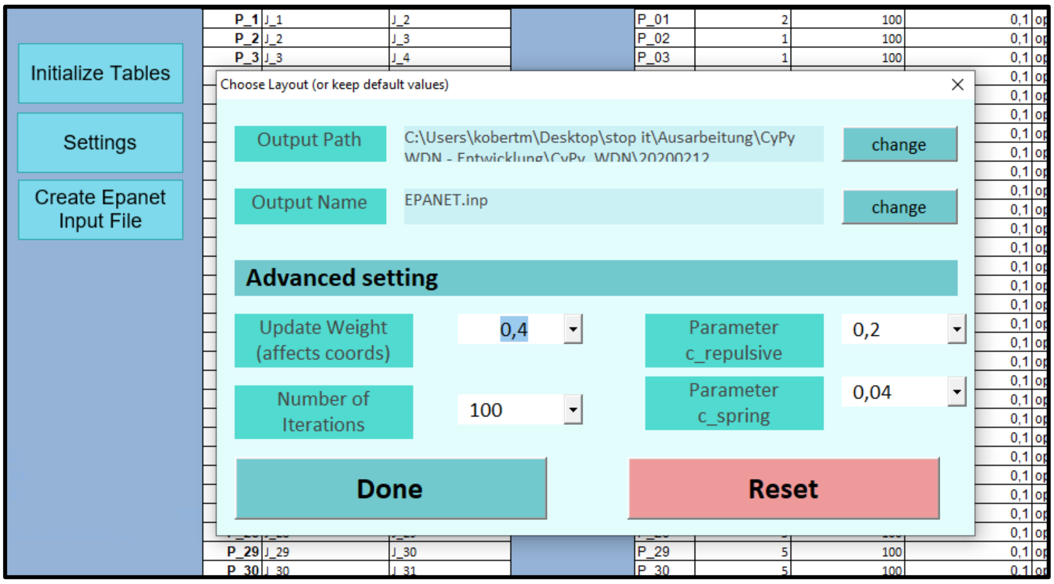

Figure 19: Settings in EES

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2. References

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[3] Kobourov, Stephen G (2012). Spring embedders and force directed graph drawing algorithms. e-print, University of Arizona. https://arxiv.org/pdf/1201.3011.pdf

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