X-WHAT.

Modeling and Design Optimization of Looped Water Distribution Networks using MS Excel

User Manual

Excel engine	version 1.5
WebGUI	version 0.0.2 (Release 1)
Manual	version 2.0

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All software, figures, and data can be freely accessed at
`https://github.com/marcusnobrega-eng/X-WHAT` |
`https://marcusnobrega-eng.github.io/X-WHAT/`

Disclaimer

Accuracy. While every effort has been made to ensure the accuracy of the information, this document may contain errors or omissions.

Updates. The document is subject to change without notice. Always refer to the latest version available in the project repository.

This manual is intended to be practical and concise. It complements the technical documentation given in the original publication. For all theoretical aspects regarding the development of the tool, consult the paper referenced below and the Theoretical Framework page of the project website.

This project is fully open source and all functionalities of the spreadsheet remain unlocked. Executing the tool and modifying its configuration are done at the user's own risk. Neither the authors nor the institutions with which they are associated assume responsibility for program modifications, content, output, interpretation, or usage.

Reference publication

Gomes Jr., M.N., Benites, I.M., Elsherif, S.M., Taha, A.F., Giacomoni, M.H. *Modeling and Design Optimization of Looped Water Distribution Networks using MS Excel: Developing the Open-Source X-WHAT Model.* Pre-print available at arXiv:2405.09044.

Contents

Part I

Getting Started

Chapter 1

Introduction

1.1 Purpose of this manual

This manual is the practical guide of the X-WHAT model, an open source tool for the simulation and design optimization of looped water distribution networks. It covers the two components of the tool and the complete workflow that connects them.

- The **Excel engine**, the workbook `X-WHAT_Model_V1.5.xlsm`, where all hydraulic and cost calculations are performed with built-in worksheet functions and the Excel Solver.
- The **WebGUI**, the set of web pages hosted with the project that includes the **Network Builder**, used to draw networks and export input packages, and the **Results** viewer, used to visualize solved workbooks.

The model requires no coding expertise. Every equation is exposed in spreadsheet cells that can be audited, traced, and modified, which makes the tool suitable for engineering practice and especially convenient for teaching hydraulic modeling and network optimization.

1.2 What X-WHAT does

Given the topology of a pressurized looped network, its pipe properties, and its boundary conditions, X-WHAT solves two classes of problems.

Water Flow Problem (WFP/HSP). Also called Hydraulic Simulation Problem. Determines the discharge and the direction of flow in every pipe so that mass conservation is satisfied at all nodes and energy conservation is satisfied in all loops. Unlike the classical Hardy-Cross procedure, no mass-conservative initial estimate is required.

Design Optimization Modeling (DOM). Finds, in addition to the flows, the tank water depths and tower heights that minimize the total cost of the network while keeping all nodal pressures within prescribed bounds. The cost function accounts for pipelines, pumping energy in present value, tank material, and tank foundation under wind loading.

Both problems are solved with the GRG Nonlinear engine of the Excel Solver.

1.3 How this manual is organized

The manual follows the order in which the tool is used.

Part I, Getting Started. The concepts, the components of the network, and the conventions adopted by the model.

Part II, Building the Network. The Network Builder, from the first node to the exported input package.

Part III, Solving in Excel. The workbook sheets, the incidence matrices, and the Solver configuration for simulation (Chapter 6) and optimization (Chapter 7).

Part IV, Results and Reference. The Results viewer, two worked examples reproduced from the publication, the troubleshooting guide, and the glossary of symbols.

1.4 Project resources

- Project website, with the Network Builder, the Results viewer, the Theoretical Framework, and the online manual:
  `https://marcusnobrega-eng.github.io/X-WHAT/`
- Repository, with the workbook, the source files, and the latest version of this manual:
  `https://github.com/marcusnobrega-eng/X-WHAT`

1.5 Typographic conventions

- **Bold** text identifies interface elements such as buttons, menus, and dialog names.
- `Monospaced` text identifies file names, cell references, and ranges, for example `Memory!BT51`.
- Tip boxes highlight shortcuts and good practices. Attention boxes flag frequent mistakes.

Chapter 2

Concepts, Components, and Conventions

This chapter gathers the concepts needed to operate the tool. The complete mathematical development is presented in the reference publication and summarized on the Theoretical Framework page of the project website.

2.1 Network components and notation

The network is described by nodes and links. Table 2.1 lists the elements of the model and the assumptions attached to each of them, and Figure 2.1 shows how they appear in the Network Builder.

Table 2.1: Components of the water distribution network model.

Element	**Class**	**Definition in the model**
Junction	Node	Connects two or more links. Defined by a ground elevation z from a reference datum. Receives the demand withdrawals Q_d, positive when water leaves the network.
Tank / Reservoir	Node	Storage element defined by the piezometric head at its surface. Under the steady-state design condition it holds a fixed head h_r, which becomes a decision variable in DOM runs. Tanks and reservoirs are treated interchangeably.
Pipe	Link	Conveying element with constant slope, defined by the diameter D, the length L, and one friction property, the roughness ϵ for Darcy-Weisbach or the coefficient C for Hazen-Williams.
Pump	Link	Used exclusively to fill the tanks. Defined by the daily operating hours n_p, the efficiency η_p, the ground elevation z_p, and a linear head loss coefficient k_p for the supply line. Pumps do not alter the hydraulic state of the network, they enter the problem through the energy cost.
Valve	Link	All valves are assumed fully open in this version. Minor losses are neglected.

2.2 Sign and numbering conventions

Three conventions govern every input of the model. Keeping them in mind prevents nearly all data entry mistakes.

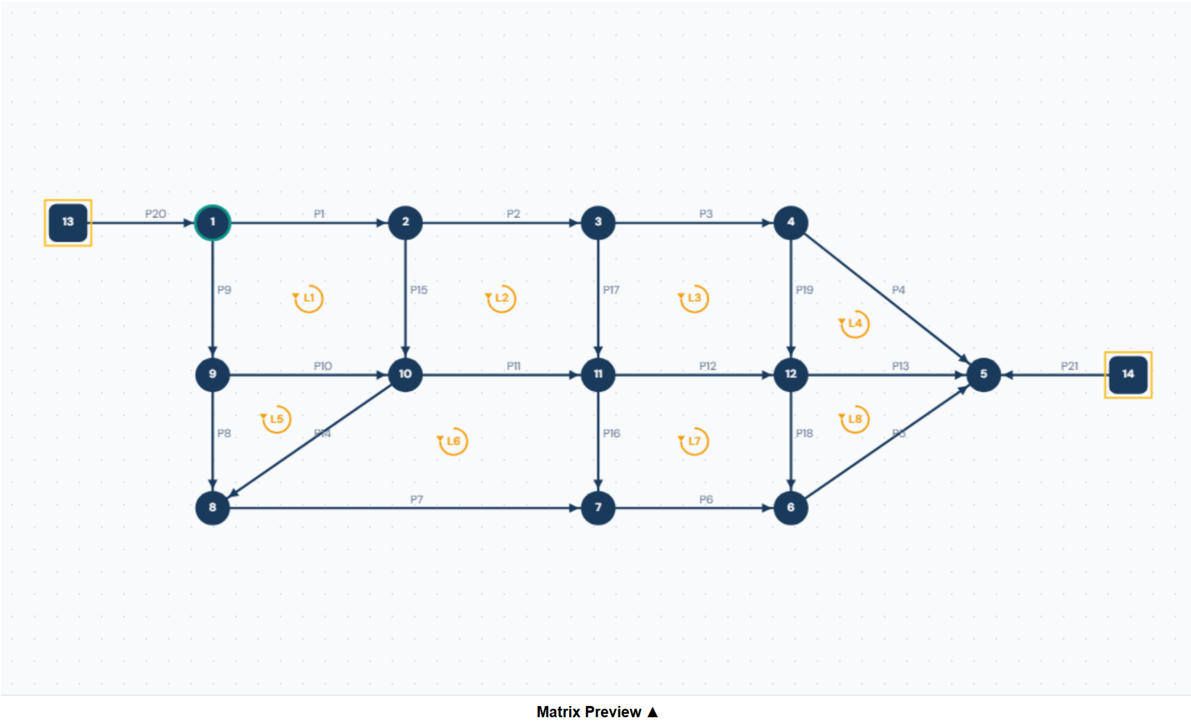


Figure 2.1: A complete network drawn in the Network Builder, the Huddleston (2004) tutorial case. Circles are junctions, squares are tanks, arrows mark the positive direction of each pipe, and the circular arrows mark the loops L1 to L8 with their clockwise circulation.

1. **Continuous numbering.** Nodes and links are numbered continuously, and the tables and matrices of the workbook follow this numbering.
2. **Pipe direction.** The direction assigned to each pipe, from the upstream node to the downstream node, defines its positive flow. A negative discharge in the results means the water flows against the drawn direction, which is a valid outcome.
3. **Clockwise loops.** Every loop follows the clockwise circulation. A pipe aligned with the circulation of its loop takes the sign $+1$ in the energy balance matrix and a pipe against it takes -1.

Demands are positive when water is withdrawn from a node and negative when an external inflow enters the network at that node.

2.3 Governing equations in brief

Mass conservation is imposed at every junction i,

$$\sum_{k=1}^{n_k} Q_{in}^i - \sum_{m=1}^{n_m} Q_o^i - Q_d^i = 0. \tag{2.1}$$

Friction losses in every pipe follow the monomial form $\Delta h_f = k\,Q|Q|^{n-1}$, with k and n given by the selected friction model as summarized in Table 2.2. Energy conservation requires the losses accumulated around every loop v to cancel,

$$\sum_{i=1}^{m_v} k_{v_i}\,Q_{v_i}|Q_{v_i}|^{n-1} = 0. \tag{2.2}$$

Table 2.2: Friction models available in the tool.

Model	k	n	**Notes**
Darcy-Weisbach (D-W)	$\frac{8fL}{D^5\pi^2 g}$	2	Physically based. The friction factor f is computed with an explicit full-range formulation, valid for any Reynolds number. Requires ϵ and ν.
Hazen-Williams (H-W)	$\frac{10.67\,L}{C^{1.85}D^{4.87}}$	1.85	Empirical, standard practice for water at ordinary temperatures. Requires the coefficient C of each pipe material.

The topology enters the model through two incidence matrices. The node incidence matrix $\mathbf{F_d}$ relates links to nodes and supports Eq. (2.1), while the loop incidence matrix $\mathbf{F_l}$ relates links to loops and supports Eq. (2.2). Their construction is the subject of Chapter 5.

2.4 The general workflow

Figure 2.2 presents the general algorithm of the tool, from data entry to the analysis of results. The WebGUI automates the left side of this flow, since the Network Builder produces a package with all tables and matrices filled. The same inputs can be typed directly in the workbook, as detailed in Chapters 4 and 5.

The complete workflow with the WebGUI has six stages.

1. Draw the network in the **Network Builder** or load a tutorial case.
2. Select the analysis mode, WFP/HSP or DOM, and review all inputs.
3. Export the `.xwhat.xml` network package.
4. Import the package into `X-WHAT_Model_V1.5.xlsm` with the **Import Network** feature.
5. Configure and run the Excel Solver.
6. Save the solved workbook and upload it to the **Results** page.

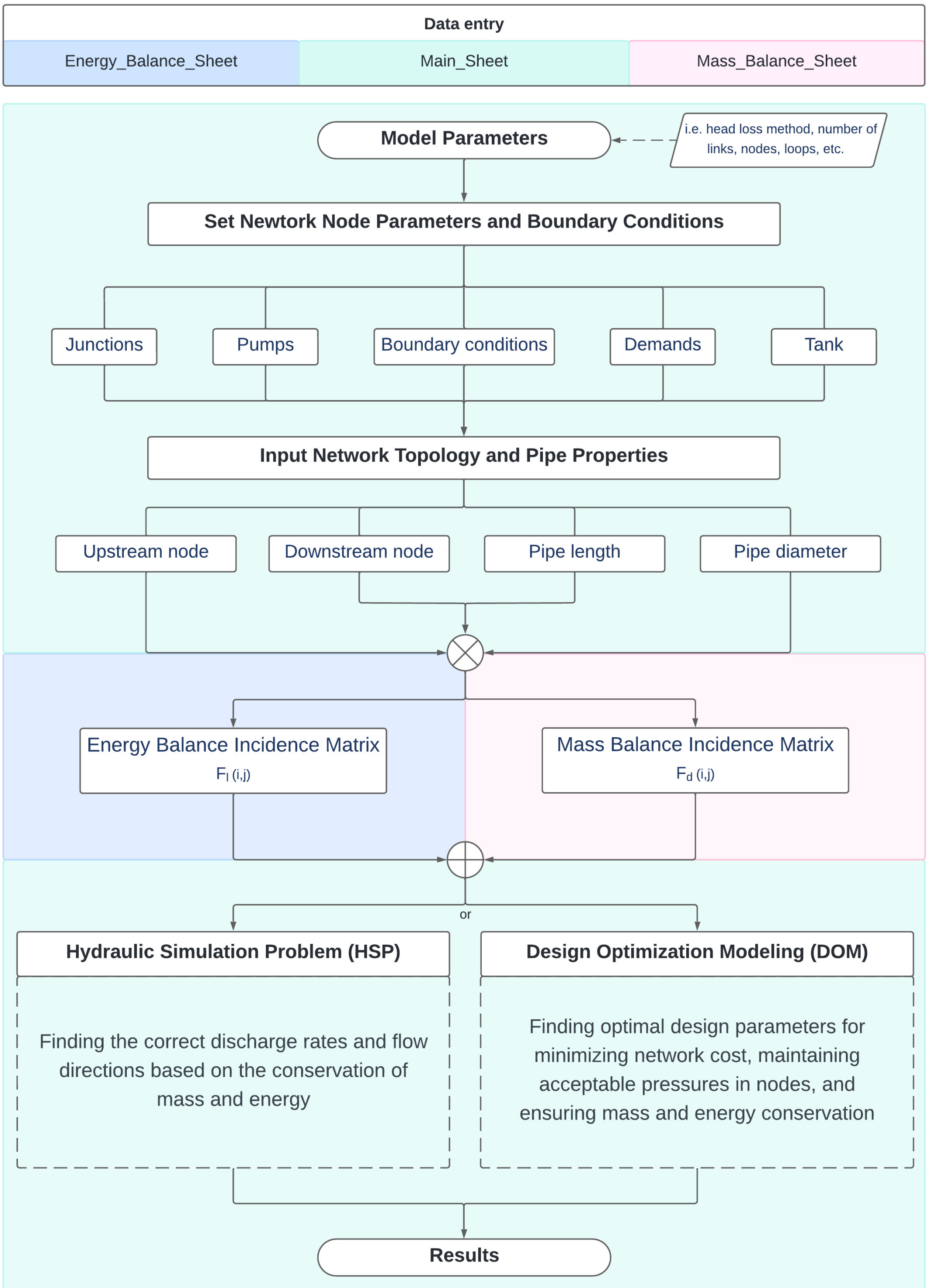


Figure 2.2: General algorithm of the model, from data entry to results.

Part II

Building the Network

Chapter 3

The Network Builder

The Network Builder is the drawing environment of the WebGUI. It runs in any modern browser, requires no installation, and produces the input package consumed by the Excel engine. This chapter describes its interface and the complete drawing procedure.

3.1 Interface overview

Figure 3.1 presents the screen with a tutorial network loaded. The numbered regions are the following.

1. **Toolbar**, with the drawing tools listed in Table 3.1.
2. **Top bar**, with the view controls, the **Settings** dialog, the analysis mode selector, the **Load Tutorial Network** menu, the **Roadmap** guide, and the **Save JSON** and **Load JSON** commands.
3. **Canvas**, where the network is drawn. The mouse wheel and the zoom buttons control the view, and **Fit** frames the entire drawing.
4. **Properties panel**, which edits the data of the selected element.
5. **Matrix Preview**, which expands to display the incidence matrices generated from the drawing.
6. **Export Network Package**, which produces the input file for the Excel engine.

Table 3.1: Drawing tools and keyboard shortcuts, in the order they appear in the toolbar of Figure 3.2.

Tool	Shortcut	Purpose
1. Select	`S`	Select and drag elements, edit their properties.
2. Pan	`H`	Move the view around the canvas.
3. Junction	`J`	Place demand nodes.
4. Tank	`T`	Place tanks and reservoirs.
5. Pipe	`P`	Connect two nodes with a link.
6. Loop	`L`	Group pipes into a closed loop.
7. Delete	`Del`	Remove the clicked element.

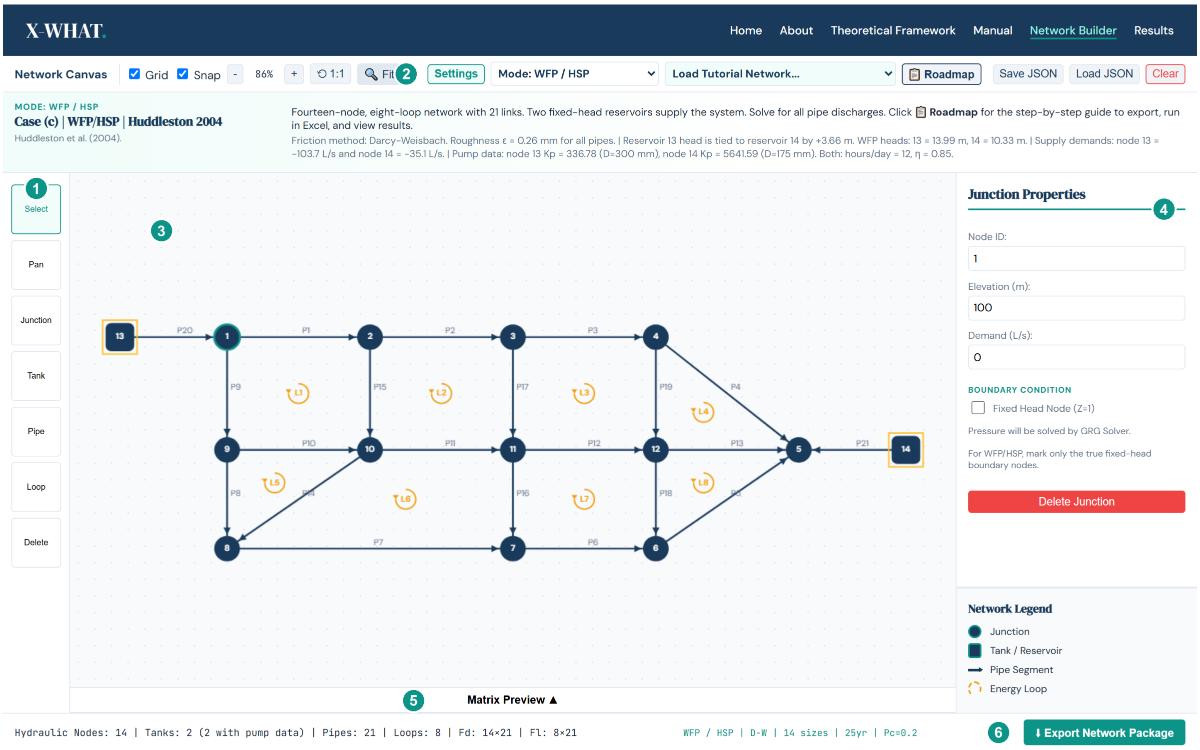


Figure 3.1: The Network Builder with the Huddleston (2004) tutorial case loaded and a junction selected. (1) toolbar, (2) top bar, (3) canvas, (4) properties panel, (5) Matrix Preview, (6) export button.

3.2 Drawing procedure

3.2.1 Placing nodes

Activate the **Junction** tool and click the canvas once per junction. Use the **Tank** tool for tanks and reservoirs. Elements receive a continuous numbering in the order of creation, which later matches the rows of the workbook tables.

Tip. Sketch the system on paper first and reproduce a similar layout on the canvas. A clean drawing makes the loops easier to trace and the results easier to read.

3.2.2 Connecting pipes

Activate the **Pipe** tool, click the upstream node, then click the downstream node. The drawing order defines the positive flow direction of the pipe. To invert a pipe drawn backwards, select it and press **Reverse Direction** in the properties panel.

3.2.3 Editing properties

With the **Select** tool, click any element and edit its fields in the properties panel. Figure 3.3 shows the three panel layouts and Tables 3.2 to 3.4 describe each field.

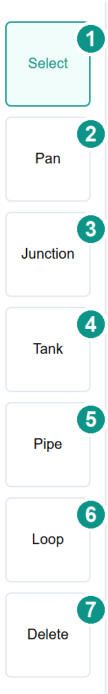


Figure 3.2: The toolbar. The numbers match the rows of Table 3.1.

Table 3.2: Properties of a junction.

Field	Description
Node ID	Identifier shown on the canvas.
Elevation (m)	Ground elevation from the reference datum.
Demand (L/s)	Positive values withdraw water, negative values supply water to the network.
Fixed Head Node	When checked, the node carries a pressure boundary condition.
Pressure Head (m)	Fixed piezometric head above the node elevation, enabled by the previous field.

3.2.4 Defining loops

Activate the **Loop** tool and click, one by one, the pipes that close each loop, following the clockwise circulation. Every independent loop of the network must be defined, since the loops generate the energy balance matrix.

The **Matrix Preview**, at the bottom of the screen, expands into the view of Figure 3.4 and displays the matrices generated from the drawing.

Tip. Check the signs of the generated matrices against the drawing before exporting. Correcting the topology in the browser is faster than correcting it in the workbook.

3.2.5 Boundary conditions

Every tank requires a fixed head. A junction with a known pressure can also be fixed by checking **Fixed Head Node** and entering the pressure head. At least one fixed head must exist in the network, otherwise the hydraulic problem has no reference level.

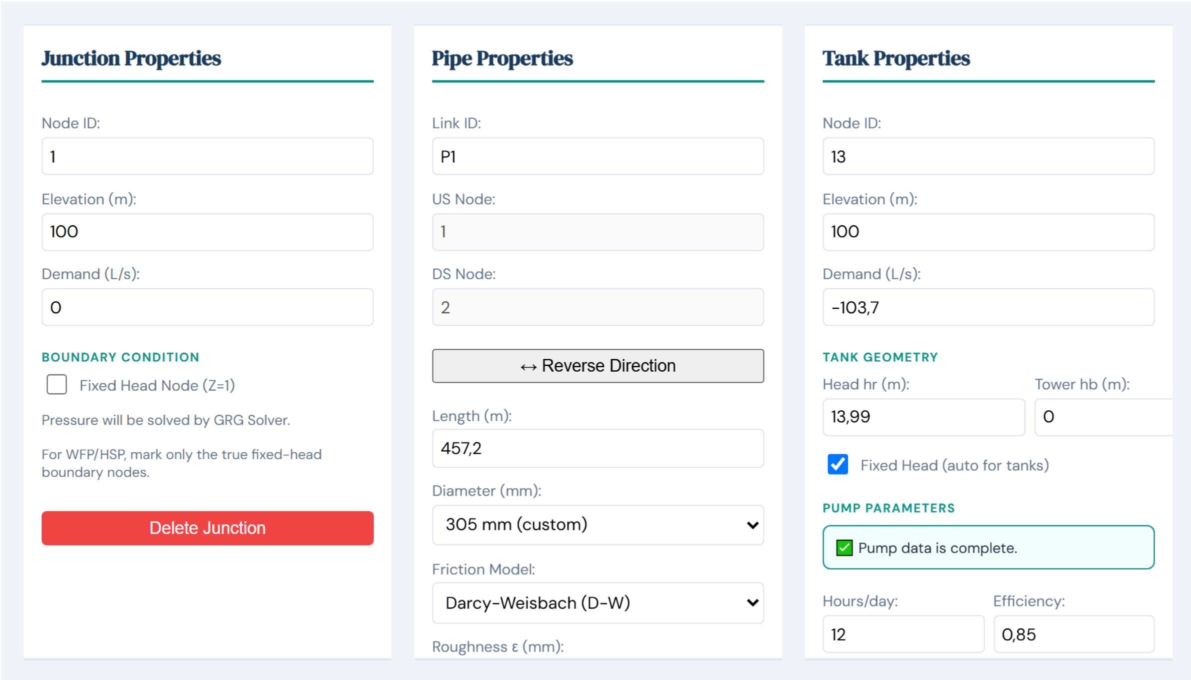


Figure 3.3: The properties panel for a junction (left), a pipe (center), and a tank (right), with the data of the Huddleston (2004) tutorial case.

Table 3.3: Properties of a tank or reservoir.

Field	Description
Node ID	Identifier shown on the canvas.
Elevation (m)	Ground elevation of the tank site.
Demand (L/s)	Negative values represent the supply released to the network.
Head h_r (m)	Water depth above the tank bottom. In DOM mode this is a starting value for the optimization.
Tower h_b (m)	Height of the tank above the ground. Zero for ground tanks.
Hours/day	Daily operating hours of the filling pump.
Efficiency	Pump efficiency, between 0 and 1.
k_p	Linear head loss coefficient of the pump supply line.

3.3 Analysis mode

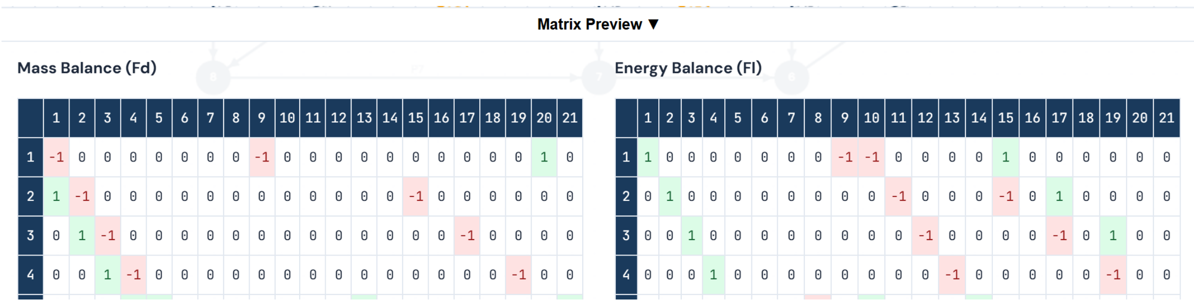
The selector in the top bar switches between the two problem types.

- **Mode: WFP / HSP**, for hydraulic simulation. The Solver finds the flows for the given diameters, demands, and fixed heads.
- **Mode: DOM (Optimization)**, for design optimization. The tank heads and tower heights become decision variables and the values typed in the properties panel act as starting points.

The selected mode is stored in the exported package and adjusts the instructions displayed by the **Roadmap**.

Table 3.4: Properties of a pipe.

Field	Description
Link ID	Identifier shown on the canvas.
US / DS Node	Upstream and downstream nodes, defined by the drawing order.
Length (m)	Pipe length.
Diameter (mm)	Internal diameter, selected from the cost catalog or typed directly.
Friction data	Roughness ϵ in mm for Darcy-Weisbach, or the coefficient C for Hazen-Williams, according to the friction model chosen in the settings.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	-1	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	1	0
2	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0
3	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0
4	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	1	0	0	0	0	0	0	0	-1	-1	0	0	0	0	1	0	0	0	0	0	0
2	0	1	0	0	0	0	0	0	0	0	-1	0	0	0	-1	0	1	0	0	0	0
3	0	0	1	0	0	0	0	0	0	0	0	-1	0	0	0	0	-1	0	1	0	0
4	0	0	0	1	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	-1	0	0

Figure 3.4: The Matrix Preview expanded, with the mass balance matrix $\mathbf{F_d}$ (left) and the energy balance matrix $\mathbf{F_l}$ (right) generated from the drawing.

3.4 Project settings

The **Settings** dialog, shown in Figure 3.5, gathers the global parameters of the model, organized in blocks for the hydraulic model, the economic parameters, and the structural data of the tanks. The values map one to one onto the parameter block of the `Memory` sheet described in Chapter 4. The dialog also holds the pipe cost catalog, a table of commercial diameters with unit costs, roughness, and Hazen-Williams coefficients, which can be edited, extended, or restored to the default values.

3.5 Tutorial networks and the Roadmap

The **Load Tutorial Network** menu provides audited versions of the case studies of the publication.

- Case (b), Porto (2006), in WFP/HSP and DOM configurations.
- Case (c), Huddleston (2004), in WFP/HSP and DOM configurations.

Each tutorial loads the complete drawing with all properties filled. The **Roadmap**, shown in Figure 3.6, then displays the workflow steps with the exact Solver configuration audited for that case, including cell ranges and constraints, ready to be copied into the Solver dialog.

3.6 Saving and exporting

Two different files serve two different purposes.

Save JSON. Stores the drawing itself in an editable file that can be reloaded with **Load JSON** to continue the work later. Use it as the project file of the Network Builder.

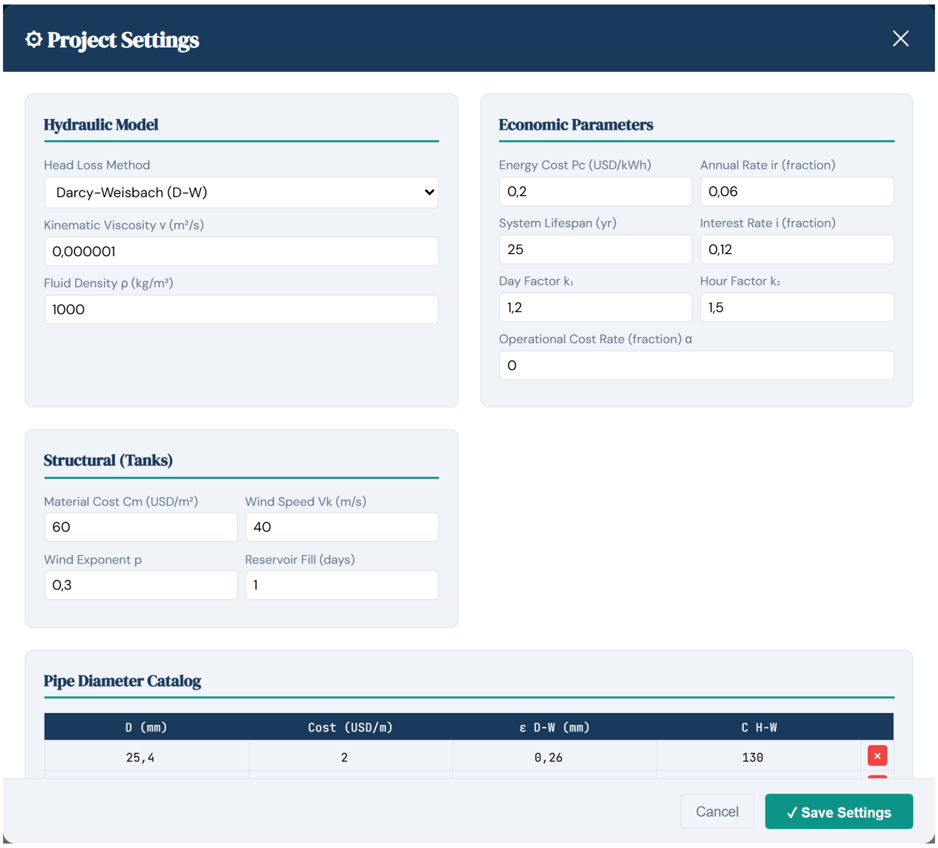


Figure 3.5: The Settings dialog with the hydraulic, economic, and structural parameter blocks and the pipe cost catalog.

Export Network Package. Produces the `.xwhat.xml` input file for the Excel engine, holding the node table, the pipe geometry, both incidence matrices, and the global parameters. The file is a plain, versioned XML document, readable in any text editor. A legacy `.xlsx` export is also offered for compatibility.

The export dialog, shown in Figure 3.7, summarizes the network and validates it first, blocking the operation if inconsistencies are found, for example pipes without geometry or loops with missing definitions. Fix the reported items and export again.

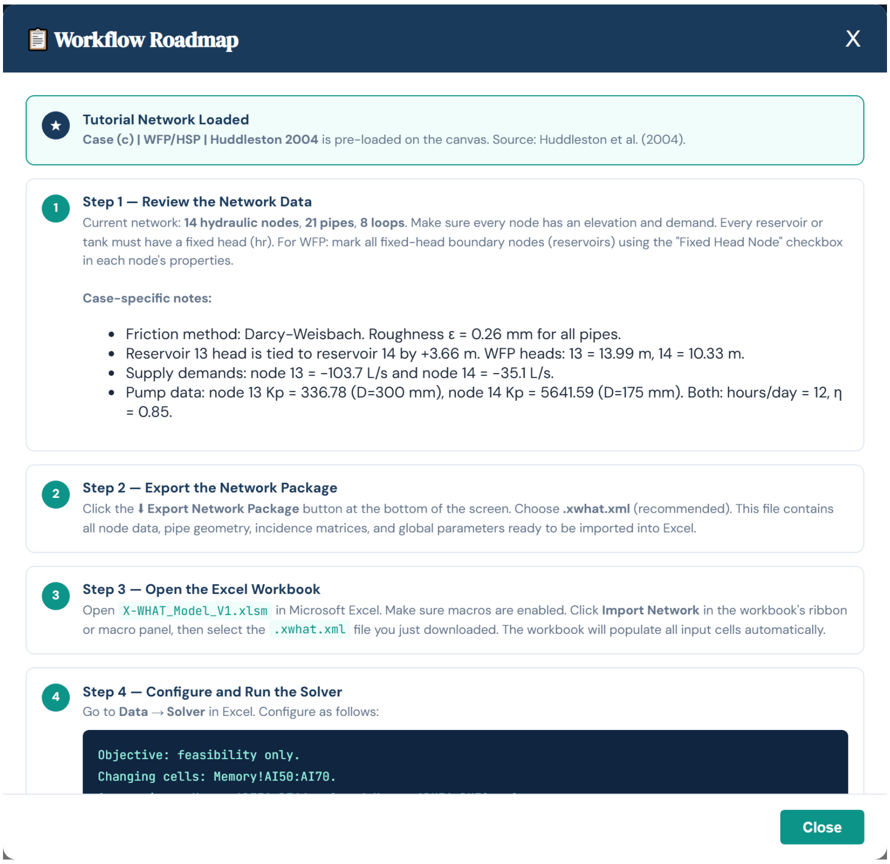


Figure 3.6: The Roadmap with a tutorial case loaded. The final step prints the audited Solver configuration for the loaded network.

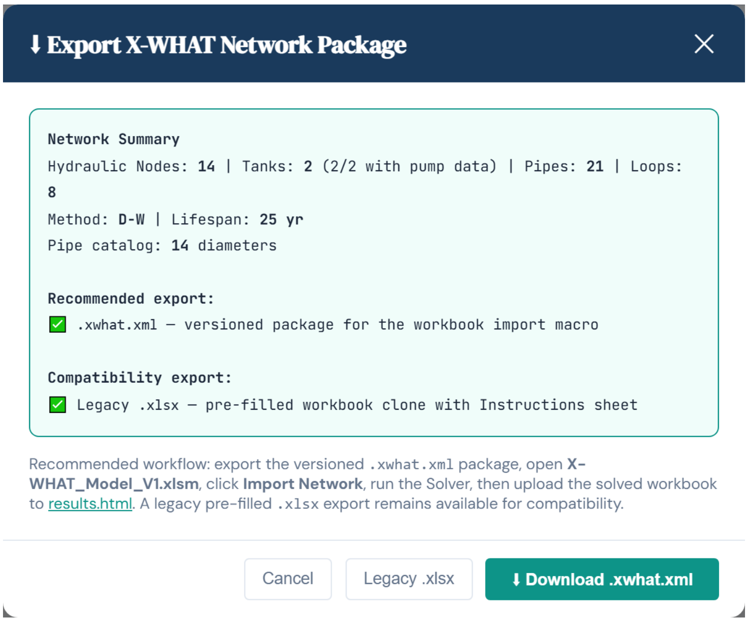


Figure 3.7: The export dialog with the network summary and the two export formats.

Part III

Solving in Excel

Chapter 4

The Memory Sheet

The `Memory` sheet concentrates all parameters, element tables, and cost cells of the Excel engine. This chapter describes each of its blocks in the order they are filled. When the workbook is populated through the **Import Network** feature, the same blocks receive the data of the exported package, and this chapter then serves as a reference for auditing and adjusting the imported values.

The figures of this chapter show the blocks filled with the data of the Huddleston (2004) tutorial case, the same network used in the worked examples of Chapter 9.

> **Attention.** White cells accept user input. Gray cells hold automatic calculations and must not be overwritten. To restore a damaged formula, copy it from an intact cell of the same column or from a fresh copy of the workbook.

4.1 Global parameters

The parameter block sits at the top of the sheet and is shown in Figure 4.1. Table 4.1 describes each field. For a plain hydraulic simulation, the friction method, the fluid properties, and the three counts are sufficient. The remaining parameters feed the cost model used in DOM runs.

> **Attention.** The three counts size every table and matrix of the workbook. Define them before filling any other block, and revisit the matrices whenever a count changes.

4.2 Pipe cost catalog

The implementation cost of pipelines is defined by discrete pairs of commercial diameter and cost per meter, shown in Figure 4.2. The workbook fits a continuous polynomial through these points, following Eq. (22) of the publication, so that the Solver can differentiate the cost function during optimization. Users can keep the default catalog or replace it with local market prices.

4.3 Node information

Each node occupies one row of the node table, shown on the left side of Figure 4.3.

Head loss method	D-W	*Head loss method.* *H-W (Hazzen-Williams), D-W Darcy Weisbach*
v	0,000001	*kinematic viscosity of the fluid in* m^2 */ sec*
ρ	1000	*Density of the fluid in* kg/m^3
Num. of links	21	*Number of links*
Num nodes	14	*Number of nodes*
Num. Loops	8	*Number of loops*
Pc	0,2	*Cost of 1 kWh of Energy (USD/kWh)*
ir	6%	*Annual increase rate in energy*
Years	25	*Lifespan of the system*
Rate	12%	*Interest rate*
α	0%	*Operational cost rate*
k1	1,2	*Day Factor*
k2	1,5	*Hour factor*
Dtr	1	*Duration to fill the reservoir (days)*
Material Cost	60	USD/m^2
Vk	40	*Windspeed velocity (m/s)*
p	0,3	
q	60	*Specific head*

Figure 4.1: The global parameter block of the Memory sheet. Each field carries a short description on its right.

4.4 Pump information

Pump data is entered only in the rows whose node type is *Reservoir or Tank*, since in this version pumps serve exclusively to fill the storage nodes. Figure 4.3 shows the input block and Figure 4.4 the calculated columns that appear automatically once the inputs are complete. Table 4.3 lists all fields.

4.5 Reservoir information

The reservoir block, shown in Figure 4.5, receives the geometry of each storage node, again only in the rows marked as *Reservoir or Tank*.

4.6 Demands and boundary conditions

Figure 4.6 shows the block, filled here with the demands of the tutorial case and the two fixed-head reservoirs in the last rows.

Table 4.1: Global parameters of the Memory sheet.

Parameter	**Description**
D-W or H-W	Head loss method, Darcy-Weisbach or Hazen-Williams.
ν	Kinematic viscosity of the fluid in m^2/s.
ρ	Density of the fluid in kg/m^3.
Num. of links	Total number of links in the network.
Num. of nodes	Total number of nodes in the network.
Num. of loops	Total number of loops in the network.
P_c	Cost of energy in USD/kWh.
i_r	Annual increase rate of the energy price.
Years	Lifespan of the system in years.
Rate	Interest rate of the project.
α	Operational cost rate for maintenance and operation.
k_1	Day factor of the demand.
k_2	Hour factor of the demand.
D_{tr}	Duration to fill the reservoir, in days.
Material cost	Tank material cost per square meter, in USD/m^2.
V_k	Design wind speed in m/s, used for the foundation model.
p	Exponent of the wind profile, typical values around 0.20.

Table 4.2: Node information fields.

Field	**Description**
Nodes	Node index, filled automatically from the number of nodes.
Elevation	Ground elevation from the reference datum, in meters.
Node type	Selected from the list, *Manhole* for junctions or *Reservoir or Tank* for storage nodes.

4.7 Link information

The link block gathers the topology and the geometry of every pipe, as shown in Figure 4.7.

Tip. The flow column accepts any starting values, including zeros. In difficult cases, a rough manual distribution of the inflows accelerates the convergence of the Solver.

4.8 Auditing the formulas

Every formula of the workbook is open for inspection. The **Trace Precedents** and **Trace Dependents** commands, in the Formula Auditing group of the Formulas tab shown in Figure 4.8, reveal how each cell participates in the model. Exploring the gray cells with these commands is an excellent classroom exercise.

4.9 Key cells for the Solver

Table 4.7 summarizes the cell ranges referenced when configuring the Solver, for a network with P links, N nodes, and L loops.

D [mm]	Cost [USD/m]	D-W Rugosity [mm]	Hazzen-Willians Coef.
25,4	2	0,26	130
50,8	5	0,26	130
76,2	8	0,26	130
101,6	11	0,26	130
152,4	16	0,26	130
200	23	0,26	130
254	32	0,26	130
304,8	50	0,26	130
355,6	60	0,26	130
406,4	90	0,26	130
457,2	130	0,26	130
508	170	0,26	130
558,8	300	0,26	130
609,6	550	0,26	130

Figure 4.2: The pipe cost catalog, with the commercial diameters, the unit costs, and the friction properties of each size.

Node Info			Pump Info					
Node	Elevation (m)	Node Type	n_p [h]	ηp	z_{pump} [m]	hg [m]	Qp-r [L/s]	Kp
1	100	Manhole						
2	100	Manhole						
3	100	Manhole						
4	100	Manhole						
5	100	Manhole						
6	100	Manhole						
7	100	Manhole						
8	100	Manhole						
9	100	Manhole						
10	100	Manhole						
11	100	Manhole						
12	100	Manhole						
13	100	Reservoir or Tank	12	0,85	95	26,19292562	137,8098589	336,78
14	100	Reservoir or Tank	12	0,85	95	22,53292562	47,25680782	5641,585329

Figure 4.3: Node and pump information blocks. Only the rows marked as Reservoir or Tank receive pump data, here the two reservoirs of the Huddleston (2004) case.

Pump Info				
hf,pump [m]	Hm,pump [m]	Pot [kW]	Cost of Energy per Day (1000 USD)	Cost of Energy per year (1000 USD)
6,40	32,59	51,83	0,12	45,41
12,60	35,13	19,16	0,05	16,78

Figure 4.4: Calculated pump columns, the friction loss, the manometric head, the power, and the daily and annual energy costs.

Table 4.3: Pump information fields. Calculated fields are marked with (c).

Field	**Description**
n_p [h]	Number of hours per day that the pump operates.
η_p	Pump efficiency, between 0 and 1.
z_{pump} [m]	Ground elevation of the pump.
h_g [m] (c)	Geometric difference between the pump elevation and the tank level, including the tank head.
$Q_{p\text{-}r}$ [L/s] (c)	Pump flow discharge, computed from the demand and the operating window.
K_p	Linear head loss coefficient of the supply line, used as $h_f = K_p\,Q\|Q\|^{n-1}$.
$h_{f,pump}$ [m] (c)	Friction loss between the pump and the tank.
$H_{m,pump}$ [m] (c)	Manometric head of the pump.
Pot [kW] (c)	Pump power.
Cost of energy per day (c)	Daily pumping cost.
Cost of energy per year (c)	Annual pumping cost.

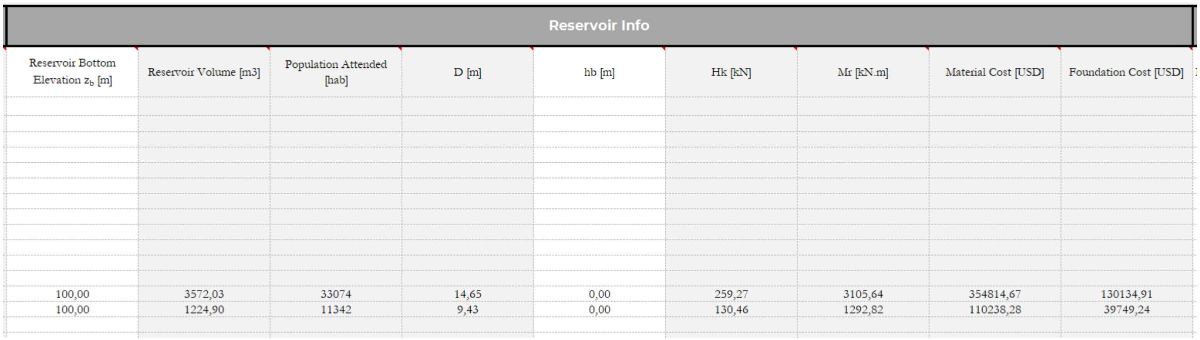

Reservoir Info								
Reservoir Bottom Elevation z_b [m]	Reservoir Volume [m3]	Population Attended [hab]	D [m]	hb [m]	Hk [kN]	Mr [kN.m]	Material Cost [USD]	Foundation Cost [USD]
100,00	3572,03	33074	14,65	0,00	259,27	3105,64	354814,67	130134,91
100,00	1224,90	11342	9,43	0,00	130,46	1292,82	110238,28	39749,24

Figure 4.5: Reservoir information block, with the geometry inputs and the calculated volume, wind forces, and costs.

Table 4.4: Reservoir information fields. Calculated fields are marked with (c).

Field	**Description**
Bottom elevation z_b [m]	Ground elevation of the tank site.
Volume [m^3] (c)	Tank volume, computed from the demand and the k_2 factor.
Population attended (c)	Equivalent population served by the tank.
D [m] (c)	Tank diameter, derived from the volume and the water depth.
h_b [m]	Height of the tank above the ground. Zero for ground tanks. In DOM runs this cell is a decision variable.
H_k [kN] (c)	Horizontal wind force on the tank.
M_r [kN·m] (c)	Wind bending moment at the foundation.
Material cost [USD] (c)	Tank material cost.
Foundation cost [USD] (c)	Tank foundation cost.

Manhole Demand	Boundary Conditions			
Demand (L/s)	Fixed Head?	Pressure (m)	Head [m]	hb + P/gamma [m]
0	0			
0	0			
0	0			
31,5	0			
0	0			
25,2	0			
0	0			
0	0			
37,9	0			
0	0			
44,2	0			
0	0			
-103,3573941	1	21,19292562	121,1929256	21,19292562
-35,44260586	1	17,53292562	117,5329256	17,53292562

Figure 4.6: Demand and boundary condition block. The last two rows are the reservoirs, with the fixed-head flag set to 1 and negative demands representing the supply to the network.

Table 4.5: Demand and boundary condition fields. Calculated fields are marked with (c).

Field	Description
Demand [L/s]	Positive values withdraw flow from the node, negative values inject flow into the network.
Fixed head?	Set to 1 for nodes with a pressure boundary condition and 0 otherwise. Every reservoir must be set to 1. Specific junctions can also be fixed to impose known pressures.
Pressure [m]	Pressure head considered when the head is fixed. In DOM runs the tank pressure cells are decision variables.
Head [m] (c)	Total piezometric head at the node.
$h_b + P/\gamma$ [m] (c)	Water depth from the ground at storage nodes.

Topology				Decision Variable	*Geometry*		
Segment	Upstream Node	Downstream Node	Name	q(L/s)	L (m)	Real Diameter [mm]	Cost (USD) fitted
1	1	2	t. 1-2	55,53	457,2	305	21295
2	2	3	t. 2-3	39,85	304,8	203	6953
3	3	4	t. 3-4	16,39	365,8	203	8345
4	4	5	t. 4-5	-10,40	609,6	203	13906
5	6	5	t. 6-5	-8,75	853,4	203	19467
6	7	6	t. 7-6	12,46	335,3	203	7649
7	8	7	t. 8-7	14,89	304,8	203	6953
8	9	8	t. 9-8	9,61	762	203	17382
9	1	9	t. 1-9	47,82	243,8	203	5561
10	9	10	t. 9-10	0,32	396,2	152	6732
11	10	11	t. 10-11	10,72	304,8	152	5179
12	11	12	t. 11-12	-7,60	335,3	254	10734
13	12	5	t. 12-5	-16,30	304,8	254	9758
14	10	8	t. 10-8	5,28	548,8	152	9325
15	2	10	t. 2-10	15,68	335,3	152	5697
16	11	7	t. 11-7	-2,43	548,6	152	9322
17	3	11	t. 3-11	23,46	365,9	254	11714
18	12	6	t. 12-6	3,99	548,6	152	9322
19	4	12	t. 4-12	-4,71	396,2	152	6732
20	13	1	t. 13-1	103,36	25	1000	950578
21	14	5	t. 14-5	35,44	25	1000	950578

Figure 4.7: Link information block, with the topology, the flow column that serves as decision variable, and the geometry of each pipe.

Table 4.6: Link information fields.

Field	Description
Segment	Link index, filled automatically.
Upstream node	Starting node, selected from the dropdown list.
Downstream node	Ending node, selected from the dropdown list.
Name	Generated automatically from the node pair.
Flow q [L/s]	Decision variable of the Solver, column `AI` starting at row 50. Any initial guess can be typed here.
l [m]	Pipe length.
Real diameter [mm]	Internal diameter of the pipe.
Cost (USD)	Pipe cost, evaluated automatically from the fitted cost function.

Figure 4.8: The Formulas tab of Excel. The Formula Auditing group, on the right, holds the Trace Precedents and Trace Dependents commands.

Table 4.7: Cell ranges used in the Solver configuration.

Range	Content
`Memory!AI50:AI(49+P)`	Pipe discharges, the decision variables.
`Memory!BE51:BE(50+N)`	Mass balance residuals, one per node.
`Memory!BH51:BH(50+L)`	Energy balance residuals, one per loop.
`Memory!BK51:BK...`	Pressure heads bounded in DOM runs.
`Memory!AA...`	Tank water depth cells, decision variables in DOM runs.
`Memory!T...`	Tower height cells, decision variables in DOM runs.
`Memory!BT51`	Total network cost, the DOM objective.

Chapter 5

The Mass and Energy Balance Matrices

The topology of the network enters the model through two incidence matrices, each hosted in its own sheet. The `Mass_Balance` sheet receives the node incidence matrix $\mathbf{F_d}$ and the `Energy_Balance` sheet receives the loop incidence matrix $\mathbf{F_l}$. The number of rows and columns of both matrices follows the counts declared in the parameter block of the `Memory` sheet.

When the workbook is populated through **Import Network**, both matrices arrive filled. This chapter explains their construction, which is required for manual data entry and recommended reading for every user, since a sign error in these matrices is the most frequent cause of infeasible runs.

5.1 The node incidence matrix

The matrix $\mathbf{F_d}$ has one row per node and one column per link, with entries

$$F_d(i,j) = \begin{cases} -1 & \text{if pipe } j \text{ leaves junction } i \\ 0 & \text{if pipe } j \text{ is not connected to junction } i \\ +1 & \text{if pipe } j \text{ enters junction } i \end{cases} \tag{5.1}$$

Multiplying $\mathbf{F_d}$ by the vector of discharges $\mathbf{q}$ and subtracting the demand vector $\mathbf{d}$ yields the mass balance residual of every node, the quantity the Solver drives to zero.

As an example, consider node 1 of the Huddleston (2004) network presented in Chapter 9. The node receives the flow of pipe 20, coming from the reservoir, and discharges through pipes 1 and 9. In the row of node 1, the column of pipe 20 receives $+1$, the columns of pipes 1 and 9 receive -1, and all remaining columns receive 0. Figure 5.1 shows the complete sheet for this network.

5.2 The loop incidence matrix

The matrix $\mathbf{F_l}$ has one row per loop and one column per link, with entries

$$F_l(i,j) = \begin{cases} -1 & \text{if pipe } j \text{ is in loop } i \text{ against the circulation} \\ 0 & \text{if pipe } j \text{ is not in loop } i \\ +1 & \text{if pipe } j \text{ is in loop } i \text{ along the circulation} \end{cases} \tag{5.2}$$

Mass Balance Matrix

Fill values of each node following the convetion that inlet pipes are positive and outlet pipes are negative

Σ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Node	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21
1	-1	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	1	0
2	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0
3	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0
4	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0
5	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
6	0	0	0	0	-1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
7	0	0	0	0	0	-1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
8	0	0	0	0	0	0	-1	1	0	0	0	0	0	1	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	-1	1	-1	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	1	-1	0	0	-1	1	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	0	-1	1	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	0	0	-1	1	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1

Figure 5.1: The Mass_Balance sheet filled for the Huddleston (2004) network, with one row per node and one column per link.

Loops always follow the clockwise convention. Consider loop 3 of the same network, formed by nodes 3, 4, 12, and 11 and containing the pipes with flows Q_3, Q_{19}, Q_{12}, and Q_{17}. Pipes 3 and 19 run along the clockwise circulation and take +1, pipes 12 and 17 run against it and take −1, and every other column of that row receives 0. Figure 5.2 shows the complete sheet for this network.

Loop Incidence Matrix

Fill the connection within each loop. Pay attention with the signal of the pipes

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Loop	hf1	hf2	hf3	hf4	hf5	hf6	hf7	hf8	hf9	hf10	hf11	hf12	hf13	hf14	hf15	hf16	hf17	hf18	hf19	hf20	hf21
1	1	0	0	0	0	0	0	0	-1	-1	0	0	0	0	1	0	0	0	0	0	0
2	0	1	0	0	0	0	0	0	0	0	-1	0	0	0	-1	0	1	0	0	0	0
3	0	0	1	0	0	0	0	0	0	0	0	-1	0	0	0	0	-1	0	1	0	0
4	0	0	0	1	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	-1	0	0
5	0	0	0	0	0	0	0	-1	0	1	0	0	0	1	0	0	0	0	0	0	0
6	0	0	0	0	0	0	-1	0	0	0	1	0	0	-1	0	1	0	0	0	0	0
7	0	0	0	0	0	-1	0	0	0	0	0	1	0	0	0	-1	0	1	0	0	0
8	0	0	0	0	-1	0	0	0	0	0	0	0	1	0	0	0	0	-1	0	0	0

Figure 5.2: The Energy_Balance sheet filled for the Huddleston (2004) network, with one row per loop and one column per link.

5.3 A compact example

For the small two-loop network of case (a) of the publication, with 5 nodes and 6 links, the matrices read

$$\mathbf{F_d} = \begin{bmatrix} -1 & 0 & 0 & -1 & 0 & 1 \\ 1 & -1 & 0 & 0 & -1 & 0 \\ 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 \end{bmatrix}, \qquad \mathbf{F_l} = \begin{bmatrix} 1 & 0 & 0 & -1 & 1 & 0 \\ 0 & 1 & -1 & 0 & -1 & 0 \end{bmatrix}.$$

Reading the first row of $\mathbf{F_d}$, node 1 receives pipe 6 and feeds pipes 1 and 4. Reading the first row of $\mathbf{F_l}$, the first loop contains pipes 1, 4, and 5, with pipe 4 running against the clockwise circulation.

> **Tip.** Fill the matrices one node and one loop at a time, and cross out each pipe of the drawing as its column is completed. The row sums provide a quick sanity check, every column of $\mathbf{F_d}$ must contain exactly one +1 and one −1 when both end nodes belong to the network.

Attention. After any change in the number of links, nodes, or loops, revisit both sheets and confirm that the active ranges match the new counts. Stale entries outside the active range are ignored by the model, while missing entries inside it produce infeasible constraint sets.

Chapter 6

Running a Hydraulic Simulation (WFP/HSP)

The Water Flow Problem determines the discharge and the direction of flow in every pipe of a network with known diameters and fixed tank heads. The Solver searches a flow vector that closes the mass balance at all nodes and the energy balance in all loops. No objective function is involved, the run is a feasibility search.

6.1 Preparing the workbook

1. Open `X-WHAT_Model_V1.5.xlsm` and click **Enable Content** in the security bar. The macro serves the import feature alone, every hydraulic calculation runs on regular worksheet formulas.
2. Populate the inputs, either through **Import Network** with a `.xwhat.xml` package or by manual entry following Chapters 4 and 5.
3. Sweep the white cells of the `Memory` sheet once and confirm that the data describes the intended network.

6.2 Enabling the Solver add-in

If the **Solver** command is absent from the Data tab, enable it once.

1. Open **File**, then **Options**, then **Add-ins**.
2. In the Manage box select **Excel Add-ins** and click **Go**.
3. Check **Solver Add-in** and confirm. The command appears at the right end of the Data tab.

6.3 Configuring the Solver

Open **Data** and click **Solver**. For a network with P links, N nodes, and L loops, configure the dialog as follows.

Set Objective	Leave blank. The run is a feasibility search.
Changing Cells	`Memory!AI50:AI(49+P)`, the pipe discharges.
Constraints	`Memory!BE51:BE(50+N)` = 0, the mass balance residuals, and `Memory!BH51:BH(50+L)` = 0, the energy balance residuals.
Method	GRG Nonlinear.

As a concrete example, the Huddleston (2004) network of Chapter 9 has 21 links, 14 nodes, and 8 loops, which gives the ranges `AI50:AI70`, `BE51:BE64`, and `BH51:BH58`. Figure 6.1 shows the corresponding dialog.

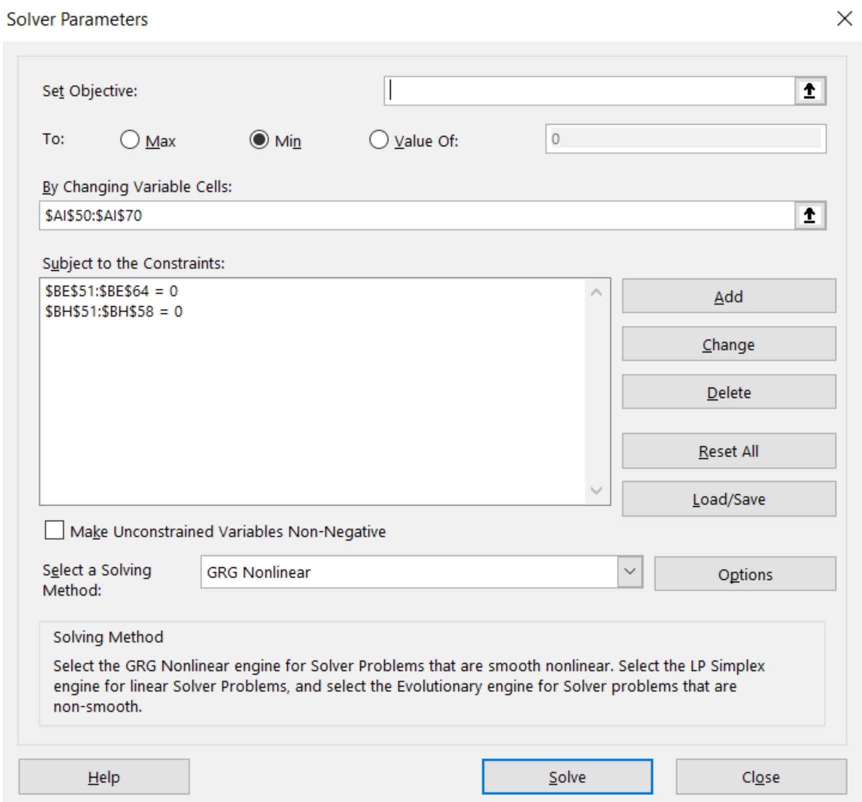


Figure 6.1: Solver configuration for the Huddleston (2004) case in WFP mode.

Tip. With a tutorial network loaded, the **Roadmap** window of the Network Builder prints the exact ranges for that case, ready to be copied into the Solver dialog.

6.4 Solving and verifying

Click **Solve**. When the Solver reports that all constraints are satisfied, accept the solution and verify three points.

1. The residual ranges `BE` and `BH` display values that are zero within the Solver precision.
2. The flow directions are physically plausible for the boundary conditions used. Negative discharges indicate flow against the drawn pipe direction and are a valid outcome.
3. The nodal pressures fall inside the expected range of the project.

Attention. If the Solver stops before converging, run it again starting from the current values. If it still stalls, open **Options**, select the GRG Nonlinear tab, and enable **Multistart** with bounds on the variables. Distant initial values are the most frequent cause of early stops.

6.5 Saving

Save the workbook after convergence. The saved file is the input of the Results Viewer described in Chapter 8.

Chapter 7

Running a Design Optimization (DOM)

Design Optimization Modeling extends the simulation by handing design variables to the Solver, typically the tank water depths and tower heights, in search of the lowest total cost. The objective gathers pipelines, pumping energy in present value, tank material, and the tank foundation under wind loading, while every nodal pressure must remain inside the allowed band.

7.1 Preparing the model

1. In the Network Builder, switch the selector to **Mode: DOM (Optimization)** before exporting. The tank heads and tower heights typed in the properties panel act as starting values, so give them reasonable initial estimates.
2. Complete the economic parameters in the project settings, the energy price, the interest and energy increase rates, the lifespan, the demand factors, the tank material cost, the wind data, and the pipe cost catalog. These fields map onto the parameter block of the `Memory` sheet.
3. Import the package and confirm that the cost cells of the `Memory` sheet respond to the imported parameters. The total cost in `Memory!BT51` gathers the pipeline, pumping, tank material, and foundation components.

7.2 Configuring the Solver

For a network with P links, N nodes, and L loops, configure the dialog as follows.

Set Objective	`Memory!BT51`, select **Min**.
Changing Cells	`Memory!AI50:AI(49+P)`, the pipe discharges, plus the tank water depth cells in column `AA` and the tower height cells in column `T`.
Constraints	`Memory!BE51:BE(50+N)` $= 0$ and `Memory!BH51:BH(50+L)` $= 0$, plus the pressure heads in column `BK` bounded between p_{min} and p_{max}, and any physical bounds on the design variables.
Method	GRG Nonlinear.

In the audited Huddleston (2004) DOM case, the changing cells are `AI50:AI70`, `AA63`, and `T62:T63`, with the pressures `BK51:BK62` bounded between 10 and 30 m, the tank head above

5 m, the tower heights between 0 and 39.5 m, and the discharges between −104 and 104 L/s. The head of the second reservoir stays formula-linked 3.66 m above the first one, so a single head cell drives both. Figure 7.1 shows the corresponding dialog.

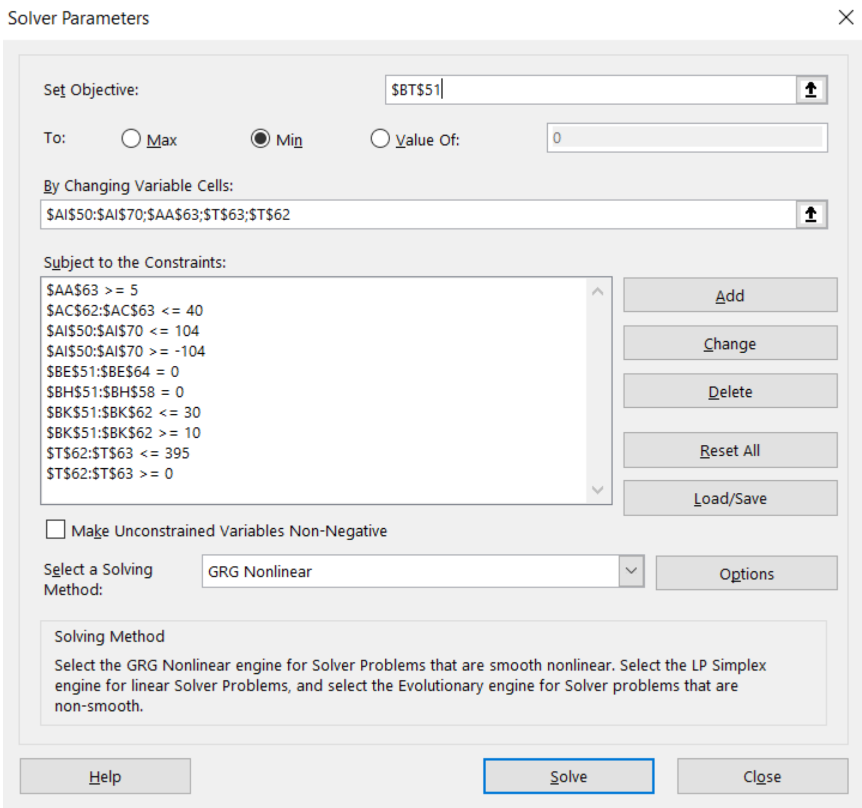


Figure 7.1: Solver configuration for the Huddleston (2004) case in DOM mode.

Tip. Bound every decision variable. The GRG engine behaves markedly better when the search space is closed, and the **Multistart** option requires bounds to operate.

7.3 Solving, restarting, and comparing

The DOM problem is non-convex, non-smooth, and non-linear, so a single run may land on a local minimum. A simple routine improves the outcome considerably.

1. Solve once and record the objective value.
2. Solve again starting from perturbed values of the design variables, or enable **Multistart** in the GRG options.
3. Repeat a few times and keep the best design found.

A useful benchmark is the standard design cost, obtained by running the same network in WFP mode with manually chosen tank depths that satisfy the pressure band. In the publication, the optimization of the Huddleston case reduced the total cost by 151,790 USD, about 9.8% of the standard design, in a network serving 44,416 inhabitants.

7.4 Reading the optimized design

After convergence, the design summary of the `Memory` sheet holds the optimized tank depths, tower heights, volumes, and the cost breakdown. Save the workbook and upload it to the Results page to visualize the optimized state, including the pressure margins consumed at each node.

Attention. An optimized design that pushes several nodes against the minimum pressure bound leaves no operational slack. Judge the margins against the uncertainty of the demand data before adopting the solution.

Part IV

Results and Reference

Chapter 8

The Results Viewer

The Results page of the WebGUI reads a solved workbook and mounts an interactive dashboard with the flows, the pressures, and the cost breakdown. The file is processed locally by the browser, nothing is sent to a server.

8.1 Uploading a solved workbook

Open the **Results** page, then drag the saved `.xlsm` or `.xlsx` file onto the upload area, or click **Choose Solved Workbook** and browse to it. The page parses the `Memory` sheet and builds the dashboard in a few seconds. The **Upload Different File** button restarts the process with another workbook.

Attention. Upload the workbook only after the Solver has converged and the file has been saved. A workbook saved before the run displays the initial guesses instead of the solution.

Once the file is parsed, the dashboard of Figure 8.1 appears. The summary cards at the top report the network size, the solver status, the pressure extremes, and the total cost, and the four tabs below organize the detailed results.

8.2 Dashboard tabs

Network Flow. Draws the network with the pipe width proportional to the flow magnitude. Blue pipes carry water along the drawn direction and red pipes carry reversed flow. Node labels display the computed pressures.

Node Pressures. Lists the head and the pressure at every node. Verify that all values sit inside the design band, commonly 10 to 30 mH_2O for distribution networks.

Link Flows. Tabulates each pipe with its length, diameter, discharge, direction, and cost. This table is a convenient basis for reports and for comparisons with EPANET.

Cost Breakdown. Splits the total cost into pipelines, pumping energy, tank material, and foundation, as in Figure 8.2. In DOM studies this chart is the natural place to compare candidate designs.

8.3 Suggested checks

After every run, three quick checks catch most modeling issues.

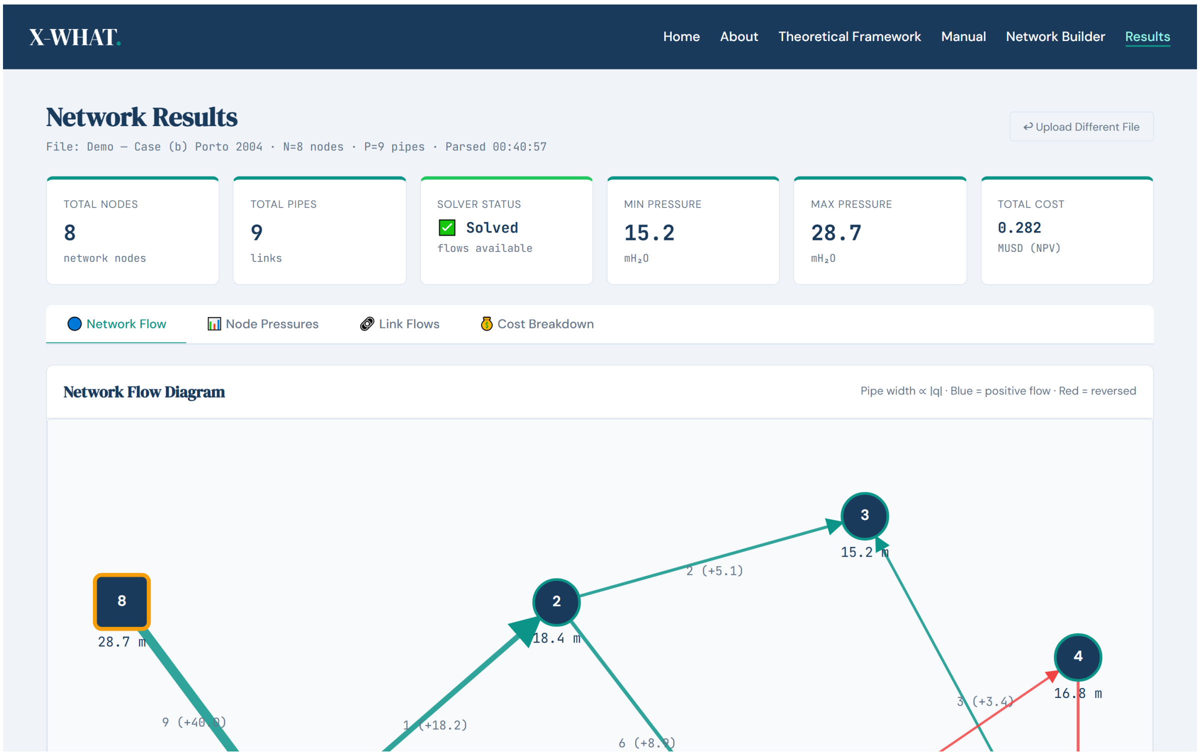


Figure 8.1: The Results page after loading a solved workbook, with the summary cards and the Network Flow tab active. The pipe width is proportional to the discharge and red pipes carry reversed flow.

1. Confirm that no node violates the minimum or maximum pressure of the project.
2. Inspect the reversed pipes and judge whether the directions are physically plausible for the boundary conditions used.
3. Compare the order of magnitude of each cost component with local references before using the totals in a design decision.

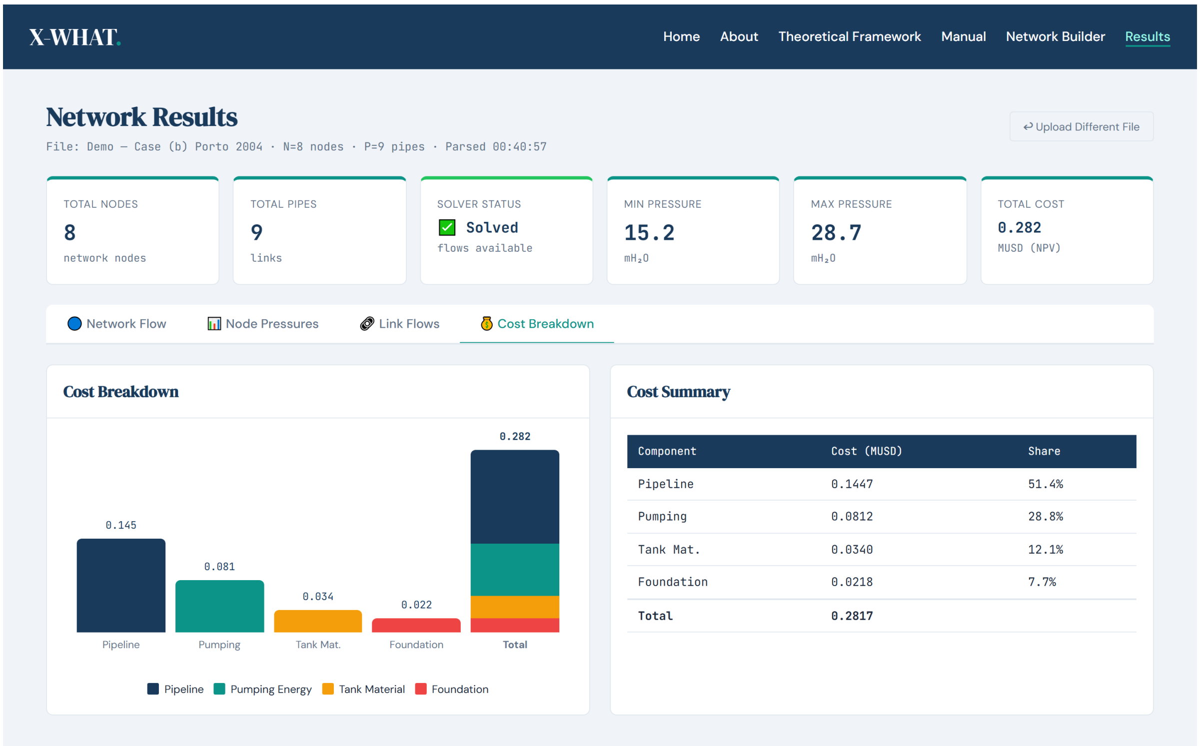


Figure 8.2: The Cost Breakdown tab, with the total cost split into pipelines, pumping energy, tank material, and foundation.

Chapter 9

Worked Examples

This chapter reproduces, end to end, the two case studies of the publication that are available as tutorial networks in the Network Builder. Both examples assume the workbook and the WebGUI introduced in the previous chapters.

9.1 Case (b), Porto (2006)

The intermediate network reproduced from Porto (2006) serves an equivalent population of 12,800 inhabitants and is used in the publication to compare both friction models against literature results.

9.1.1 Simulation run

1. In the Network Builder, open **Load Tutorial Network** and select **Case (b) | WFP/HSP | Porto 2006**. The complete drawing loads with every property filled.
2. Open the **Roadmap** and read the audited Solver configuration for this case, then press **Export Network Package** and download the `.xwhat.xml` file.
3. Open `X-WHAT_Model_V1.5.xlsm`, enable the content, click **Import Network**, and select the downloaded package.
4. Configure the Solver following Chapter 6 with the ranges given in the Roadmap, solve, and confirm that all residuals vanish.
5. Save the workbook and upload it to the Results page. Compare the discharges with the values reported in the literature for this network.

9.1.2 Optimization run

Load **Case (b) | DOM | Porto 2006** and repeat the procedure with the DOM configuration of Chapter 7. The audited setup of this case is shown in Figure 9.2.

9.2 Case (c), Huddleston (2004)

The largest example depicts a network with 8 loops, 12 internal nodes, 2 reservoirs, and 21 links, serving 44,416 inhabitants. All internal nodes share the same elevation, reservoir 1 sits

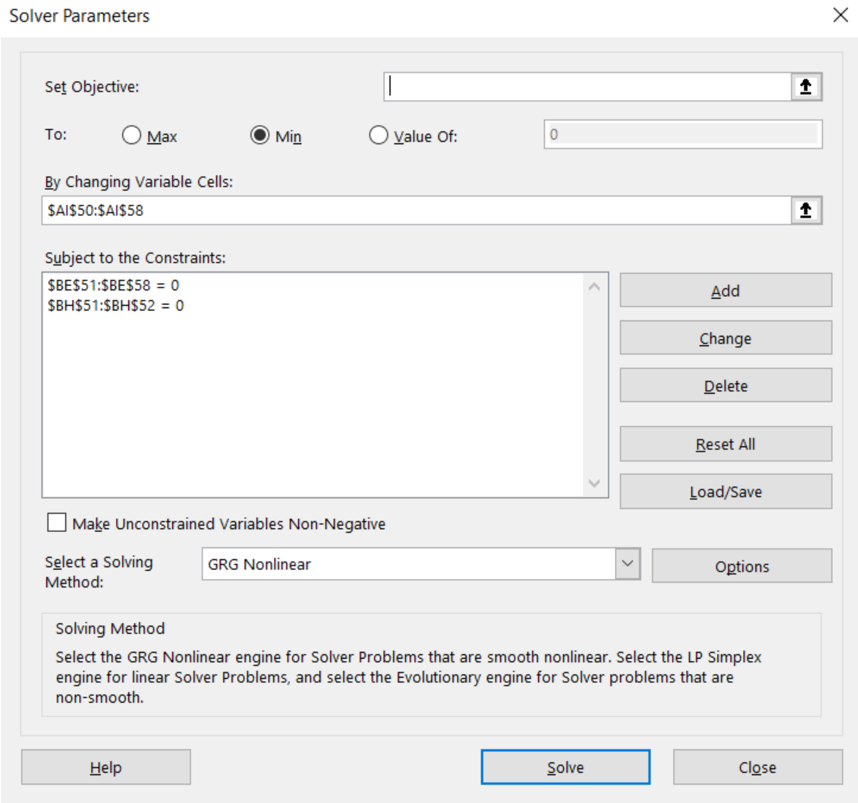


Figure 9.1: Audited Solver configuration of case (b) in WFP mode.

3.66 m above reservoir 2, and demands act at four nodes. The problem consists of determining the discharges and flow directions subject to the known reservoir heads. Figure 9.3 presents the schematic of the system with the pump and reservoir arrangement, and Table 9.1 lists the link data.

Table 9.1: Input data of the Huddleston (2004) network. Q_h is the discharge reported in the literature.

Link	D [mm]	L [m]	ϵ [mm]	Q_h [L/s]
1	305	457.2	0.26	55.8
2	203	304.8	0.26	40.0
3	203	365.8	0.26	16.5
4	203	609.6	0.26	−10.3
5	203	853.4	0.26	−8.7
6	203	335.3	0.26	12.6
7	203	304.8	0.26	15.0
8	203	762.0	0.26	9.7
9	203	243.8	0.26	48.0
10	152	396.2	0.26	0.4
11	152	304.8	0.26	10.8
12	254	335.3	0.26	−7.4
13	254	304.8	0.26	−16.0
14	152	548.6	0.26	5.3
15	152	335.3	0.26	15.7
16	152	548.6	0.26	−2.4

Link	D [mm]	L [m]	ϵ [mm]	Q_h [L/s]
17	254	365.9	0.26	23.6
18	152	548.6	0.26	4.0
19	152	396.2	0.26	−4.7
20	1000	25.0	0.26	103.7
21	1000	25.0	0.26	35.1

9.2.1 Simulation run

1. Load **Case (c) | WFP/HSP | Huddleston 2004** in the Network Builder and export the package. The loaded drawing is the one shown in Figure 2.1.
2. Import it into the workbook. With 21 links, 14 nodes, and 8 loops, the Solver ranges are `AI50:AI70` for the discharges, `BE51:BE64` for the mass residuals, and `BH51:BH58` for the energy residuals.
3. Solve with the GRG Nonlinear method and compare the resulting discharges with the Q_h column of Table 9.1. The publication reports close agreement, with mean absolute errors of the order of the measurement precision.

9.2.2 Optimization run

Load **Case (c) | DOM | Huddleston 2004** and configure the Solver as in Chapter 7, with `Memory!BT51` minimized, the changing cells `AI50:AI70`, `AA63`, and `T62:T63`, and the audited constraint set of the case. After a few restarts, the optimized design reaches a total cost about 9.8% below the standard design, a saving of 151,790 USD for this network.

Tip. Use the **Cost Breakdown** tab of the Results page to compare the standard and the optimized designs component by component. The saving concentrates in the tank and pumping terms, since the pipeline layout is identical in both designs.

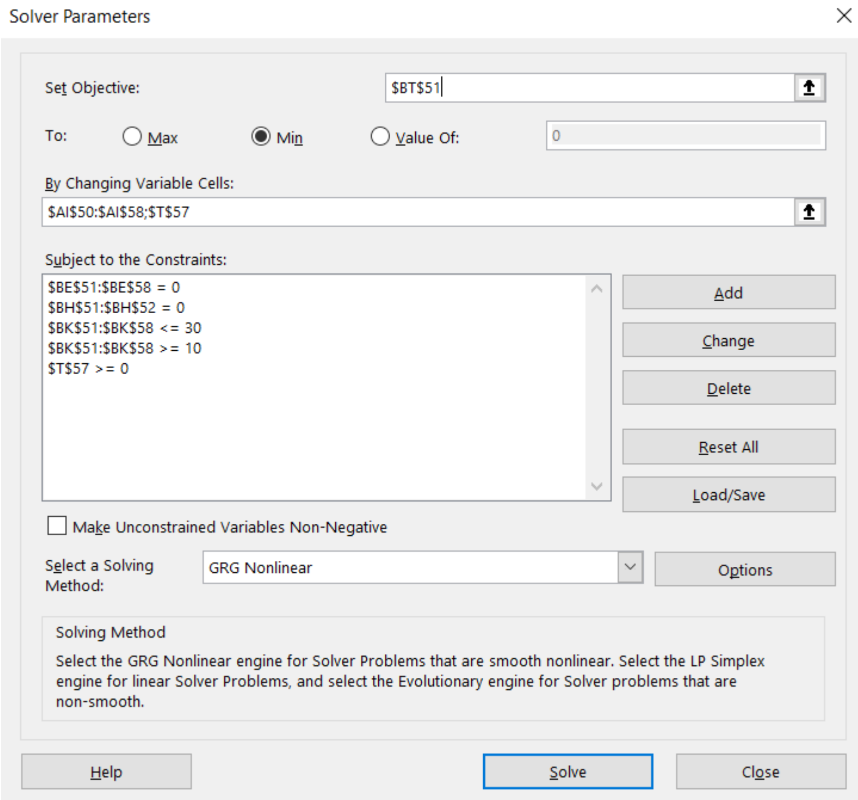


Figure 9.2: Audited Solver configuration of case (b) in DOM mode.

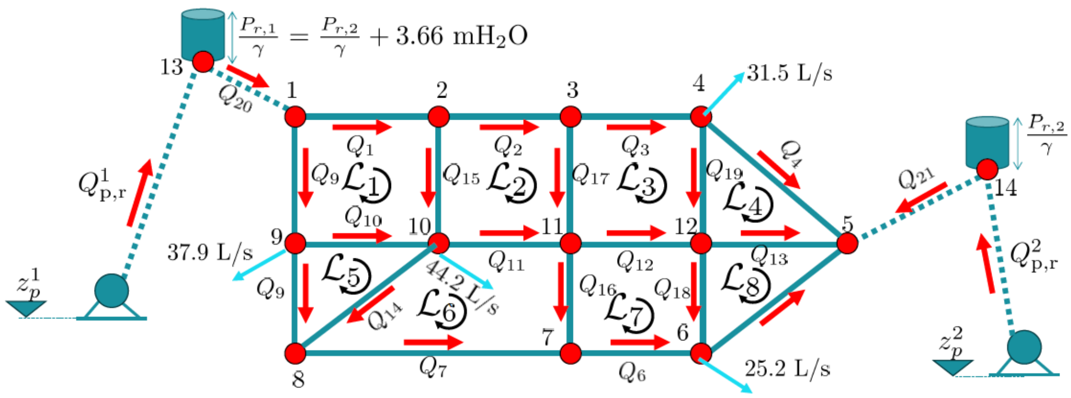


Figure 9.3: Schematic of the Huddleston (2004) network, with the two reservoirs, their filling pumps, the eight loops, and the demand nodes.

Chapter 10

Troubleshooting

This chapter gathers the issues most frequently reported by users, together with their solutions.

10.1 Solver issues

The Solver stops without finding a solution

Run the Solver again starting from the values of the previous attempt, convergence often completes on the second pass. If the run still stalls, open **Options**, select the GRG Nonlinear tab, and enable **Multistart** with bounds on all variables. Verify also that the constraint ranges match the counts of nodes and loops declared in the `Memory` sheet, a mismatch there produces infeasible constraint sets.

The Solver command is missing from the Data tab

Enable the add-in once, through **File**, **Options**, **Add-ins**, selecting **Excel Add-ins** in the Manage box, clicking **Go**, and checking **Solver Add-in**.

The Solver reports convergence but the residuals are visibly nonzero

Tighten the convergence settings in **Options**, reducing the constraint precision, and solve again from the current values. Verify that no residual cell was overwritten by a manual entry.

10.2 Workbook issues

Excel blocks the macros when the workbook opens

Click **Enable Content** in the yellow security bar. If the bar does not appear, close Excel, right click the file, open **Properties**, check **Unblock**, and open the workbook again. The macro serves the import feature alone.

A gray cell was overwritten by accident

Copy the formula from an intact cell of the same column, or recover it from a fresh copy of the workbook downloaded from the repository.

The tables seem smaller or larger than the network

The counts of links, nodes, and loops in the parameter block size every table and matrix. Correct the counts first, then review the tables and both incidence matrices.

10.3 Modeling issues

The mass balance never closes at one specific node

Review the signs in that row of the `Mass_Balance` sheet, entering pipes take +1 and leaving pipes take −1, and double check the demand sign at the node, positive demands withdraw water. A single swapped sign explains almost every case.

Some discharges come out negative

Negative values are expected and indicate flow against the drawn direction of the pipe. The head loss formulation uses $Q|Q|^{n-1}$ precisely to preserve this information. The Results page draws such pipes in red.

Pressures far outside the expected band

Check the elevations and the fixed heads first, an elevation typo of one order of magnitude is easy to spot in the **Node Pressures** tab. Confirm also that the friction data matches the selected model, roughness values entered as Hazen-Williams coefficients produce unrealistic losses.

10.4 WebGUI issues

The export is blocked with a validation message

The export dialog lists the inconsistencies found, for example pipes without geometry or loops with missing pipes. Fix the reported items on the canvas and export again.

The Results page does not recognize the uploaded file

Upload the solved workbook itself, in `.xlsm` or `.xlsx` format, saved after the Solver run. Files exported from other tools or renamed extensions are not parsed.

10.5 Scale limits

The workbook is dimensioned for networks of up to 200 links. The practical limit comes from the Excel Solver, which handles up to 200 decision variables. Larger systems can be addressed by coupling the same spreadsheet structure with OpenSolver.

Appendix A

Glossary of Symbols

Table A.1: Symbols used in this manual and in the publication.

Symbol	Meaning
Q	Flow discharge in a link.
Q_d	Nodal demand, positive for withdrawals.
$Q_{p,r}$	Pump flow rate filling a tank.
q	Vector of link discharges, the decision variables.
d	Vector of nodal demands.
$\mathbf{F_d}$	Node incidence matrix.
$\mathbf{F_l}$	Loop incidence matrix.
Δh_f	Head loss by friction in a link.
k, n	Resistance term and exponent of the friction model.
f	Darcy-Weisbach friction factor.
Re	Reynolds number.
ϵ	Pipe roughness.
C	Hazen-Williams coefficient.
D, L	Pipe diameter and length.
ν	Kinematic viscosity of the fluid.
ρ	Density of the fluid.
γ	Specific weight of the fluid.
g	Gravity acceleration.
z	Ground elevation of a node.
h	Piezometric head, $h = P/\gamma + z$.
h_r	Tank water depth above the tank bottom.
h_b	Tank tower height above the ground.
z_b	Ground elevation of the tank site.
z_p	Ground elevation of the pump.
h_g	Geometric lift between pump and tank level.
H_p	Manometric head of the pump.
k_p	Head loss coefficient of the pump supply line.
n_p	Daily operating hours of the pump.
n_{WDN}	Daily duration of network operation.
η_p	Pump efficiency.
k_1, k_2	Day and hour demand factors.
P_c, P_e	Energy price in USD/kWh.
i_r	Interest rate of the project.

Symbol	**Meaning**
i_e	Annual increase rate of the energy price.
n_l	Lifespan of the system in years.
I_{NPV}	Conversion factor to net present value.
C_e	Daily pumping energy cost.
C_p	Pumping cost in present value.
C_l	Pipeline cost per meter as a function of the diameter.
C_r^m	Tank material cost.
C_f^r	Tank foundation cost.
C_r	Total tank cost.
C_t	Total network cost, the DOM objective.
c_m	Tank material cost per square meter.
V_r	Tank volume.
D_r	Tank diameter.
v_w, V_k	Design wind speed.
p	Exponent of the wind profile with elevation.
k_w	Wind drag coefficient.
H_k	Horizontal wind force on the tank.
M_r	Wind bending moment at the tank foundation.
p_{min}, p_{max}	Pressure bounds of the design problem.
MAE	Mean absolute error, used in the validation studies.