

Interactive hydraulic design of ground loop networks

USER MANUAL

3.0 VERSION

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Foreword — Is the pump undoing the ground heat exchanger?

Many geothermal heat pump systems never achieve their promised energy efficiency, and the problem often lies not in the ground, but in the pumping system. An oversized circulator, or a poorly designed network that requires a large circulator to deliver the nominal flow rate, converts electricity into heat, wasting energy through hydraulic losses year after year. This parasitic energy consumption can significantly reduce overall system efficiency, even when the geothermal heat exchanger itself has been correctly designed.

For example, on a fifty-six-borehole installation, thirty months of data yielded a seasonal performance of 3.54 for the compressor alone, 2.97 when the ground-loop circulator was included, and 2.49 when every pump was taken into account. Moving the fluid cost nearly 30 % of the compressor's figure (3.54 to 2.49), while the heat pumps themselves performed only slightly below the manufacturer's data. For the excess pump energy the authors name high pipe velocities, short and frequent cycling, and faults in the control system — questions of design and commissioning rather than of the heat pumps (Naicker and Rees, 2018). Only the first is a hydraulic question, and it is the one this module addresses. Kavanaugh and Rafferty (2014) found a central pump oversized by half can eat past four-fifths of the heat pump's operating cost, and an oversized variable-speed pump does not fix itself: its minimum speed stays too high for anything but peak load.

A second common failure undermines the thermal efficiency of the GHE: a field of boreholes piped in such a way that flow is never distributed among the boreholes in the proportions assumed by the thermal model. Some boreholes receive too much flow, others too little, and the heat pump plant is blamed for a problem that originates in the piping. A well-designed ground loop is simple to define. Every borehole should receive nearly the same flow, with sufficient flow at peak heating demand to maintain turbulent conditions. A borehole operating under laminar flow transfers heat poorly precisely when the greatest amount of heat must cross the borehole wall. Away from peak demand, however, the flow should decrease, since pumping power rises—and falls—steeply with flow rate. Boreholes can be drilled and grouted perfectly, and still be connected to a hydraulic network that fails every one of these fundamental requirements. The only way to know is to calculate it.

In fact, a ground loop is judged on four questions: does every borehole get its share of the flow, does that flow stay turbulent at the peak, is each pipe the right size, and what head must the pump supply? I built GLN Analysis to make these questions easier to answer. You draw the circuit as a piping and instrumentation diagram, a node for every component and an edge for every pipe, set the properties, and instantly obtain a robust solution. What comes back is a full nodal pressure field: the spread of flow between loops, the Reynolds number in each borehole, the velocity and friction gradient in every pipe, and the head each pump must supply.

In my experience, three of those numbers are easier to get right before a system is built than after: whether the pump is the size it needs to be, not just one that will certainly be big enough; whether the antifreeze chosen for thermal protection has moved the operating point somewhere the circulator cannot follow, a question a purely thermal analysis never raises; and whether the network can be purged of air and debris with the equipment that will actually be on site, not a temporary pump nobody budgeted for.

I developed GLN Analysis, distributed by P³ Geothermal, a Polytechnique Montréal spin-off, as the third module of the Analysis Suite. I built it because users kept asking for it: thermal response and borehole sizing were covered, and the

network connecting them to the plant room was not. Hydraulic calculation software is common; what I added with GLN Analysis is a place inside the same suite, at a price low enough that using a precise tool costs less than guessing. My hope is that this module will make it easier to design a good geothermal system than a mediocre one.

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Lead Programmer, P³ Geothermal



How to cite

If GLN Analysis supported your work, please cite it. Acknowledging this work sustains its continued development and the open sharing of the research behind it.

Citing the software and the manual

Pasquier, P. (2026). *GLN Analysis – Interactive hydraulic design of ground loop networks*. P³ Geothermal inc. **[DOI to be assigned]**

The archive of this module is not deposited yet. Once it is, the entry above will carry its **concept DOI**, which always resolves to the latest deposited version.

Citing the underlying methods

The hydraulic methods implemented in GLN Analysis are documented in the engineering literature rather than being proprietary to this software. When a specific method is central to your own work, the Darcy-Weisbach formulation of distributed losses, the Colebrook-White friction factor and its explicit approximations, the loss-coefficient treatment of fittings, or the correlations used for the thermo-physical properties of antifreeze solutions, please cite the corresponding source listed in the [References](#) section at the end of this manual.



Feature overview

GLN Analysis version 3.0 answers the four questions a ground loop network is judged on: (1) does every borehole get its share of the flow, (2) is that flow turbulent at the heating peak, (3) is each pipe the right size, and (4) what head must the circulating pump supply. The last one decides the energy efficiency of the installation, because the pumping power it implies is subtracted from the benefit of the system for as long as the system runs. The module answers them on the drawing itself, and updates the answers as the design changes. The table below summarises the principal features available in this release.

 GLN Analysis FEATURE OVERVIEW	
DRAWING & MODELLING	
Diagram-driven modelling (<i>a node per component, an edge per pipe</i>)	✓
Component types in the palette (<i>active, passive, thermal, instrumentation, storage</i>)	35
Valve, exchanger and heat-pump genres, each with its own symbol and default K	✓
Ready-made archetypes shipped with the module	4
Ground heat exchanger generator (<i>single-U, double-U, coaxial; parallel or series</i>)	✓
Reusable archetypes with thumbnails	✓
Independent networks in one drawing, each with its own fluid, flow rate and temperature	✓
Result maps drawn on the network itself (<i>pressure, velocity, head, elevation</i>)	4
HYDRAULIC SOLVER	
Newton-Raphson mass balance at every free node	✓
Darcy-Weisbach distributed losses, Swamee-Jain friction factor	✓
Minor losses as $K \cdot pv^2/2$	✓
Piezometric head formulation (<i>gauge pressure plus $pg \cdot z$</i>)	✓
Sparse Jacobian, pattern analysed interactively	✓

Solution recalculated interactively, in a few milliseconds	500 boreholes
PUMPS	
Pump slots, each with its own H-Q points and efficiencies (<i>seeded as a size ladder, meant to be replaced by the curve of the pump specified</i>)	5
Curve completed to the shutoff head and the runout flow	✓
Separate hydraulic and motor efficiencies	✓
Operating point — flow, head, fluid power and electrical draw	✓
Control modes (<i>constant speed, constant head, imposed flow</i>)	3
FLUIDS & PIPES	
Heat carrier fluids through the Melinder correlations	5
ρ and μ evaluated at each network's own temperature	✓
Pipe entries (<i>28 metric DN and 21 imperial IPS, SDR 9 / 11 / 17</i>)	49
DESIGN CHECKS & DIAGNOSTICS	
Velocity window checked per pipe (<i>m/s</i>)	0.3 – 2.5
Friction gradient window checked per pipe (<i>Pa/m</i>)	100 – 400
Reynolds number and flow regime, per pipe	✓
Balancing indicator (<i>highest to lowest borehole loop flow</i>)	✓
RESULTS & FILES	
Guided analysis-tree workflow	✓
Per-pipe and per-node results tables (<i>sortable, with the three advisory checks in the cell they judge</i>)	✓
Unified project file (<i>drawing, pumps, fluid and project record, shared with the GHE and TRT modules</i>)	.ghe
Reusable pipework archetypes (<i>saved from a selection, inserted from a thumbnail gallery</i>)	.hya
High-resolution capture of the active view (<i>animated GIF while the flow animation runs</i>)	PNG
VERIFICATION	
Reference scenarios	40

Cross-checked against an independent solver (<i>EPANET 2</i>)	✓
Worked examples of the reference textbook reproduced	✓
ANALYSIS SUITE	
Modules in one application (<i>TRT interpretation, GHE design, GLN hydraulics</i>)	3
Parameters carried from one module to the next (<i>TRT → GHE → GLN, choosing which technique's value travels</i>)	✓
DOCUMENTATION	
Illustrated user manual written for this module (<i>9 figures</i>)	33 000 words
Read inside the application, as a PDF, and online (<i>no registration</i>)	✓
Context help on every panel, opened from the panel itself	✓
Quick-start walkthrough of a complete analysis	✓
Linked reference section — every method traced to its publication	✓
SPECIFICATIONS	
Operating system	Windows 10+, macOS 26+
gheanalysis.com	



Quick start

One application, three modules - GLN Analysis is one of the three modules of the **Analysis Suite**, which are installed together and share a single window. The three buttons at the left of the toolbar switch between them, and the button that is lit tells you which module is active:

- **TRT** — interpretation of a thermal response test, which measures the ground properties the design relies on.
- **GHE** — design and simulation of a ground heat exchanger field.
- **GLN** — design of the hydraulic network that connects it, the subject of this manual.

Switching module rebuilds the analysis tree, the panels and the console; the window shown in the figure below is the GLN one. Each module is licensed separately, and the licence that applies is that of the active module. The project sheet is shared by the three modules, so a project keeps one identity. Panels shared between modules, such as the heat carrier fluid, change meaning with the module and have their own help page.

The three modules also follow one another: a thermal response test interpreted in TRT gives the ground thermal conductivity and the borehole thermal resistance used by GHE, and the borehole field designed in GHE is then balanced hydraulically in GLN. Each module can also be used on its own.

Activating a professional licence - GLN Analysis runs in demonstration mode until a valid licence is loaded. In that mode the sample network of Example 3 is loaded. Its parameters — pipe diameters, fittings, pump settings, network temperatures and the fluid — can be edited, and the solver recomputes at each change; the drawing itself is read only: the palette places nothing, nothing can be redrawn, and nothing can be saved or exported. To activate the professional version, open **License Agreement** from the main menu and accept the end-user licence agreement. This opens the Licenses panel, a table listing every module of the Analysis Suite with its current status — Licensed, Demo, or Expired — and, once licensed, its expiry date. Click **Open .lic file...** and select the licence file received after purchase: a licence activates the module it was issued for, and a Suite licence activates every module. Licences are available at gheanalysis.com. The licence is validated online each time the software starts; a short offline grace period keeps a previously activated licence working if no connection is available, after which the module falls back to demonstration mode.

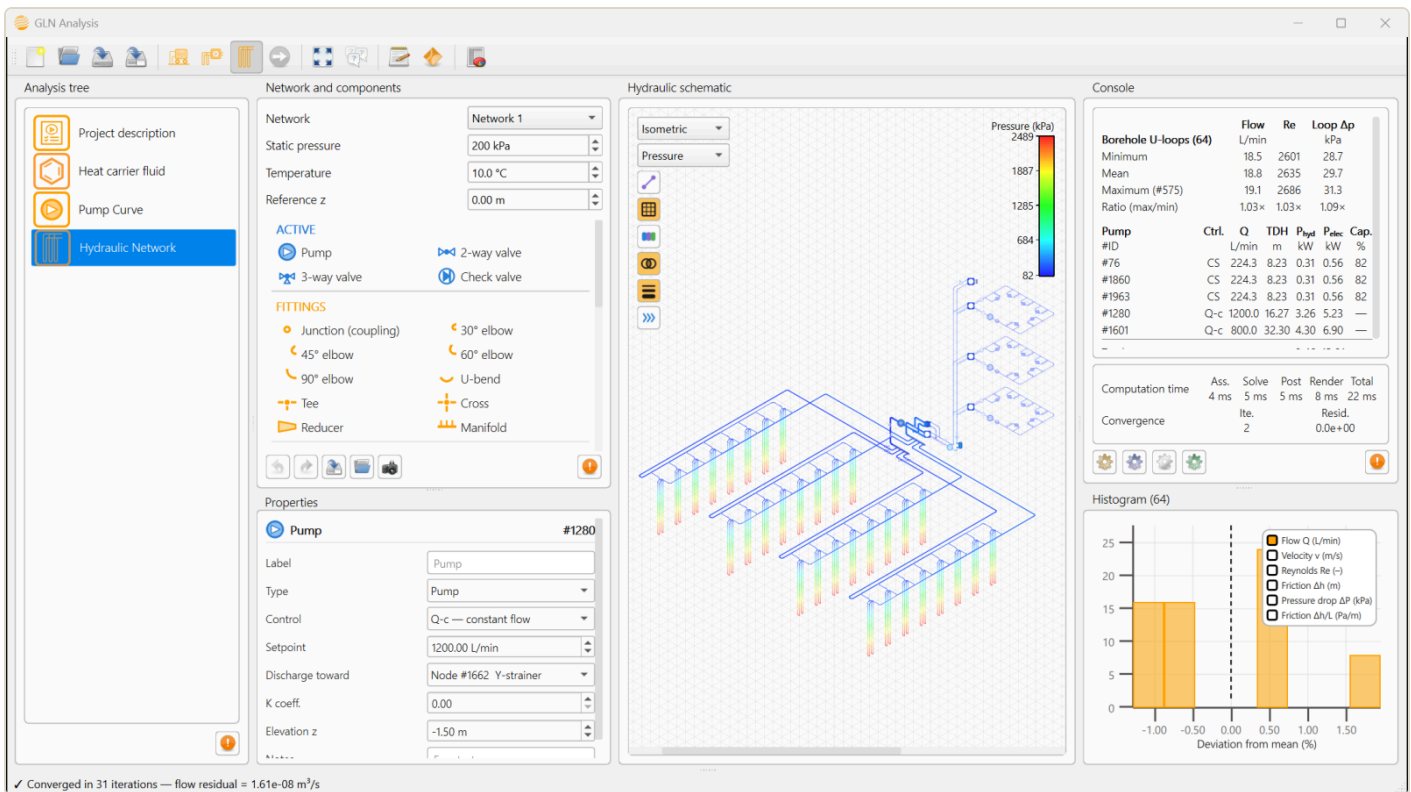


Figure 1 — GLN Analysis interface — the analysis tree on the left, then the Network and components box with its palette above the property inspector, the network canvas in the centre, and the design console with the borehole histogram on the right

A first network in a few minutes - The simplest way to build a first network is to follow the analysis tree from top to bottom, since each node sets part of what the next one needs.

- Project description** - record the project, the client and the site. This information travels inside the network file.
- Heat carrier fluid** - select the fluid and its antifreeze concentration. It sets the density and the viscosity used in every pressure loss.
- Pump curve** - the five pump slots already hold a usable ladder of curves, from a small residential circulator to the primary pump of a commercial field, so a first network solves without touching this panel. Replace them with the manufacturer H-Q points, and the hydraulic and motor efficiencies, of the pump you actually intend to install before quoting a result.
- Hydraulic network** - draw the circuit, give it its properties, and place the pressure reference:
 - Draw the circuit* - place components from the palette and connect them with pipes. For the ground heat exchanger itself, use the Network Builder rather than the mouse: choose the probe type, the connection scheme, the number of boreholes, the spacing and the depth, and the whole field is generated at once.
 - Set the properties* - give each pipe a type from the library, which fills its diameter and roughness together, and check the elevations. **Then type the real length of every pipe.** A freshly drawn pipe only carries a *seed* length, one metre per grid square, and a network solved on seed lengths looks normal while being wrong. The *Length* column of the Pipes table flags these pipes with a small orange bar; see *Pipe length* in the *Hydraulic network* chapter.

- *Place the pressurization point* - an expansion vessel, a reservoir or a fill connection, marked as the fixed-pressure node. A circuit without one is still solved, anchored to the *Static pressure* of its Network entry, and the console names the node it chose; place one yourself to choose where the pressure reference sits.
1. **Read the result** - the network is solved as you draw, with no button to press: the tables fill in, the drawing takes the colours of the display mode, and the four console pages report the pump operating points, the design checks, the critical head of each network and the conservation check. If the solve does not converge, no results are shown and page 4 of the console gives the reason.

At any step, the help button  gives guidance on the current panel, and the same content forms the chapters of this manual.

Before you begin - Four inputs decide whether the results mean anything. The pipe **lengths** must be typed, since the drawing carries no distances. The **fluid** must be the one that will circulate, at the temperature at which it will circulate: an antifreeze solution near 0 °C is far more viscous than water at 20 °C, and the difference goes straight into the pump head. The **elevations** must be entered, since a borehole leg is mostly a hydrostatic column. And no closed circuit may carry **more than one** fixed-pressure node: two over-determine the loop and drive a flow that nothing is pumping. A circuit with none is solved with a reference chosen by the software.

A quick sanity check - A well-behaved ground loop usually shows velocities between 0.3 and 2.5 m/s, with the mains toward 0.6 to 1.2 m/s; friction gradients between 100 and 400 Pa/m; and a borehole balance ratio close to 1. A balance ratio well above 1 means some loops are starved while others are over-supplied, which is a piping problem and not a sizing problem. A friction gradient far above the window on a single pipe usually means a diameter one size too small, and one far below it usually means an oversized pipe carrying an unnecessary volume of antifreeze.

Panel layout and numerical input - The module reuses the resizable split layout of the suite. In GLN the lower row of the window carries the result tables on the left and the property inspector on the right, so the drawing, the numbers and the inputs are visible at the same time. Drag the dividers to give more room to whichever of the three you are working in. As elsewhere in the suite, numerical fields respond to the mouse wheel and to the ↑ / ↓ keys as well as to typing.



Shortcuts

The keys, gestures and mouse actions that speed up drawing and editing on the *Hydraulic network* canvas. None of them changes what a network computes.

F	fit the view to the drawing
H	pan
Ctrl+Z / Ctrl+Y	undo / redo
Ctrl+C / Ctrl+V	copy / paste
Ctrl+A	select all
Ctrl+D	duplicate the selection
Del	delete the selection
Esc	end the current placement, drawing or selection
Ctrl+ / Ctrl- / Ctrl+0	zoom in, zoom out, fit
Shift+F	zoom to the selection
Ctrl+Shift+G	align the selection to the grid
Arrow keys	move the selection by one grid step (Shift = ten)
drag from a node's ring	draw a pipe from that node
T	Pipe tool — draw by clicking one node then the next, no drag
Shift + click	add to the selection
Ctrl + click	add or remove one object from the selection

Drawing without leaving the canvas - Two tools stay armed until you stop them, so repeated work takes one click per item.

Placing components. Pick a component in the catalogue and every click drops one. Place twenty valves with twenty clicks; press **Esc**, right-click, or pick another tool when you are done.

Drawing pipes. With the **T** tool, each pipe you finish starts the next one from the point you just reached, so a header is drawn as a polyline: click, click, click, then **Esc** to end the run. Dragging from one node to another still draws a single

pipe. Outside that tool, drag from a node's **ring** to draw one without changing tool.

Nudging. The arrow keys move whatever is selected by exactly one grid step, ten with **Shift**. Unlike dragging, it never welds the object to a neighbour or drops it into a pipe.

Putting a drawing back on the grid. Moving a selection snaps the *movement*, not each object, so the group stays rigid and a drawing already off-grid stays off-grid. **Ctrl+Shift+G** puts every selected node back on the nearest grid point, which slightly changes the shape of the group. Pipe lengths are typed values and are not affected.

Deleting. Deleting does not ask for confirmation, however large the selection: the status bar reports how many elements were deleted, and **Ctrl+Z** restores them all, including the pipes attached to a deleted node.

Mouse and trackpad - On a **trackpad**, pinch to zoom, scroll with two fingers to pan in any direction, and double-tap with two fingers to fit the drawing to the view. On a **mouse**, hold **Ctrl** and turn the wheel to zoom; the wheel alone scrolls. Zooming always keeps the point under the cursor in place. Dragging with the middle button, or with the right button, pans the view, and the **H** tool does the same with the left button.

Drawing a pipe on a trackpad. The ring of a node is a small target, harder to hit with a trackpad than with a mouse. If it is hard to catch, press **T** and click the two nodes instead: clicks are easier than drags on a trackpad, and they chain into a polyline as described under *Drawing pipes*. The node's tooltip gives this hint when the ring lights up.

Reading the canvas: hover and selection - Two marks show what the mouse is on. **Hovering** lays a pale orange glow behind the object; **selecting** draws a blue outline and a translucent blue wash. In the result modes, both marks take the colour of the object instead. They are painted *behind* the component, so a symbol keeps its drawing and a pipe keeps its result colour while selected. An object both selected and hovered shows the glow around the outline. Nodes, pipes, heat pumps, exchangers and manifolds all use the same two marks.

When **two or more objects** are selected, an orange frame encloses them, like the selection frame of the GHE Designer, with a badge counting the objects. **Drag inside it** to move the whole selection, snapped to the grid as one block, and **drag the round handle at its lower-right corner** to rotate it about the centre of the frame; the frame turns with its contents. A rotation changes no pipe length, so a solved network keeps its results. A plain click inside the frame still selects the single object under the cursor. Selecting a different set of objects starts a new frame, square to the drawing.



Saving, loading and exporting

GLN Analysis is one of three modules of a single Analysis Suite project. The drawing, the properties of every component, the pump library, the heat carrier fluid and the project description all travel inside the project's **.ghe** file, alongside whatever GHE and TRT work shares it. Reopening the file restores the network as it was left, including its working view, and solves it with its own fluid.

Creating, saving and opening a project - While the GLN module is active, New , Open , Save  and Save as , in the application toolbar, all act on the **.ghe** project, not on the drawing alone: New clears every module at once, and Save writes the network together with whatever GHE and TRT work accompanies it. There is no separate network-only save.

If the drawing has unsaved changes, **New** first asks *Save / Discard / Cancel*, before anything is cleared. **Open** uses a single dialog for the whole suite, and opening a **.ghe** project activates the **GHE** module: switch back to GLN with the module button of the toolbar. The file is checked before anything on screen is cleared: a corrupt or unrelated file is refused with the reason, and the current project is left intact.

The .ghe project file - A **.ghe** file is a compact binary archive (CBOR-encoded JSON) carrying the full project state: the drawing and the properties of every node and pipe, the pump library, the fluid and its concentration, and whatever GHE and TRT work accompanies them. It is written to a temporary file that replaces the project file only once complete, so a crash or a full disk leaves the previous version intact.

Inside, each module owns its own block with its own schema number. A block written by a **later** release that this one cannot read is kept and written back unchanged, so nothing is lost when a project goes back and forth between versions.

Because the three modules share the file, a project opened and saved from one of them keeps what the others hold.

Besides the nodes and pipes, the project stores four things that affect the results or the drawing when it is reopened:

- **the pump library**, so a node that references a pump by name still finds its curve;
- **the heat carrier fluid** and its concentration, since p and μ enter every pressure loss; it is independent of the fluid chosen in the GHE module;
- **the project description**, the one element shared with the other modules, so the drawing stays attached to the project that produced it;
- **the working view**, plan or isometric, since the two views do not share the same snap grid.

A file written by an earlier release opens normally; fields that did not exist then take a fixed default. Pumps read from an older file, for instance, report a hydraulic efficiency of 100 %.

Automatic export of the results - Each time the project is saved, the results of the network are written beside the **.ghe** file in **{project}_GLN_Results.csv**, the same way the GHE and TRT modules write theirs. There is no export button: saving is the only step. The file is overwritten at each save.

The file always describes the drawing that was saved. If the last computation no longer matches the drawing, a computation is run before the file is written. Nothing is written when the project holds no network or when no computation converges, and the file left by a previous save is then deleted so that it cannot be mistaken for current results.

The file follows the conventions shared by every CSV of the suite: columns separated by semicolons, a point as decimal separator, SI units whatever unit system the interface displays, UTF-8 encoding that Excel reads correctly, and a few opening lines starting with # that give the project name, the software version and the date of the save. An empty cell means that no value is defined, which is not the same as zero.

Inside the results file - Three short tables come first, because what they hold is the attribute of no pipe:

- **the solver status:** whether the computation converged, in how many iterations and to what flow residual, and any network left out of the computation with the reason;
- **the fluid of each network,** at the temperature the network was computed at: name, static pressure, density and dynamic viscosity, as they entered the calculation;
- **the pump operating points,** one line per pump node: network, control mode and setpoint, the curve it was resolved against, and Q, TDH, hydraulic power, efficiency, electrical power and the fraction of the curve's capacity it uses. Only the two powers are totalled, since two heads do not add.

The main table follows, with **one row per pipe** carrying the properties and results of its two end nodes in `From_...` and `To_...` columns. Each row stands on its own, like a line of a pipe schedule: network, pipe id and label, internal diameter, length and whether that length was typed or is still the seed taken from the drawing, the minor-loss coefficient of each end, then flow, velocity, Reynolds number, Darcy friction factor and flow regime, then `dP_nodes` (the difference between the two end pressures) and `h_L` (the head loss of the pipe itself), then, for each end node, its id, label, component type, elevation, pressure and singular loss, and finally the pipe's note. Internal edges of composite devices are not listed, and a node that touches no pipe still gets a row of its own.

A node shared by several pipes repeats its values on each of their rows. Those columns are made to be filtered, never totalled. The result cells of a network left out of the computation are empty.

Archetypes - An archetype is a piece of network saved on its own, outside any project, so that recurring pipework does not have to be redrawn.

The archetype commands are the third and fourth buttons of the row under the **Network and components** panel of the *Hydraulic network* page, after Undo and Redo.

Select the nodes and pipes concerned — at least one node — then press *Save the selection as an archetype* . A short form opens in the Properties panel asking for a name, a category and a description; the archetype is then written to the application data folder as a **.hya** file, plain readable JSON, with a 320 × 240 **.png** thumbnail beside it.

Insert an archetype , the button next to it, opens the gallery in that same Properties panel. It lists the archetypes **shipped with the application** alongside those saved from earlier drawings, each with its thumbnail. The archetype selected is inserted with a translucent preview that follows the cursor until the next click. Archetypes are independent of any project, so a plant room drawn once is available in every network afterwards. The application ships two borehole fields, eight single-U and eight double-U boreholes; they are drawn in isometric view and are inserted on an isometric canvas only.

An archetype that would take the drawing past the pipe limit of the current licence is listed greyed, with the number of pipes it would add and the limit of the licence.

Your own archetypes are maintained from the same gallery. *Edit...* reopens the save form on the selected archetype to change its name, category or description; renaming renames the file and its thumbnail. *Delete* moves the archetype and its thumbnail to the recycle bin, where it can be restored. Both buttons are greyed on the archetypes shipped with the application. To change the network itself, insert the archetype, modify it on the canvas, select it and save it again under the same name: the application asks before replacing the existing one.

Saving a picture of the drawing - The camera button  of the same row, right after the archetype pair, saves the **active view** as it is framed on screen: a PNG, or a 30 s animated GIF when the flow animation is running. Resolution and frame rate are given under *Capturing the view*, in the *Hydraulic network* chapter.

The file is proposed next to the open project and named after it. If it cannot be written, most often because it is still open in another application, the status line reports it and nothing is overwritten.



Project description

The Project description panel records the administrative context of the hydraulic study: project identity, site location and client, together with a general notes field for the assumptions that shape the network. None of this affects the solution, but it travels inside the project's **.ghe** file, so a drawing sent to a colleague or archived at the end of a project arrives with the context needed to read it.

The screenshot shows the GLN Analysis software interface. The 'Project description' panel is active, displaying the following information:

- Project name:** Polytechnique Montréal — Building loop
- Project no.:** GML6113
- Client name:** My favourite client
- Address:** 2500, chemin de Polytechnique
- Currency:** \$ CAD — Canadian dollar
- Prov./State/Depart.:** Québec
- City:** Montréal
- Postal Code:** H3T 1J4
- Country:** Canada
- General notes:** A complete ground-source system of 615 nodes and 701 pipes, forming five independent networks. The borehole field, 32 double U-loop boreholes 225 m deep gathered by a supply and a return manifold into four branches, each with its own balancing valve, runs 20 % propylene glycol at -2 °C; its plant room holds a constant-flow pump (72 m³/h), a strainer, a three-way valve, and the field side of a production heat pump and of a geocooling plate heat exchanger. The building loop, at 10 °C, carries the other side of those two units, a buffer tank, a three-way valve, a check valve, an air separator at the top of the riser and its own constant-flow pump (48 m³/h). It serves a heat pump on each floor (1, 4 and 7 m) and a fourth one at 10 m. Each floor heat pump feeds its own fan-coil loop: six fan coils, a pump running on its curve, an expansion tank and a fill connection that sets the loop's pressure. Every network is computed at its own temperature; at -2 °C the borehole legs run near a Reynolds number of 2 400, in the transition band. The same network is verified against EPANET 2.2 in the Complete system category of the Examples and verification window.
- Location map:** A map showing the location of Polytechnique Montréal, with latitude 45.505° N and longitude 73.615° W.
- Console:** Displays performance metrics for Borehole U-loops (64) and Pump (64).
- Histogram (64):** A bar chart showing the distribution of various parameters, with a legend for Flow Q (L/min), Velocity v (m/s), Reynolds Re (-), Friction Δh (m), Pressure drop ΔP (kPa), and Friction Δh/L (Pa/m).

Figure 2 — Project description panel — project number, name and client, site address with the location map, currency, and the general-notes field

Project information - Enter the project number, project name and client name for your records; none of it affects the hydraulic study.

Site location and map - Provide the site address, city, postal code, province or state and country, then press the Validate address button . It sends the address to an online mapping service, which returns the site latitude and longitude and displays a location map. An active internet connection is required. If the address cannot be resolved, refine it, since a complete street address gives the best result, and validate again. The coordinates are stored with the project for documentation.

General notes - Use the General notes field for anything a later reader would need in order to judge the network. A hydraulic drawing is a set of decisions, and most of them are invisible in the geometry: which return scheme was adopted and why, where the balancing devices are expected to be installed, what pipe material and jointing method

the installer will use, what the plant room actually looks like compared with the simplified diagram, and which lengths were entered from the real installation rather than left at the value a freshly drawn pipe starts from. Record also the design condition the network was solved at, in particular the fluid temperature chosen, since a loop sized at an annual average behaves differently on the coldest day of the year.



GLN in practice: documenting what the drawing cannot show

A hydraulic model is a diagram, not a construction drawing. It carries the topology, the diameters, the lengths and the elevations, and those are enough to compute the flows, but it says nothing about how the network will be built. Two networks with identical models can behave very differently once installed, depending on how the headers are actually assembled, how the loops are purged, and whether the balancing devices reach the site at all.



Heat carrier fluid

This panel selects the fluid that will circulate in the network. The density ρ and the dynamic viscosity μ enter every pressure loss the solver computes, so the fluid chosen here sets the friction of every pipe, the operating point of every pump and the pumping energy of the system. **The current version assumes one and the same fluid for every network of the drawing, evaluated at a different temperature for each** — see *Where the temperature comes from* below.

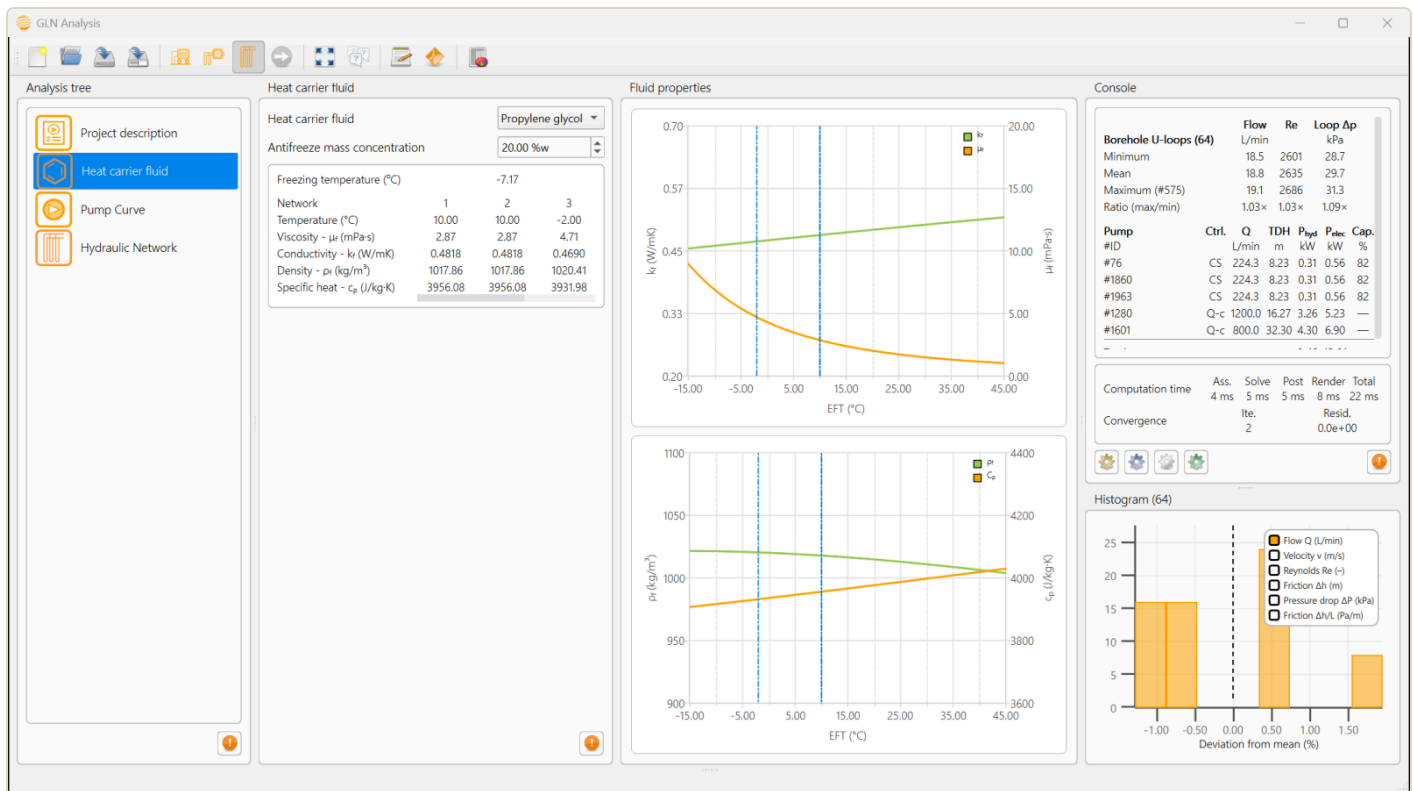


Figure 3 — Heat carrier fluid panel — fluid selector, antifreeze concentration and the thermo-physical property charts

Heat carrier fluid - Five fluids are available: pure water, ethylene glycol, propylene glycol, methyl alcohol and ethyl alcohol. Their properties come from the Melinder correlations (Melinder, 2010), which are fitted from 0 to 60 % mass fraction and, in temperature, from the freezing point of the solution up to 100 °C for the two glycols and 40 °C for the two alcohols. The way those correlations were built is summarised in the author's thesis (Melinder, 2007), which shows the comparison against the source data for ethyl alcohol and refers to earlier work for the glycols. GLN evaluates them inside a narrower window that stays within that domain: from -15 °C, or the freezing point of the mixture if it is higher, up to 50 °C for water and the glycols and 40 °C for the alcohols, and from 0 to 60 % in concentration. A 20 % propylene glycol solution, for instance, freezes near -7 °C, and a network declared colder is evaluated at -7 °C. A network configured outside the window is still solved, but with the properties taken at its edge rather than with an extrapolation that could return a non-physical density or viscosity. When that happens, the fluid name reported in the console shows

both the configured temperature and the temperature at which the correlation was actually evaluated. Changing the fluid or its concentration clears the results on screen and solves the network again with the new fluid.

Antifreeze mass concentration - The mass concentration of antifreeze, in kilograms of antifreeze per kilogram of solution, reported as a percentage, assuming pure water as the solvent.

Where the temperature comes from - The fluid type and its concentration belong to the **network**, and the temperature at which they are evaluated belongs to each **independent network** inside it, set in the *Network* section of the Hydraulic network panel. A drawing holding a primary loop at 30 °C and a ground loop at 0 °C is therefore solved with two different densities and viscosities.

Summary & charts: the fluid, network by network

The table beside the selector reports the **freezing point** of the mixture, and then one **column per network**: the temperature that network is solved at, and the viscosity, thermal conductivity, density and specific heat the solver reads at that temperature (read from the same Melinder evaluation the hydraulic solver itself calls). Each column heading carries the network's number, the same as in the Network section of the hydraulic panel and in the console.

The charts below plot each property against temperature over the range the correlations cover; they show how steeply the viscosity of a glycol solution climbs as the loop cools. **A vertical line marks the temperature of each network.**

GLN in practice: what viscosity costs a ground loop

Do not over-concentrate the fluid. The freezing point should sit a few degrees below the coldest temperature the loop will see, **and no lower**. More antifreeze adds no safety: it thickens the fluid, raises the pump head, lowers the Reynolds number and pushes a marginal leg toward laminar flow. Take the concentration from the minimum leaving fluid temperature GHE Analysis predicts, then solve at that temperature. The choice between propylene glycol, ethylene glycol and the alcohols is rarely hydraulic alone — toxicity, code, compatibility and disposal usually weigh as much as friction.

A common field mistake. When a heat pump trips on high pressure, the fix often proposed is more antifreeze. It raises the viscosity, reduces the flow the installed circulator can deliver, may drop a marginal leg into laminar flow and moves the return temperature further from the ground temperature, which worsens the fault. The antifreeze is also usually added without measuring what the loop already holds, which may be at or above the design concentration. A field hydrometer answers that in a minute: draw a sample, read the concentration and compare it with the value set in this panel.



Pump curve

This panel holds the library of circulating pumps available to the hydraulic network. Each pump is described by its head-flow characteristic and its efficiencies; the network solver then finds where each pump's curve meets the resistance of the circuit it sits in. The five default pumps, described below, let you solve a network before your own pump is chosen; replace a slot with the manufacturer's curve of your pump as soon as it is known.

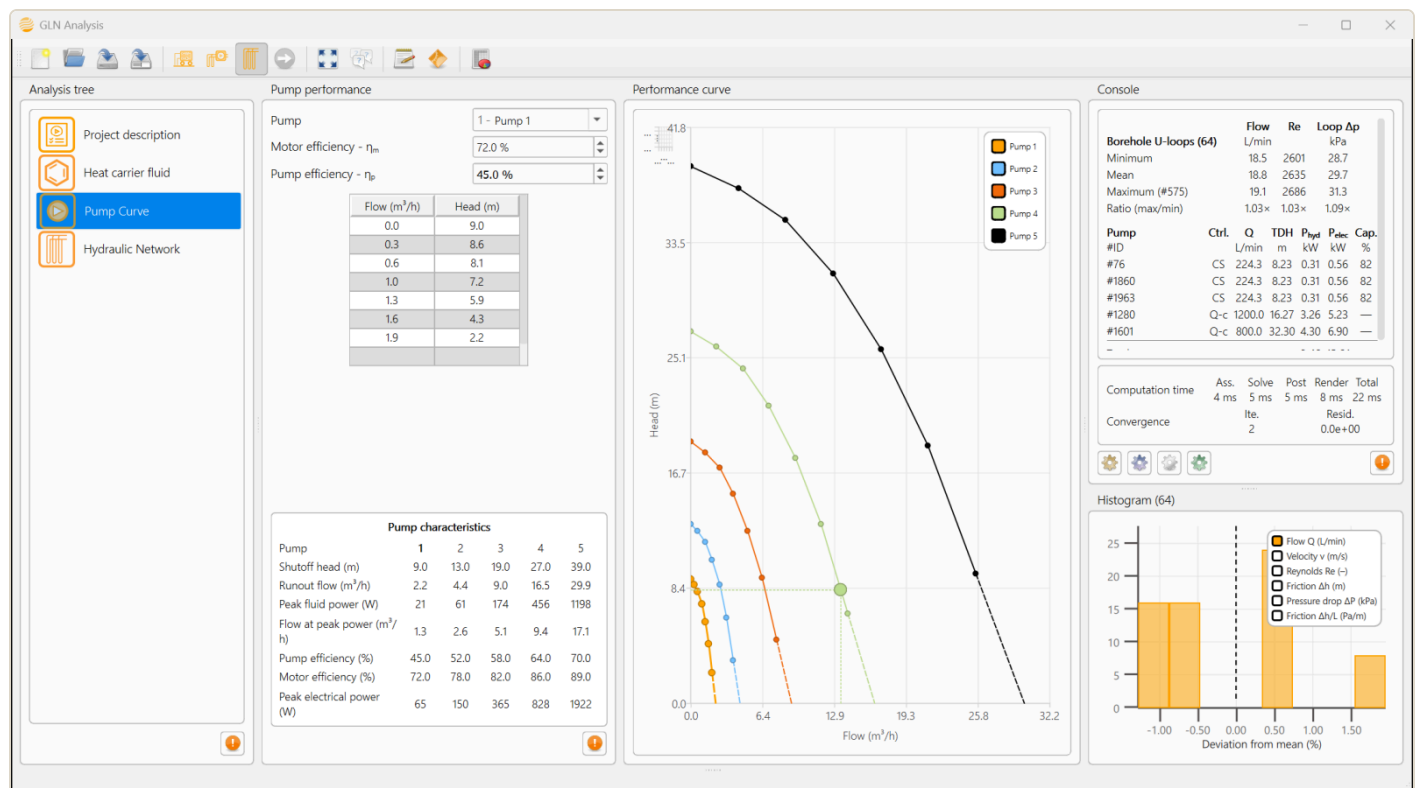


Figure 4 — Pump curve panel — the five curve slots, the H-Q point table with the motor and hydraulic efficiencies, the chart of all five characteristics with the operating points, and the table of pump characteristics

Defining a pump - The library holds five pump slots, listed in the **Pump** box at the top of the panel. Pick one there to edit its curve and efficiencies; everything below the box applies to the pump shown in it. Slots cannot be added or deleted; an unused slot keeps its default name and curve.

The five slots start out as five **real pumps**, from the smallest to the largest, each read off the maximum curve of its Grundfos data sheet:

| Slot | Pump | Shutoff head | Last point read | Power input | |---|---|---|---|---| | Pump 1 | UPS 15-58 FC, speed 3 (wet rotor, 60 Hz) | 5.9 m | 0.7 m at 3.6 m³/h | 87 W | | Pump 2 | UP 26-116 F (geothermal flow-center pump, 60 Hz) | 11.3 m | 1.6 m at 7.7 m³/h | 385 W | | Pump 3 | MAGNA3 32-100 F, MAX curve (60 Hz) | 10.2 m | 1.5 m at 10.2 m³/h | 180 W | | Pump 4 | MAGNA3 40-180 F, MAX curve (60 Hz) | 17.9 m | 2.9 m at 24.8 m³/h | 614 W | | Pump 5 | TPE3 40-240-S, 100 % then power limit (dry rotor, 50 Hz) | 24.8 m | 6.8 m at 35.9 m³/h | 1.7 kW |

The overall efficiency (pump × motor) of each slot is the one its data sheet gives in the middle of the maximum curve, from about 21 % for the two single-speed wet-rotor circulators to about 67 % for the dry-rotor pump. The curves are digitised from the published graphs, to the tenth of a metre and of a cubic metre per hour: close enough to size a loop, not a substitute for the manufacturer's selection software. The slots keep their names, *Pump 1* to *Pump 5*, because the nodes of a drawing refer to a pump by its name.

Each slot carries its **rank** in front of its name — 1 - Pump 1, 2 - Pump 2 and so on — in the box and in the list it drops down. The number is fixed and identifies the slot's column in the table below and its entry in the chart legend, even after the pump is renamed. It is not part of the name.

Rename a pump by typing over the name in that same box and pressing Enter (or clicking elsewhere); the leading number stays where it is and cannot be typed over. The name is what the hydraulic inspector offers in its *Pump curve* combo box, so name them after the model or the position they occupy rather than leaving Pump 1, Pump 2. Renaming follows through to the network: every pump node that referenced the old name is re-pointed to the new one. Two pumps cannot share a name, and a blank name is refused — in both cases the former name comes back.

H-Q points - Enter the manufacturer's curve as up to eight flow-head pairs, flow in m³/h and head in metres. All eight rows are on screen at once whenever the panel has the height for them. Points may be entered in any order; they are sorted and duplicates averaged. A published curve usually stops well before the head reaches zero. The panel completes it, extrapolating back to a shutoff head at Q = 0 if the first point is not there and extending the tail down to the runout flow where H = 0, beyond which the pump can supply no head at all. Both completed segments are drawn dashed, distinct from the points you supplied. Without this completion, the solver could place the operating point on a non-physical extension of a truncated curve.

Motor η (motor efficiency) - The electrical-to-mechanical efficiency of the motor. About 95 % is a reasonable estimate for a motor above 50 hp, and 80 to 90 % for a smaller or repeatedly rewound one (U.S. DOE and Hydraulic Institute, 2006); the small circulators of a ground loop are often lower still. The distinction between the two efficiencies, and the way an operating point is read off the intersection of a pump curve with a system curve, are covered in U.S. DOE and Hydraulic Institute (2006) and, for geothermal loops specifically, in Lamarche (2023), Ch. 7.

Pump η (hydraulic efficiency) - The mechanical-to-fluid efficiency of the pump itself, at the operating point. This is a **different quantity** from the motor's, and the two multiply.

$$P_{\text{electrical}} = P_{\text{fluid}} / (\eta_{\text{pump}} \cdot \eta_{\text{motor}})$$

Typical values are 25 to 45 % for a small wet-rotor circulator and 60 to 80 % for a well-sized centrifugal pump. Setting $\eta_{\text{pump}}=100\%$ neglects pump losses and therefore gives an optimistic estimate of the required shaft or electrical power.

Summary & charts: the five characteristics, side by side

The chart - All five pumps are drawn together, each in its own colour, to show which curves pass above the required head at the required flow. The pump currently selected in the **Pump** box is drawn thicker and carries the markers of the points you entered; the dashed tail of each curve is the completion down to H = 0 described above.

The legend is interactive. Click a pump's name to hide its curve, click again to bring it back; a hidden pump stays in the legend, greyed out. The axes cover all five curves and do not change when one is hidden.

Metrics

Pump characteristics is a table of the whole library, not of the pump on display: one row per characteristic, one column per pump, in the order of the chart legend. Each column is headed by the pump's number — the same number the **Pump** box shows in front of its name — and its full name is in the tooltip of every cell. The column of the pump currently selected is in bold.

The rows are read from the curve itself and from the two efficiency fields above:

- **Shutoff head** — the head at $Q = 0$, the top of the characteristic;
- **Runout flow** — the flow at $H = 0$, its right-hand end;
- **Peak fluid power** — the largest value of $p \cdot g \cdot Q \cdot H$ anywhere on the completed curve, that is, the most hydraulic work this pump can deliver at any point of its range;
- **Flow at peak power** — where on the curve that maximum falls;
- **Pump efficiency** and **Motor efficiency** — the two values entered for that pump;
- **Peak electrical power** — the peak fluid power divided by the product of the two efficiencies, an order of magnitude for the motor the pump will need.

The **operating points of the solve** are not repeated here. They are in the console, page *Pumping & operating point*: one line per pump node found in the drawing, identified by its node number, with its control mode, its flow and head, its hydraulic power, the combined efficiency $\eta_p \cdot \eta_m$, the electrical power $P_{hyd}/(\eta_p \cdot \eta_m)$ and **Cap.**, the share of the assigned curve's capacity the point uses — the larger of the two fractions a curve bounds, flow against runout and head against shutoff. A curve is used only in CS mode: a pump in ΔP -c or Q-c is its setpoint, so its **Cap.** is a dash and no curve warning is issued for it. Which network each pump serves is on page *Critical path & networks*.

Points drawn on the chart. Only the operating points of pumps in CS mode are plotted, in the colour of their pump and larger than the entered points, each with crosshairs down to both axes (thicker for the pump on display). A pump in constant-head or constant-flow mode does not operate on its curve, so its point is not drawn; it still appears in the console, where the *Ctrl.* column gives its mode.

GLN in practice: pump selection

Read the operating point, not only the curve. A pump whose curve passes above the required head at the design flow will work, but its position on its own curve decides its running cost and its life. Aim for the best-efficiency point: a pump running far to the left of it, throttled by an over-restricted circuit, is noisy, inefficient and wears its bearings.

Avoid sizing against a head that includes a safety margin on every branch. The margins add up, and a pump chosen for a head that never occurs runs far to the right of its intended point, draws more power than predicted and may cavitate. Size against the computed critical path and apply a single margin.

For a ground-loop circuit, remember that the fluid is not water. Antifreeze raises the viscosity, which raises the friction and shifts the system curve up. The effect grows as the loop gets colder, when the pump works hardest. The hydraulic network evaluates each network's fluid at its own configured temperature; make sure that temperature reflects the coldest condition you expect, not an annual average.

A variable-speed pump can be solved in constant-head or constant-flow control, but there is no speed-scaled curve: the affinity laws are not applied. To analyse a variable-speed drive at reduced speed, enter the scaled curve as a separate pump slot.



Hydraulic network

This panel is where the piping that connects the various components of a ground-source heat pump system is drawn and solved. You lay out the network as a P&ID diagram (nodes for components, edges for pipes), assign the properties of each element, then compute the pressures, the flow distribution and the head the circulating pump must supply. The hydraulic balance computed here tells whether every borehole receives the flow assumed by the thermal design: a correctly sized field that is piped unevenly will not deliver the performance predicted by GHE Analysis.

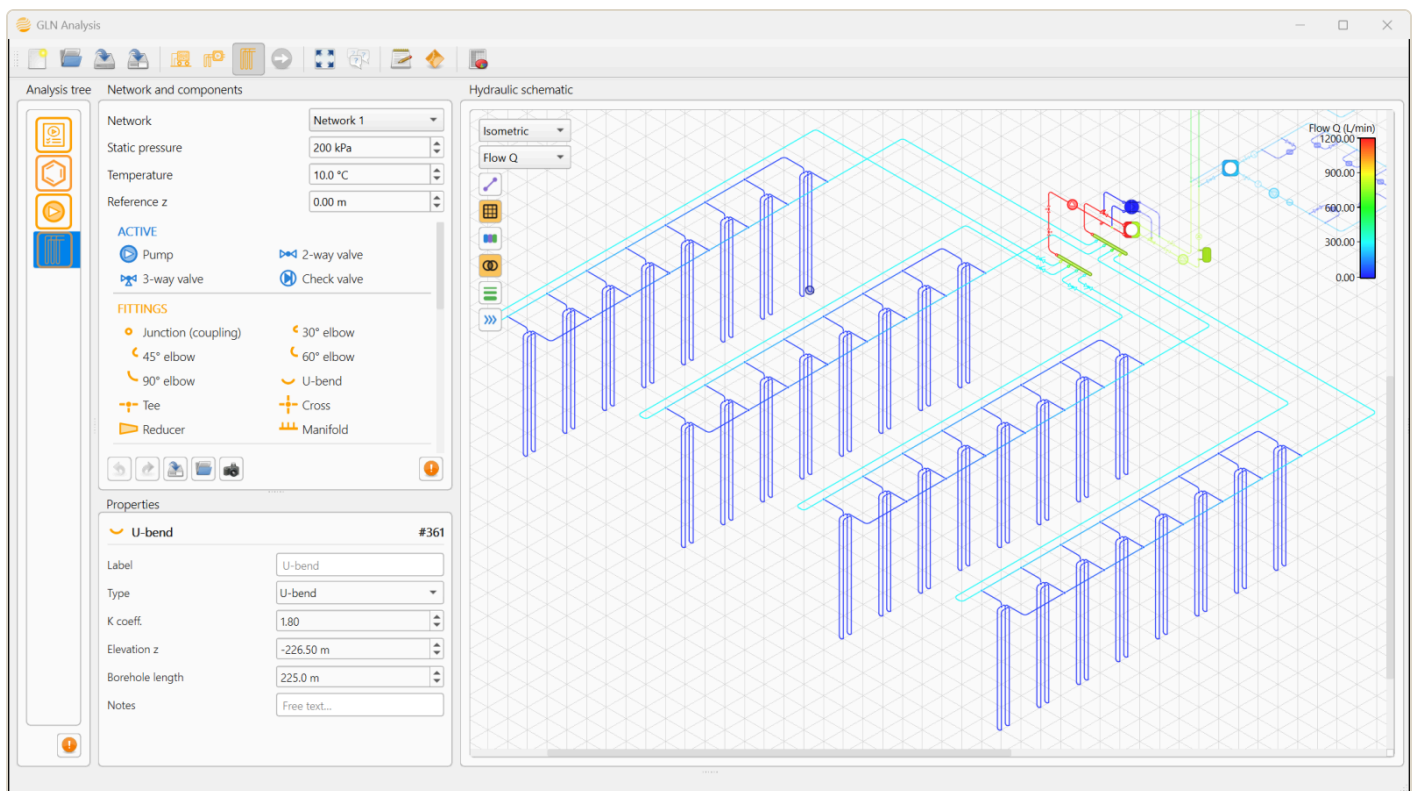


Figure 5 — Hydraulic network panel — the Network and components box with its palette, the Properties inspector below it, and a solved ground heat exchanger on the drafting canvas, widened here by folding the console away



Nodes, pipes and what the solver reads

Whatever you draw, the solver sees only two kinds of object, nodes and pipes, and every panel, table and result column of this module is organised around them.

A **node** is a point where a pressure is computed. Every component of the catalogue is a node, or a small cluster of them: a valve, an elbow, a tee, a pump, an expansion vessel. What a node contributes to the calculation is its **elevation z**, which sets its hydrostatic term, and its **minor loss coefficient K**, the local loss of the fitting. A few node types carry more: a pump adds head, a three-way valve splits a flow, and a node marked as the pressure reference fixes the level of the whole circuit. A **pipe** joins exactly two nodes and carries a flow between them. What a pipe contributes is its **length**,

its **internal diameter** and its **roughness**, which together give the distributed friction loss. Its length is typed, never measured off the drawing.

A network can be solved when its nodes and pipes are complete and consistent, and the result is reliable when their values match the real installation. The two tables at the bottom of the window list the nodes and the pipes, with their inputs on the left and their computed values on the right.

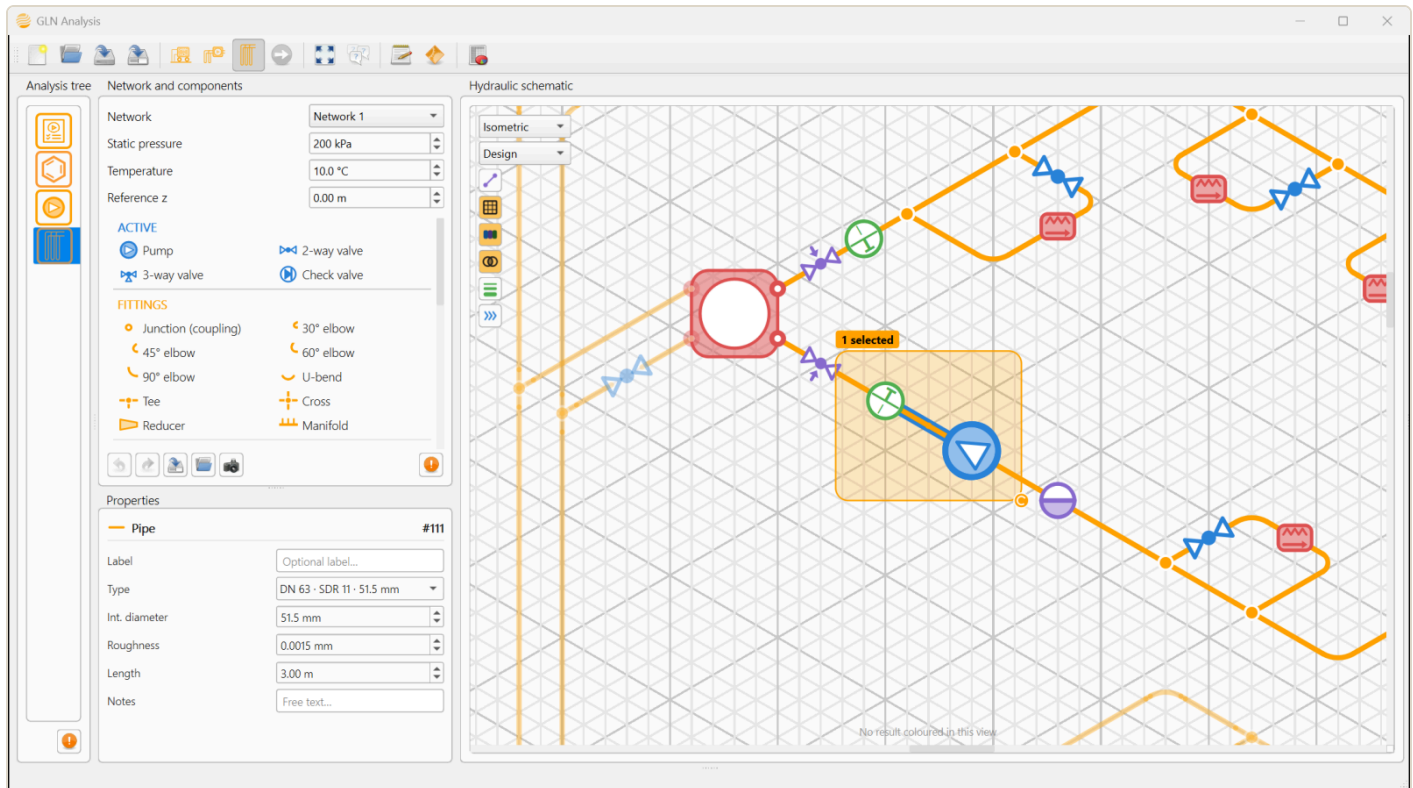


Figure 6 — The two objects the solver sees: a node, carrying its elevation z and its minor loss coefficient K , and a pipe, carrying its length, its internal diameter and its roughness

The solution is a **steady, isothermal** snapshot: the pressure at every node and the flow in every pipe, for one operating condition. Its limits are listed under *Known modelling limits*, in *Solving*, below.

The Network and components panel

The box on the left of the panel holds, from top to bottom, the properties of the selected **network**, the **palette** of components and a **row of buttons**.

The network and its properties - A drawing may hold several **independent networks**, connected components that share no pipe. Each has its own entry in the selector, its own static pressurization and its own fluid temperature.

- **Static pressure** (kPa): the pressurization applied to that network's fixed reference node. It shifts every pressure by a constant; it does not change the flows.
- **Temperature** (°C): the temperature at which that network's fluid properties are evaluated. Two networks at different temperatures are each solved with their own density and viscosity.

- **Reference z** (m): an elevation offset for the selected network only. It enters no calculation; it is a convenience so that a node's own **Elevation** can be typed relative to a local datum — the plant-room floor, say — instead of everything being counted from one absolute zero.

The fluid itself, water or a given antifreeze at a given concentration, comes from the shared **Heat carrier fluid** panel and applies to the whole project.

The list of networks is built from the drawing: a loop appears in the selector as soon as no pipe joins it to the rest, and two networks merge as soon as a pipe connects them. Networks are therefore not added, removed or renamed by hand.

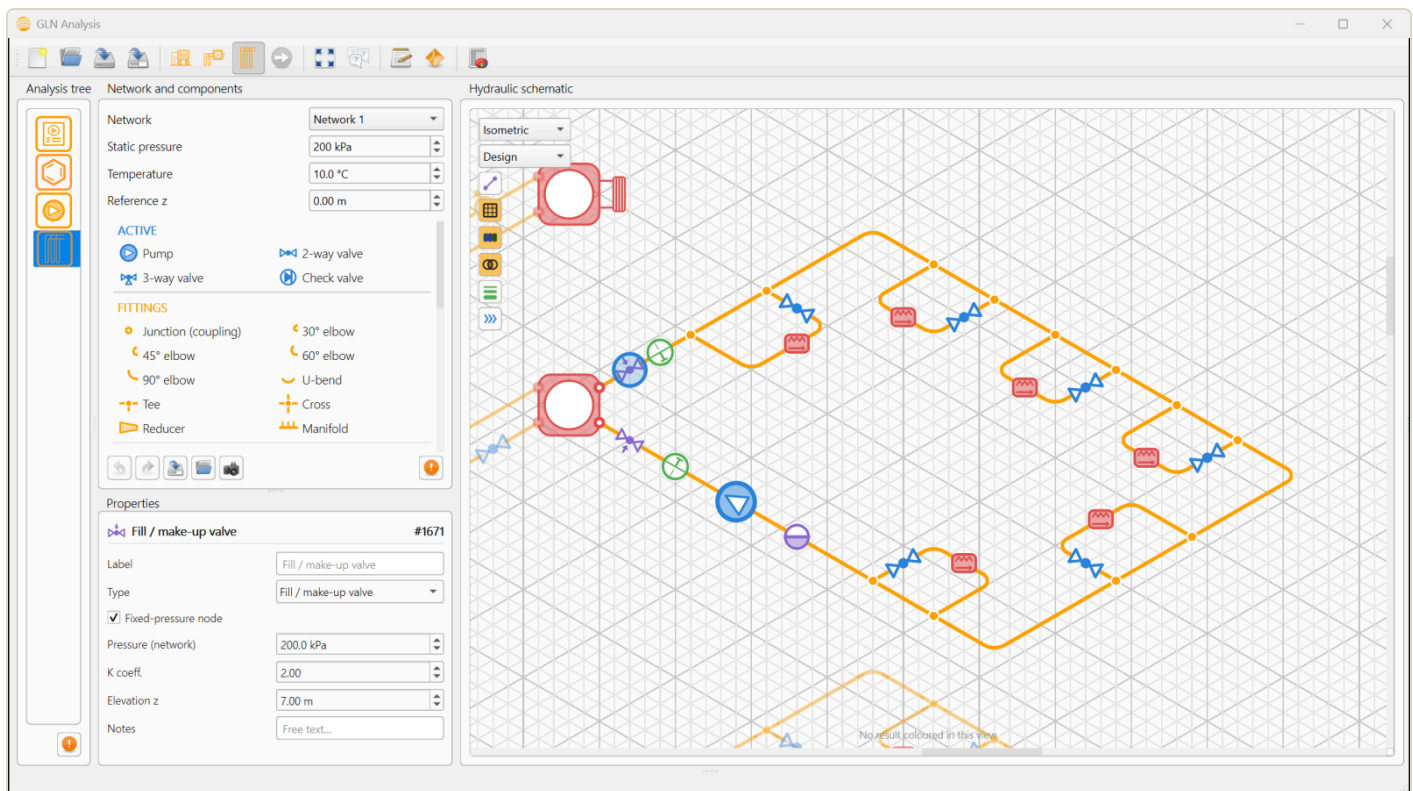


Figure 7 — The head of the Network and components box: the independent-network selector and the three properties that belong to the selected network alone

The component palette - The palette groups the components in seven families, each in its own colour, from **Active** components at the top to **Treatment** items at the bottom. An item can be clicked and then placed, or dragged straight onto the canvas; its tooltip gives the full name when the label does not fit. The full list, family by family, is the *Component catalogue* of the *Catalogues* section.

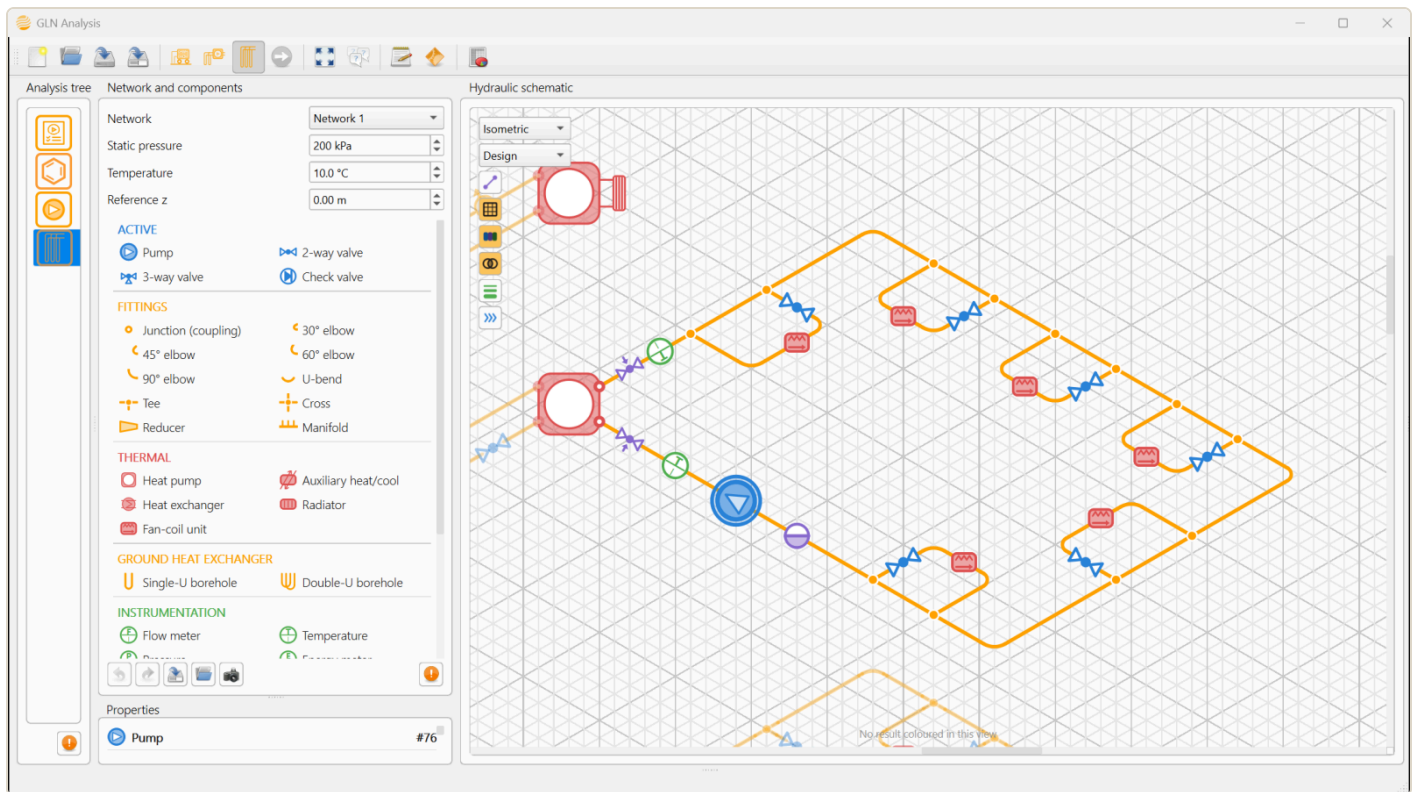


Figure 8 — The component palette, its seven families each in its own colour, from Active at the top to Treatment at the foot

Setting a component before you place it - Picking a component in the palette shows in the **Properties** panel the values it will carry once placed: its K, its elevation, its kind and, for a borehole, its length and leg diameter. The identity strip then reads *to place* instead of a node number. Values edited there apply to every component of that type placed afterwards: set a borehole to 180 m once and every following borehole is 180 m, until you change it. These presets belong to the project, and **New** resets them to the defaults.

Kind - Components that differ only by their symbol or their default K share **one** palette entry, and the **Kind** field of the inspector selects the variant: the two-way valve (gate, ball, butterfly, balancing, purge, safety), the three-way valve (mixing, diverting), the heat pump (water-water, water-air), the heat exchanger (plate, coaxial, shell-and-tube) and the temperature and pressure instruments (gauge, sensor). On all of them except the heat pump, Kind changes the symbol and seeds the default K, but leaves a K you have typed yourself untouched.

On the heat pump, Kind changes the drawing. A water-air unit exchanges with air on its building side and has a single water circuit: choosing *Water-air* removes the load circuit and its two ports, **together with any pipe still attached to them**, and the status bar says how many pipes were removed. Choosing *Water-water* again re-creates the circuit, with the default K. The source side is not affected: its two ports keep their position, their K and their piping, so a field already connected stays connected.

Placing a single borehole - Each of the three boreholes of the palette places a **whole borehole** in one gesture: two legs, a U-bend at the foot and a connection point at the head of each leg. The borehole is dropped at its **head** and extends below it. In the **isometric** view, the single-U and double-U boreholes also come with their piped head (elbows, and for the double-U the tees joining the two circuits), ending on two connections labelled **Supply** and **Return**. By default the legs are 225 m long with a 32.7 mm bore, the U-bend sitting at -225 m; the coaxial borehole is 150 m long. After placement the U-bend is left selected, so its **Borehole length** field in *Properties* is ready to edit: one entry sets

both legs and moves the U-bend to z(head) – length. Selecting every U-bend of a field sets all the depths at once. Leg diameters are edited on the *Pipe* page.

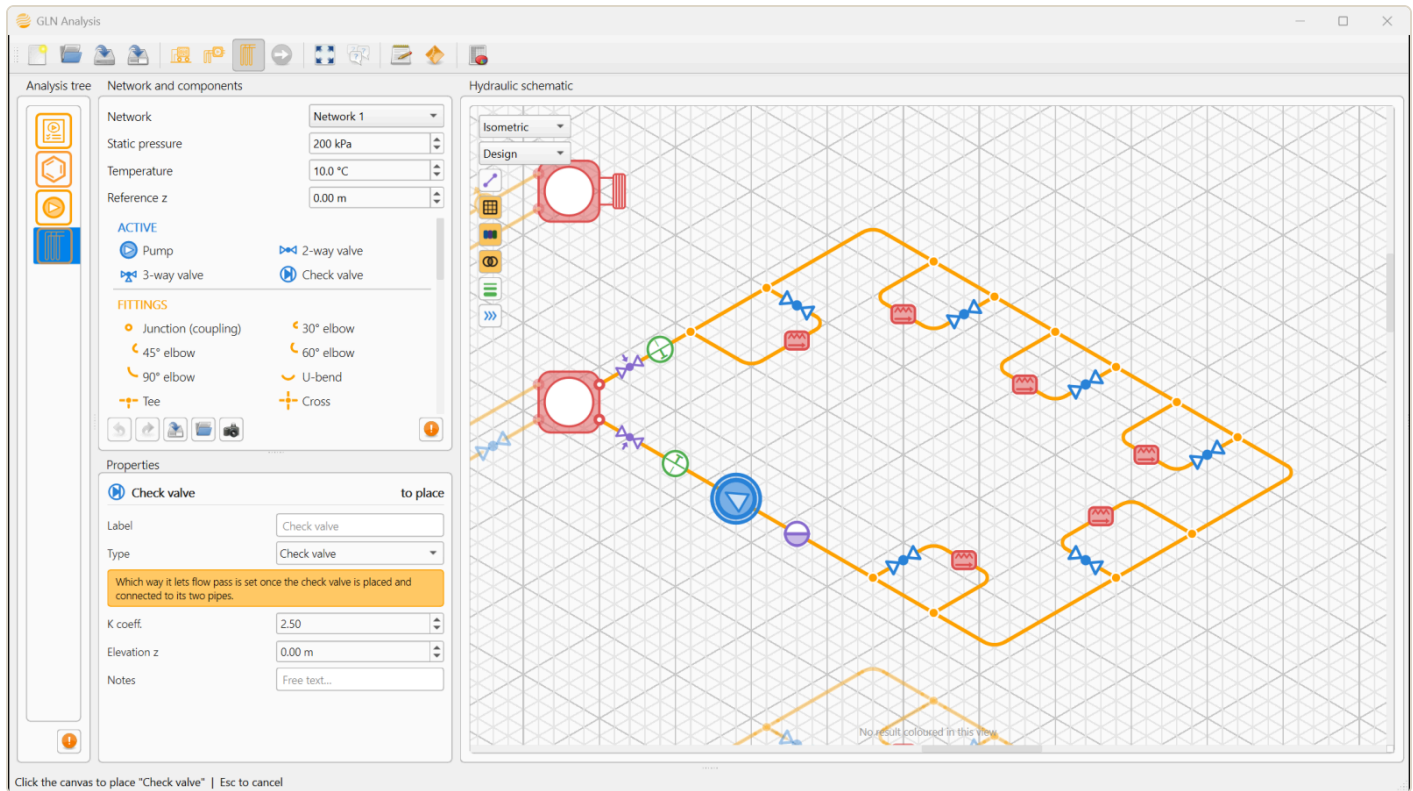


Figure 9 — Properties showing a component picked but not yet placed: the identity strip reads to place instead of a number, and what is typed here is what the next one dropped will carry

The button row under the panel - The row under the panel holds **five command buttons**, with the help button set apart at the right end; each has a tooltip.

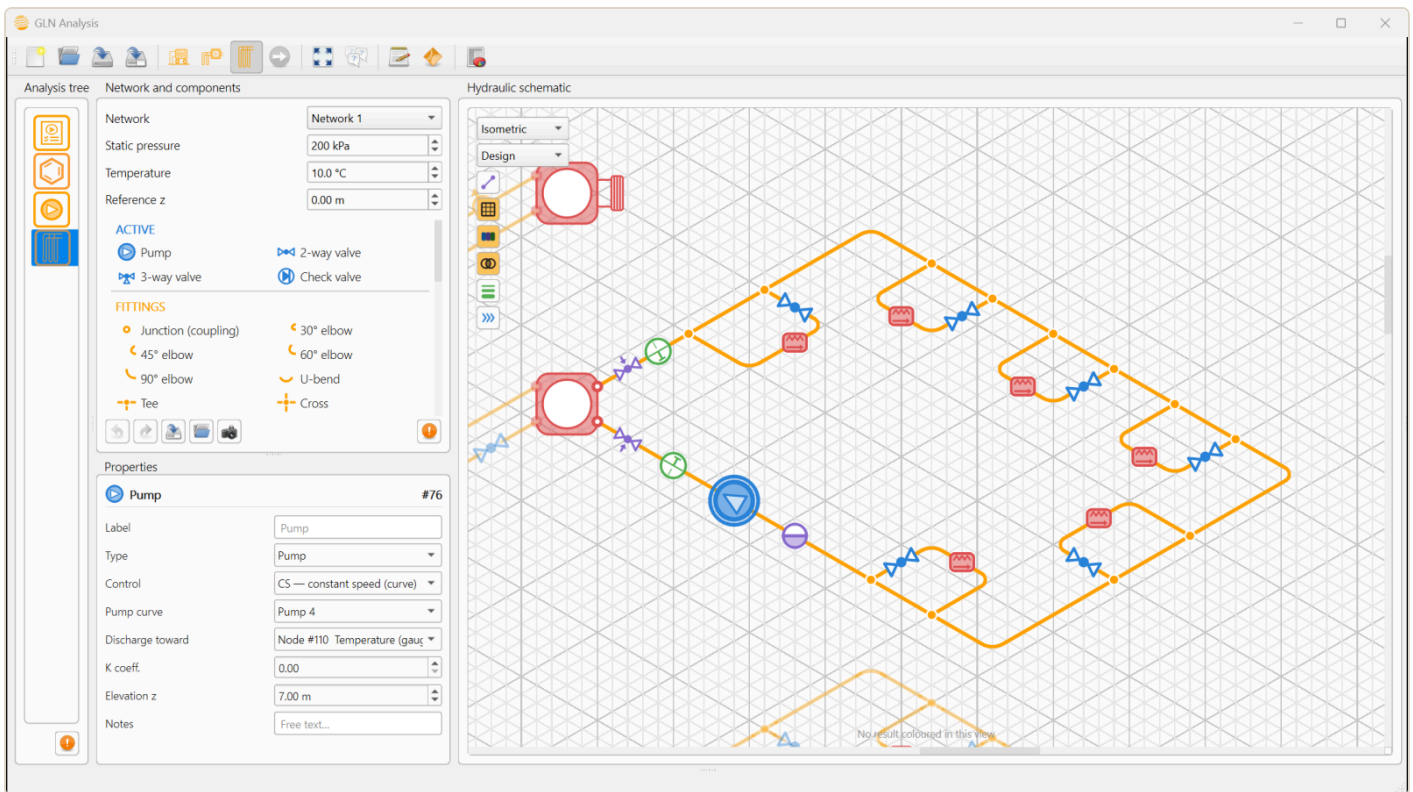


Figure 10 — The button row under the panel: undo, redo, save the selection as an archetype, insert an archetype, capture the view, and the help button at the right end

ICON	BUTTON	WHAT IT DOES
	Undo (Ctrl+Z)	Steps back through the drawing history, inspector edits and table entries alike. A batch edit over a selection undoes as one step.
	Redo (Ctrl+Y)	Steps forward again.
	Save as archetype	Saves the current selection as a reusable sub-network in the archetype library, so a plant room or a borehole head drawn once can be dropped into any later project.
	Insert an archetype	Opens the archetype gallery and inserts the chosen one, with a preview that follows the cursor until you click.
	Capture the view	Writes a PNG of what the canvas is showing — or, when the flow animation is running , a 30 s animated GIF, and the icon then shows a movie camera. See <i>Capturing the view</i> , under <i>Showing the network</i> .
	Help	Opens this page in the console, in place of the results. Any console page button brings the results back.

Show table is not in this row but in the main toolbar, at its right end. It shows and hides the Nodes and Pipes tables at the bottom of the window. The tables are **hidden when the module opens**, leaving the full height to the drawing;

while they are hidden, *Properties* moves to the bottom of the Network panel and the **Histogram** panel appears under the console.

The canvas

The canvas and its grid - Nodes carry the standard P&ID symbols; pipes show their diameter and length. The canvas is a schematic and carries no distances: a pipe's length is typed in its Properties panel (see *Pipe length*, below), and the grid only gives a freshly drawn pipe a starting length of one metre per square. The **Grid** button  of the floating toolbar hides the grid and turns the snapping off with it. Pinch a trackpad to zoom, scroll with two fingers to pan, or hold the right mouse button to pan; **F** frames the whole drawing. The full list of gestures and keyboard shortcuts is in the *Shortcuts* chapter, near the front of this manual.

View selector - The first list above the canvas switches the canvas to the plan or isometric convention. In isometric view, nodes snap to a 30° lattice and pipes are drawn along its three directions: 30° up to the right, 30° down to the right, and vertical. A header run and a borehole drop can then be drawn together, the drop being vertical. The isometric view is a drafting mode, not a 3D view: the elevation remains the **z** typed on each node, which is what the solver reads. Switching views moves nothing already drawn and changes no length; it only changes where the next node snaps and which directions a pipe can take.

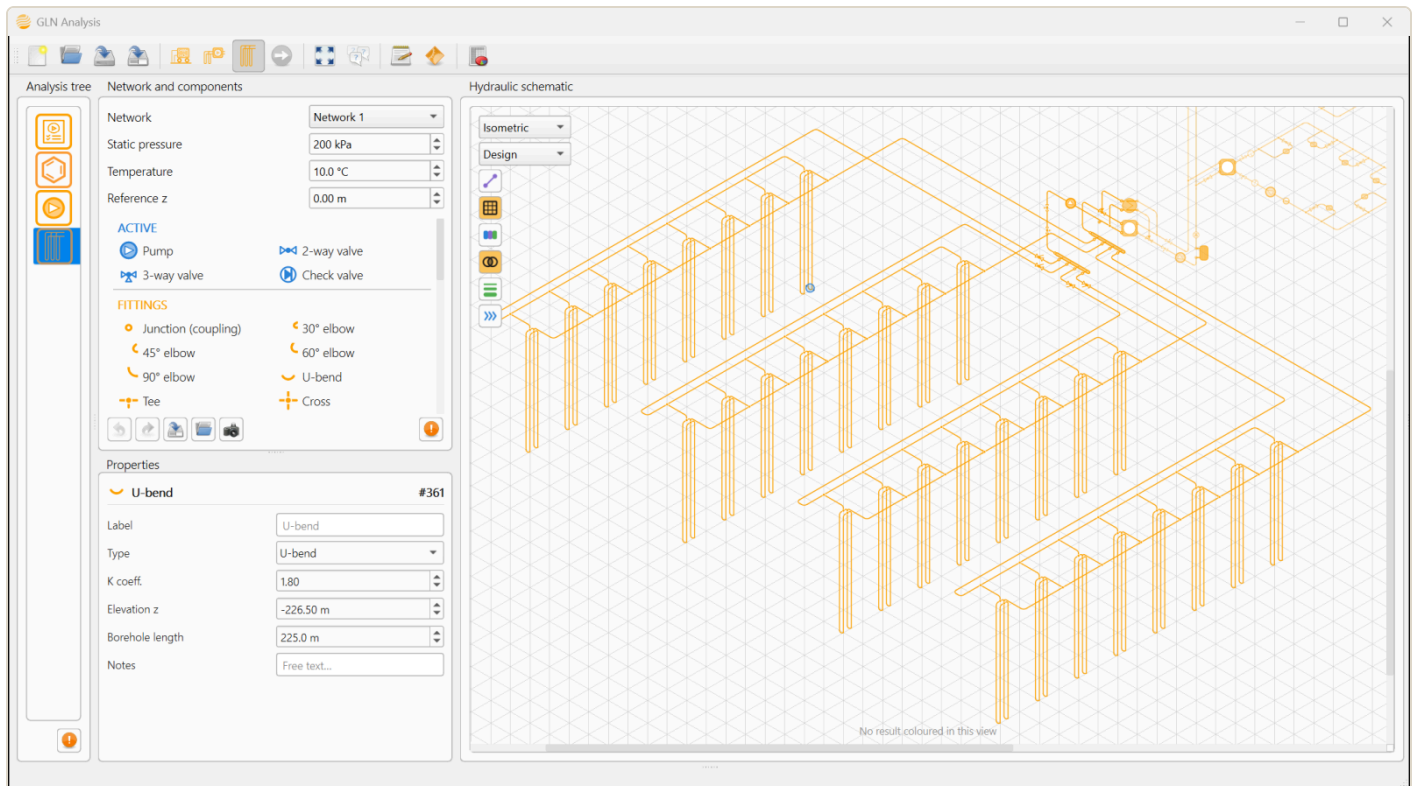


Figure 11 — The ground heat exchanger in the drafting view, on its 30 degree lattice, where a borehole drop reads as vertical

Presentation selector - The second list above the canvas sets **what the colours of the drawing represent**. It holds *Design* and two groups of modes, *Inputs* and *Results*, whose headings cannot be selected.

Design, alone at the top, shows the drawing in its own colours, without results. The network is still solved as you draw: hovering a pipe or a node opens its callout on an orange background, with its inputs and the results of the latest solve.

Inputs — *Elevation z , Diameter $\varnothing$, Length L* — colour the drawing with values you typed and need no solve. They reveal a mistyped elevation or an undersized header before the network is computed.

Results — *Flow Q , Velocity, Pressure, Head H , Friction Δh* — show the solution. The hover callout of a pipe lists the same quantities in the same order.

Two diagnostic modes close the group. **Reynolds Re** shows the flow regime in three fixed colours: blue for laminar flow ($Re < 2300$), green for the transition band, red for turbulent flow ($Re > 4000$). Nodes have no Reynolds number and stay grey; the exact value of a pipe is in its hover callout. **Head loss** shows where the head is lost, element by element, in metres: a pipe shows its friction alone, $fD \cdot L/D \cdot v^2/2g$, and a node the loss of its own fitting, merged reducers included. This differs from *Friction Δh* , where a pipe shows $R \cdot Q^2$, which includes the share of the fittings at its two ends; showing the fittings on the nodes as well would count them twice. The hover callouts give the **Head loss** value in every mode, marked "(friction)" on a pipe, next to its Δh , and "(fitting)" on a node.

Pressure, Head H and Elevation z are node quantities: they differ at the two ends of a pipe, which is painted with a gradient. Flow, velocity, friction, diameter and length belong to **the pipe as a whole**, which is painted in one colour.

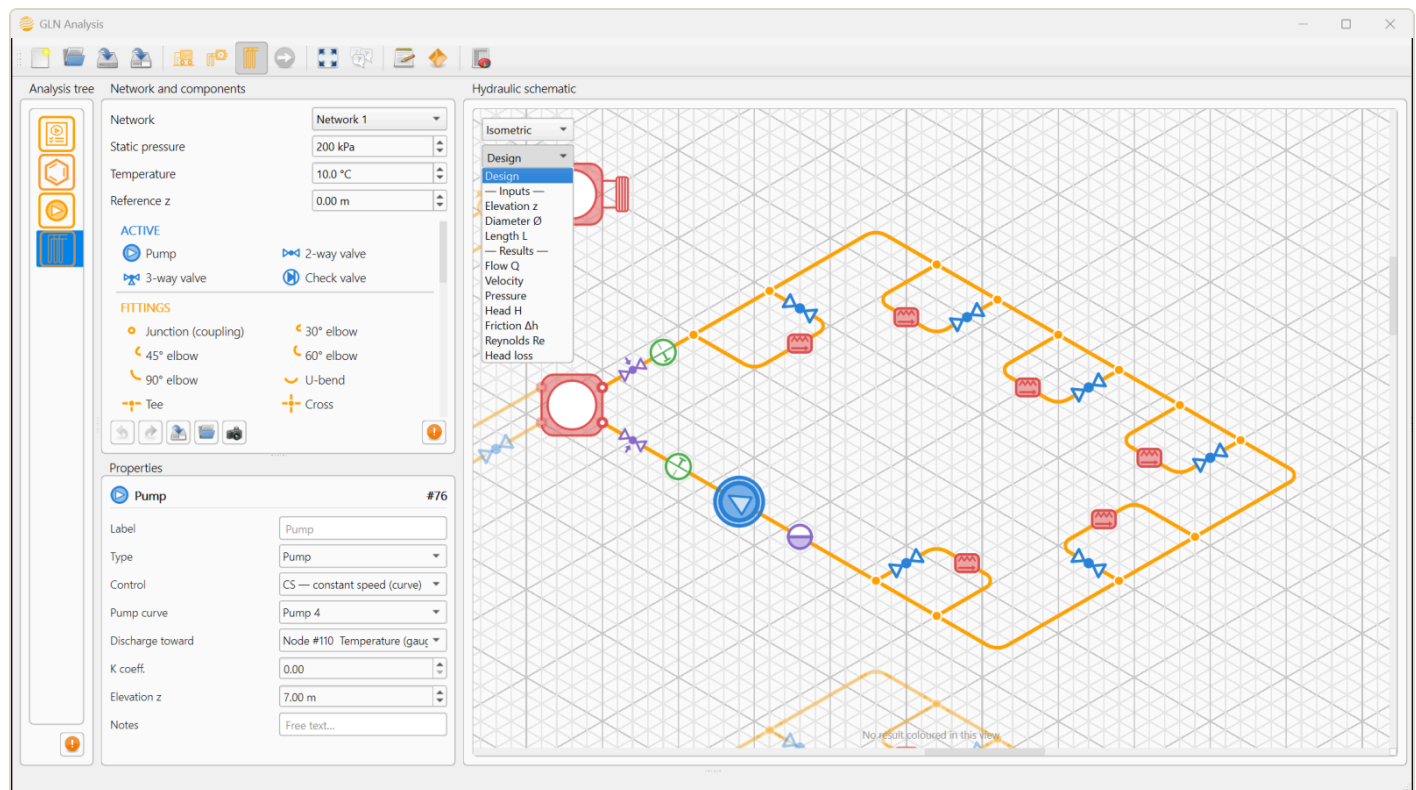


Figure 12 — The presentation selector open, showing *Design* alone at the top, then the *Inputs* group that needs no solve and the *Results* group in its reading order

The colour bar is described under *The colour scale*, in *Reading the results*.

Drawing - Pick a component in the palette, then click the canvas to place it. **Dropping a component onto a pipe inserts it into that pipe**, which is split in two at the drop point; the two halves keep the diameter, roughness and name

of the original, and share its length in proportion. The pipe about to be split is highlighted during the drag. This works for a component dragged from the palette as well as for a node already on the drawing, and the  *Weld nodes on drop* button of the floating toolbar turns it off. **The free end of a pipe can also be dropped onto a port of a heat pump, an exchanger or another composite device**, which welds it there: the dropped node disappears and its pipes connect to the port. The weld is refused, with a message in the status bar, for a node carrying a component (a pump welded onto a port would break the device) and for a manifold take-off, whose cluster is regenerated.

Double-clicking a pipe splits it in two and puts a plain junction at the cut, ready to be given a type in *Properties*: this is the quickest way to insert a fitting in a line already drawn. **To connect two nodes, hover one and drag from the ring that appears around it**; dragging from the middle of the node moves it instead. For several runs in a row, use the **Pipe** tool (**T**): it stays armed and chains from one node to the next until you click its button again, press **T** or **Esc**, or right-click. Pressing **T** with a node selected, or with the cursor on a lit ring, starts the pipe from that node, leaving only the far end to click; otherwise the first click picks the start.

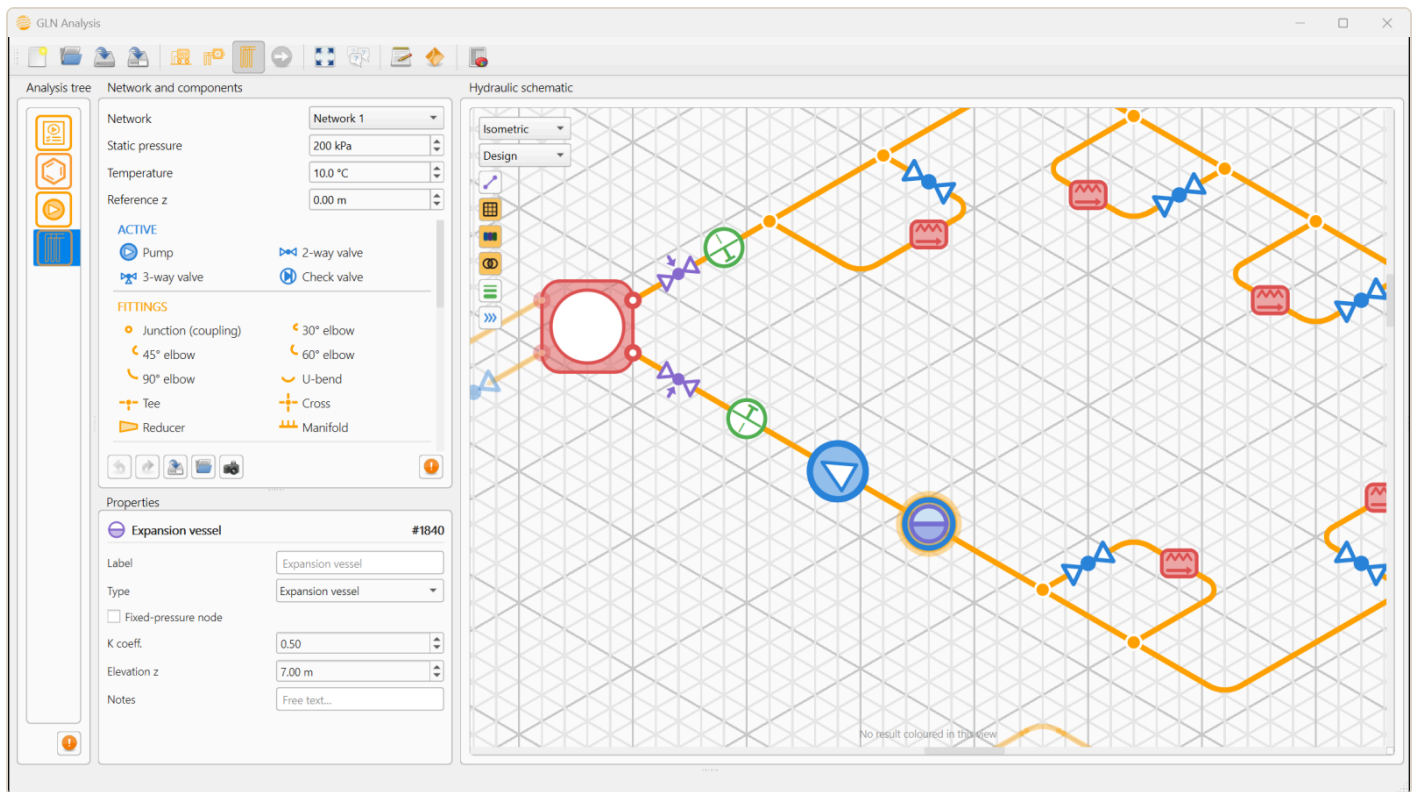


Figure 13 — *Hovering a node lights the ring around it: dragging from the ring draws a pipe, dragging from the middle moves the node*

The circuit highlight **Selecting anything on the drawing lights the whole network it belongs to** and dims the rest. The highlight follows the pipes outward from the selected node, pipe, device or manifold. A heat pump or an exchanger belongs to two networks, one on each side, and selecting it lights both.

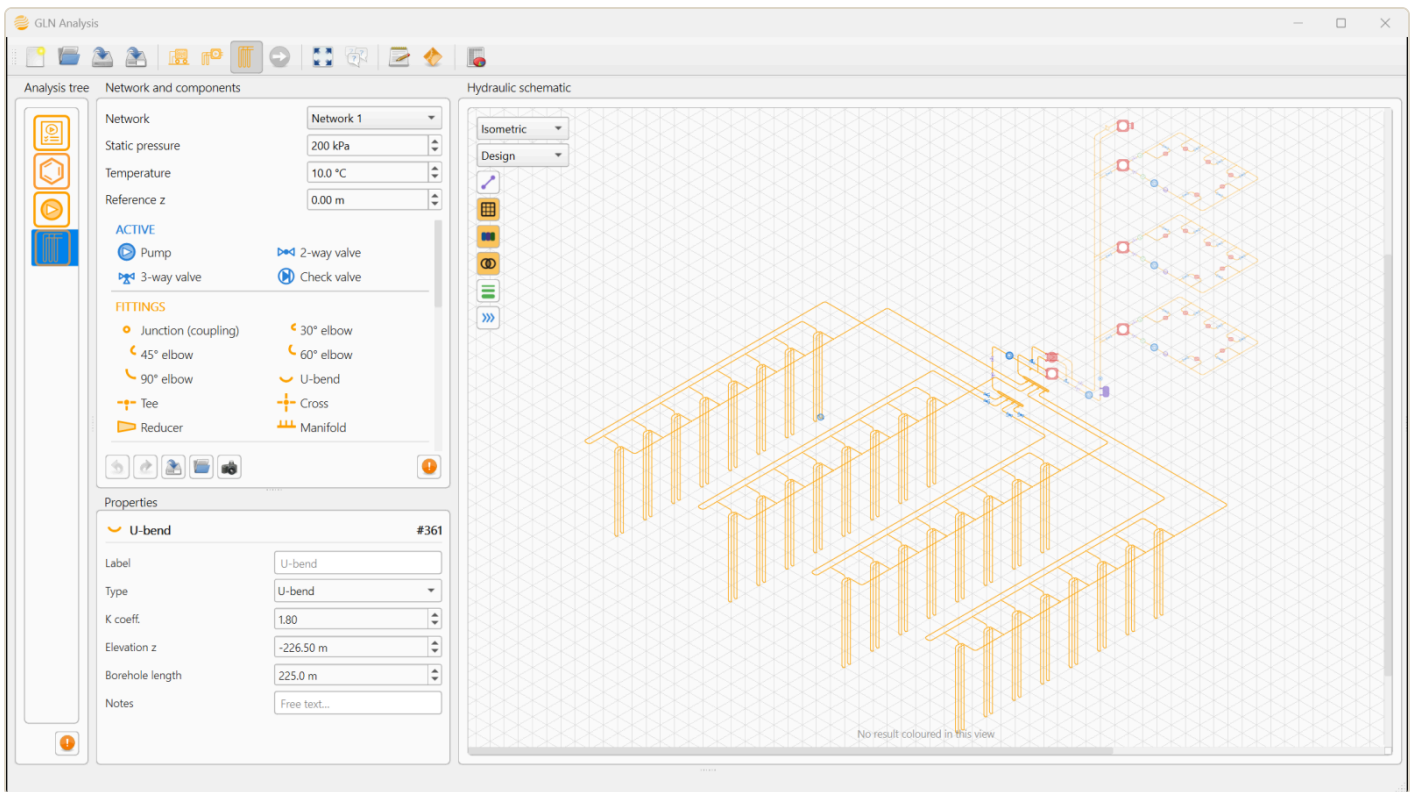


Figure 14 — Selecting one borehole lights the whole network it belongs to and dims the rest: on a drawing holding several loops, this is what says at a glance which pipes are connected to which

The floating toolbar - The floating toolbar over the canvas holds the two selectors described above and, below them, **six toggles**, listed here from top to bottom. Each has a tooltip and stays pressed while it is on.

ICON	BUTTON	WHAT IT DOES
	Pipe tool (T)	Arms the pipe tool: click a node, then the far end of the run, and the tool stays armed and chains from one node to the next. Leave it by clicking the button again, by pressing T or Esc , or with a right-click. See <i>Drawing</i> , above.
	Grid	Shows and hides the grid, and the snapping with it .
	Colour by family	Tints each component with the colour of its palette family. Design mode only , since the result modes use colour for values.
	Weld nodes on drop	Dropping a node onto another joins the two, and dropping a component onto a pipe inserts it into that pipe. Turning it off lets you place a component beside a line without connecting it. A drop is refused when both nodes already carry a component type.
	Draw to scale (Ø)	Draws every pipe, and the arms of the fittings that continue it, with a stroke proportional to its diameter. See <i>Drawing pipes to scale with their diameter</i> , under <i>Showing the network</i> .

ICON	BUTTON	WHAT IT DOES
	Animate the flow	Animates the computed flow, and cycles through two ways of showing it : dashes, then beads  , then off. Reads the solved flow, so it does nothing in Design mode. See <i>Animating the flow</i> , under <i>Showing the network</i> .



Node and pipe properties

The fields of the inspector for a selected **node**, then for a selected **pipe**. What each component does with them is given in the *Component catalogue* of the *Catalogues* section.

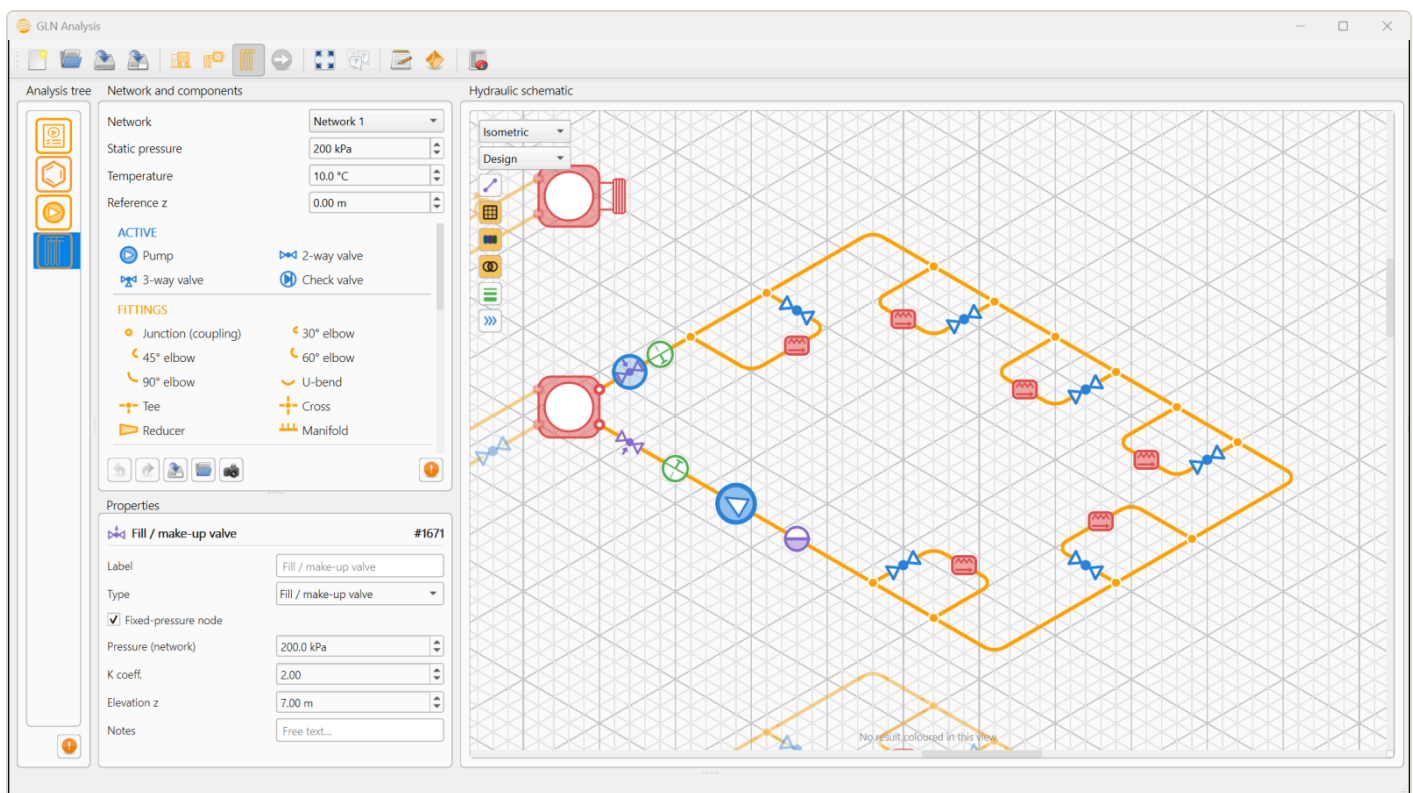


Figure 15 — The Properties page of a selected node: its type and kind, its minor loss coefficient K, its elevation z, and the pressure-reference box the three eligible component types carry

Node type and category - The type sets the symbol and the default minor loss coefficient. Changing the type resets K to that type's default, so set the type first and adjust K afterwards.

K, the minor loss coefficient - The fitting loss, as $\Delta P = K \cdot \rho v^2 / 2$. Selecting a type seeds K with that type's usual value; a manufacturer's figure for the actual component is always preferable. A node's K is divided equally among its connected pipes, each applying its share at its own velocity.

The default K of each fitting, and how it compares with published American and European values, are discussed under *Minor loss coefficients*, in the *Catalogues* section.

Elevation z - The height of the node above the datum, in metres. Elevation matters: the solver drives the flow with the piezometric head, pressure plus $pg-z$, so a borehole leg carries a large hydrostatic term on top of its friction.

Fixed-pressure node No closed network may carry more than one. It is the pressurization point (the expansion vessel, the open reservoir or the fill connection), and only those three component types may carry it. Its value is the *Static pressure* of the network, set in the Network panel.

Two fixed nodes in the same closed loop over-determine it and force a non-physical flow between them; the console warns and badges both nodes. For that reason **only the first** pressure reference placed on a network is armed. A second expansion vessel is placed *without* a fixed pressure, a console note says which node carries the reference, and it remains a vessel in every other respect. The reference is a checkbox and can be moved by hand.

The pressure itself belongs to the **network**, not to the node: the field under the checkbox and the *Static pressure* row of the Network panel edit the same number, and every reference node of that network reads it. Two nodes of one network therefore cannot hold two different pressures.

A **fill / make-up connection** may carry the reference, but it does not by default. It holds the loop at its set pressure only while it is *open*; in normal operation it is closed, and what holds the pressure is the expansion vessel.

Pipe type - The **Type** list is the pipe catalogue: standard thermoplastic (PE) pressure pipe, in a **Metric** family whose nominal size is the outside diameter in millimetres (DN) and an **Imperial** family whose nominal size is the IPS size in inches. Within each family the entries are grouped by **SDR**, the ratio of outside diameter to wall thickness, because that is what decides the bore. Every entry spells out its bore, so the two families compare without a conversion.

Picking an entry fills the **internal diameter** below and seeds the **roughness** at 0.0015 mm, the design value for PE. Both fields remain editable afterwards. The list holds thermoplastic pipe only, SDR being a thermoplastic designation.

The first entry, **Custom**, sets nothing. The list shows it whenever the diameter matches no catalogue size, for instance after you type a diameter of your own.

Where the catalogue sizes come from, why the roughness is 0.0015 mm and what a wrong roughness costs are under *The pipe catalogue and its roughness*, in the *Catalogues* section.

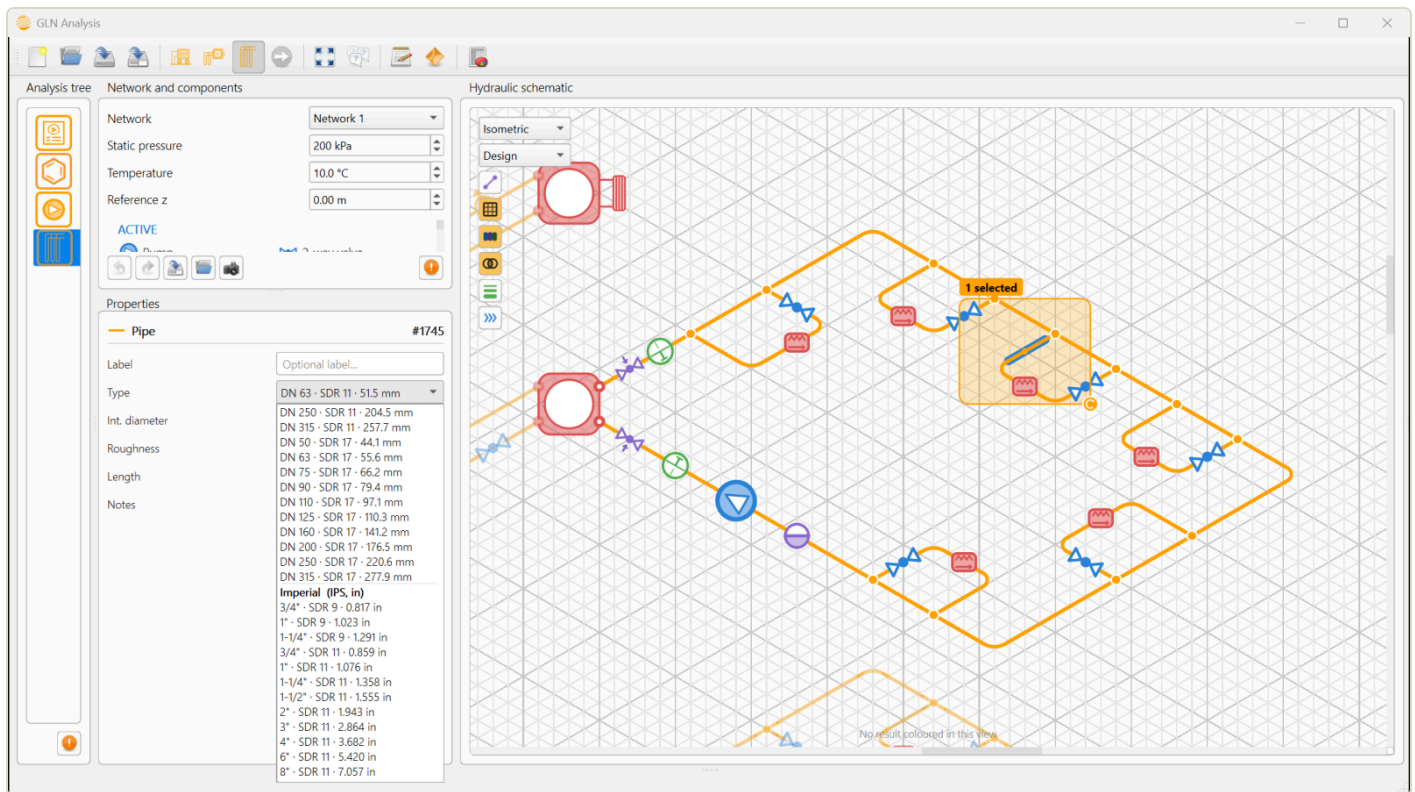


Figure 16 — The Properties page of a selected pipe, its catalogue list open on the two families and their SDR groups, each entry spelling out the bore it gives

Pipe length - This field is the **only way to set a pipe's length**. The drawing carries no distances, so moving a node never changes a length; this is what allows a horizontal header and a 150 m borehole leg to be drawn on the same schematic.

A freshly drawn pipe carries a seed length: its drawn distance, at one metre per grid square. The seed lets a network be solved before every length has been typed, but it is not a measurement: a 150 m borehole leg is drawn a few centimetres long. A network solved on seed lengths converges and colours normally while being wrong, so every seed must be replaced by the real length, like any other input of the model.

The *Length* column of the Pipes table marks every pipe still carrying its seed with a small orange bar; sort on that column to list them. Typing a length clears the mark. Retyping the same value does not, since an unchanged value is ignored: to keep a seed as it is, type another value, then the one you want.

Splitting a pipe shares its length between the two halves in proportion, and both halves keep the state of the pipe they came from: a length you had entered stays entered, a seed stays a seed. A pipe cannot be shorter than the elevation it spans; a warning appears under the field and on page 4 of the console.

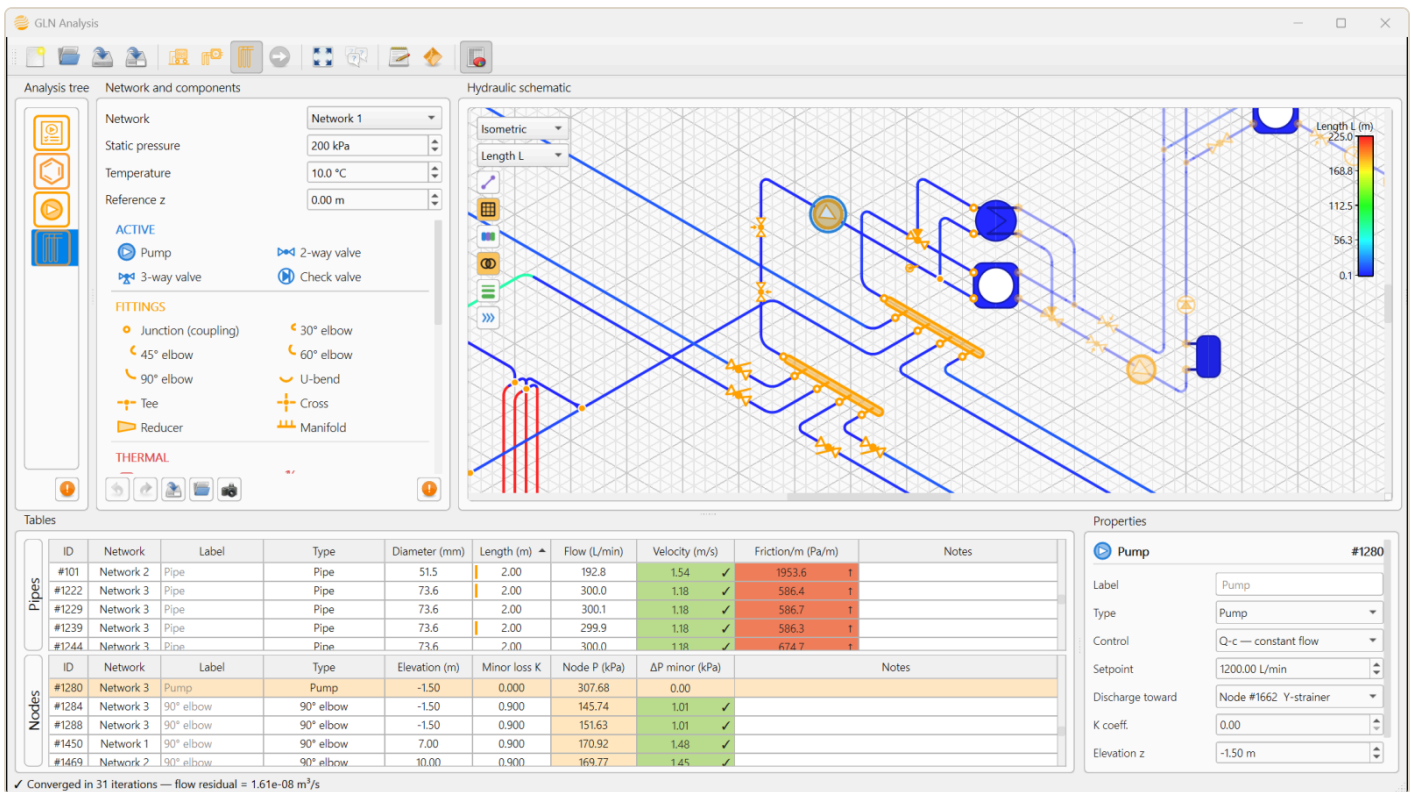


Figure 17 — The Length column of the Pipes table, sorted: the small orange bar marks every pipe still carrying its seed length, which is the list of what remains to be checked against the project

Solving

The network is solved in the background after every change; there is no button to press. A solve needs:

- **A closed path for the fluid.** An open branch between two dead ends carries no flow, which is the correct result.
- **A roughness smaller than the bore.** Above $\epsilon/D = 0.05$ the network is still solved, but the friction factor is extrapolated and the console says so; a roughness equal to or larger than the bore blocks the pipe.

A network that cannot be solved is left out and the others are computed anyway, so an orphan node or a half-drawn branch does not stop the computation. Networks left out carry no results: they keep their design colours and are excluded from the colour scale. Page 4 of the console names each of them with the reason, and the components concerned are badged on the drawing. The table below lists the messages and what to do about them.

WHAT YOU SEE	WHAT IT MEANS	WHAT TO DO
A network is skipped, <i>degenerate geometry</i>	A pipe has zero length: its two end nodes sit on the same point	Move one node apart, or delete the pipe. A typed length cannot cause this — the field stops at 0.01 m
A network is skipped, <i>roughness larger than the bore</i>	The roughness is at least as large as the internal diameter, so the pipe is blocked solid	Retype the roughness. PE is 0.0015 mm

WHAT YOU SEE	WHAT IT MEANS	WHAT TO DO
<i>Relative roughness beyond the correlation's domain, and the network still solves</i>	ϵ/D is above 0.05, where the friction factor is an extrapolation	Retype it. This is where a millimetre slip lands: 1.5 mm in a 25 mm bore gives $\epsilon/D = 0.06$
<i>no pipe, or not connected to anything</i>	An isolated node, or a group with nothing to carry flow	Connect it, or delete it. Harmless otherwise: the rest of the drawing still solves
A node carries the ! badge	More pipes are attached than its symbol can show	Its tooltip names the component to use instead; a cross or a manifold takes more
A node carries the ! badge, and a pipe runs right under it	It sits on that pipe without being connected to it: the drawing shows a junction the model does not have, so nothing flows between them	Drag the node off and drop it back onto the pipe, which splits it. Its tooltip names the pipe and both its ends
A node is badged, <i>off every isometric axis</i>	One of its pipes follows none of the three isometric directions, so the fitting cannot meet it: that is the kink you see	Redraw that pipe along an axis. Reported only in the isometric view with snapping on
A 3-way valve is badged, and its position changes nothing	No common port, or other than exactly three pipes: it was solved as a plain fitting carrying its K	Assign the common port. Dropping the valve onto an existing pipe gives it two pipes, not three
A tee or a cross with a merged reducer is badged	The arm the reducer named no longer carries a pipe, so the reducer loss was not applied	Set <i>Reducer on</i> again, or clear it with <i>None</i>
<i>Over-determined loop, and two nodes badged as pressure references</i>	One closed circuit carries two fixed-pressure nodes	Clear the checkbox on one of them; the loop needs at most one
A pump is reported as not connected to exactly two pipes	A pump is a two-port machine and cannot sit at a branch	Move the branch off the pump, so it has one suction and one discharge pipe
A pump is reported with its two pipes drawn the same way	Both point in, or both point out, so the suction side is only assumed	Set <i>Discharge toward</i> in <i>Properties</i> : it reorients the two pipes
A pipe is reported as shorter than the elevation it spans	Its length contradicts the z of its two ends. A length never entered still carries its seed, which is the usual cause	The network is still computed , with friction under-estimated. Correct whichever of the two is wrong

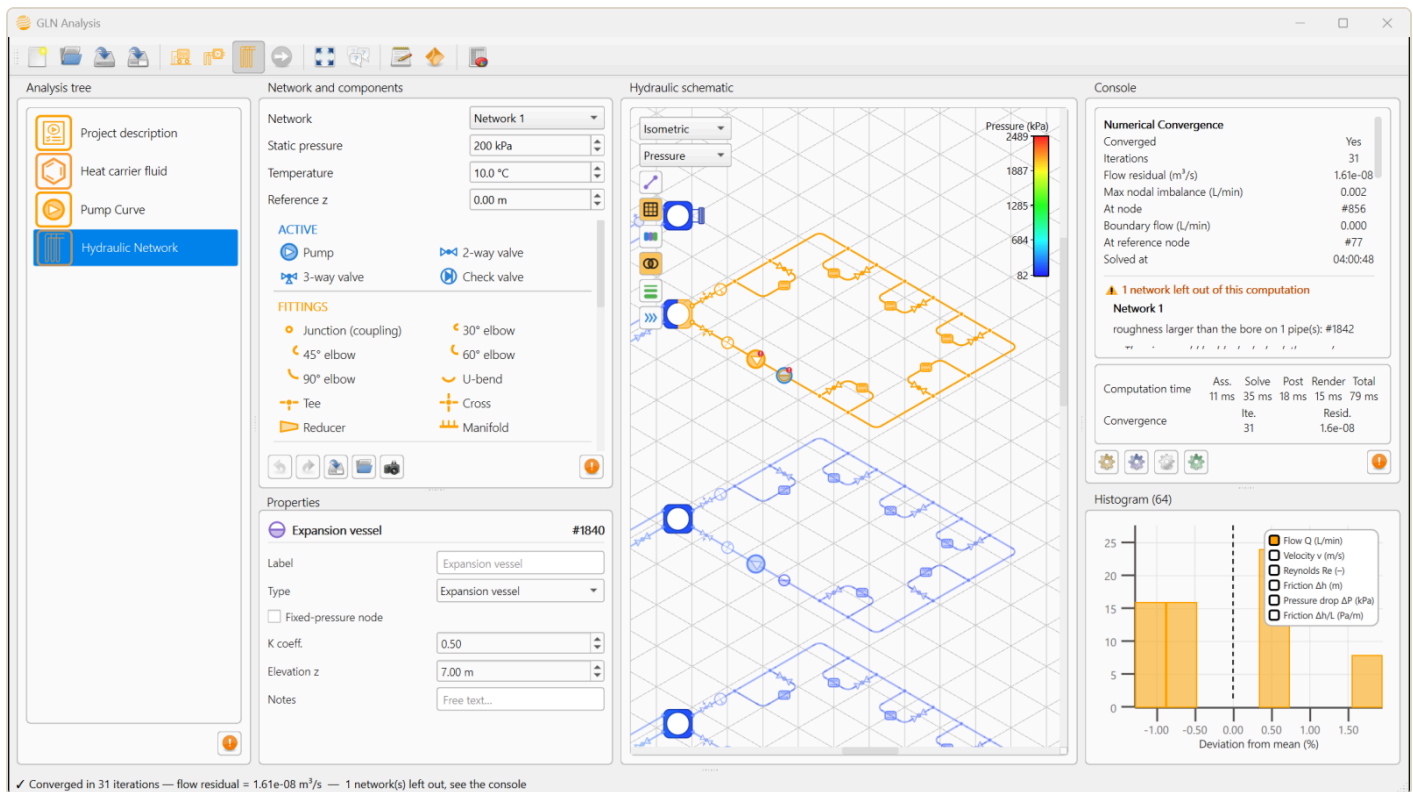


Figure 18 — The Solver health console page beside the drawing it describes: every network left out is named with its reason, and the components concerned are badged on the canvas

A network that converges with no flow anywhere is usually correct: without a closed loop nothing circulates, and the pressure still rises by $\rho g H$ through a pump. Conversely, **a solve on seed lengths** looks entirely normal; check the orange bars of the *Length* column before trusting any number.

Continuous recomputation - The network is recomputed after every change: moving a node, editing a cell in the tables, changing a property, and also changing the heat carrier fluid or a pump curve. The canvas colours, the result columns and the four console pages are updated each time, including in *Design* mode, which only hides the colours. The solver finds the nodal pressures by Newton-Raphson, driven by the piezometric head so that two nodes at different heights feel $\rho g \Delta z$ between them, with pumps folded out of the system and solved on their own curve. Friction follows Darcy-Weisbach throughout, with the friction factor taken from the Swamee-Jain form of the Colebrook-White law above $Re = 4000$, from $64/Re$ below $Re = 2300$, and interpolated between the two across the transition band.

Known modelling limits - Valves are modelled by a loss coefficient only. There is no C_v model and no equivalent-length model, so a manufacturer's C_v must be converted to K by hand. **A check valve carries its K in the direction it passes and closes against it.** The direction it passes is the *Flow toward* row of its Properties page, which is also the way its two pipes are drawn. When a check valve closes, the console names it: either the valve is doing its job, or a branch was drawn the wrong way round. A check valve whose direction cannot be read from the drawing (it needs exactly two pipes, one of them drawn away from it) is left open with its K in both directions, and the console reports it too.

Dividing a node's K equally among its pipes under-states the loss at a change of section. Each pipe applies its share at its own velocity: right for a fitting whose pipes are the same size, too low otherwise, since half of the coefficient then acts on the slow side and contributes almost nothing. On a reducer joining 100 mm to 32 mm the loss comes out about

half of what the same K referred to the small bore would give. Where a reduction matters, enter a K already scaled for it.

The solve is isothermal. Temperature enters only through the fluid properties of each network. There is no heat transfer along the pipes and no coupling with the ground model.

Reading the results

The colour scale - The colour bar beside the drawing is graduated over the range that was actually used to colour it, with five values from the minimum at the bottom to the maximum at the top. It uses as many decimals as needed for the five values to differ, so a narrow range still gets a readable scale. A single value appears only when the field is uniform, for instance with no flow anywhere, and the drawing is then painted in one colour.

A recomputation updates the colours and the bar but never changes the display mode you chose.

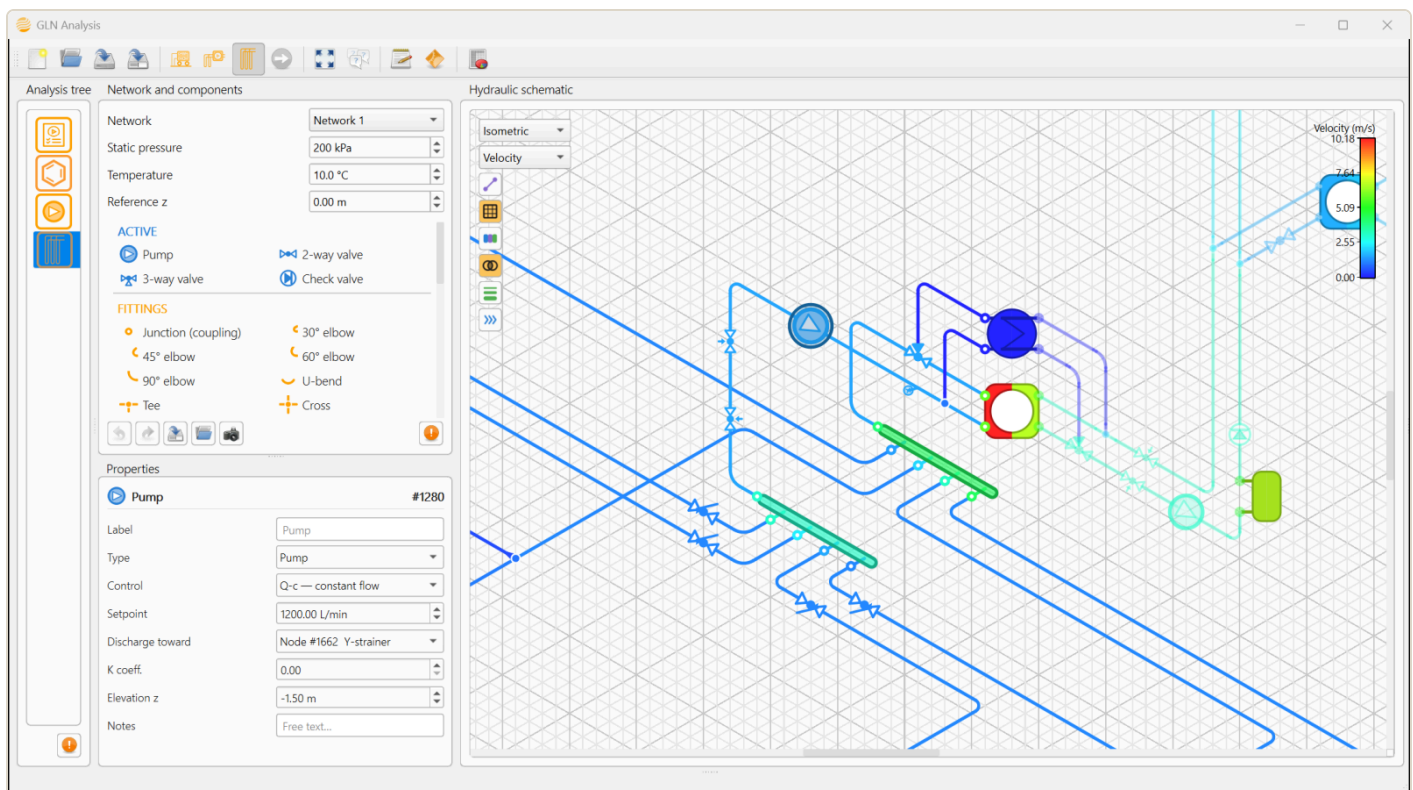


Figure 19 — The colour bar beside the drawing, graduated over the range actually used to colour the network

The Nodes and Pipes tables - The two tables at the bottom of the window are an **input grid** as well as a report: columns on a white background are inputs, those on a tinted background are computed. Both open on their **essential** columns, the ones used to size a network; right-click any column header to switch to *All columns* and back. The lists below give every column, marked **input**, **computed** or **check**.

Units follow the current unit system, and each header shows its unit.

Nodes table, column by column - One row per node of the drawing, ports of composite devices included.

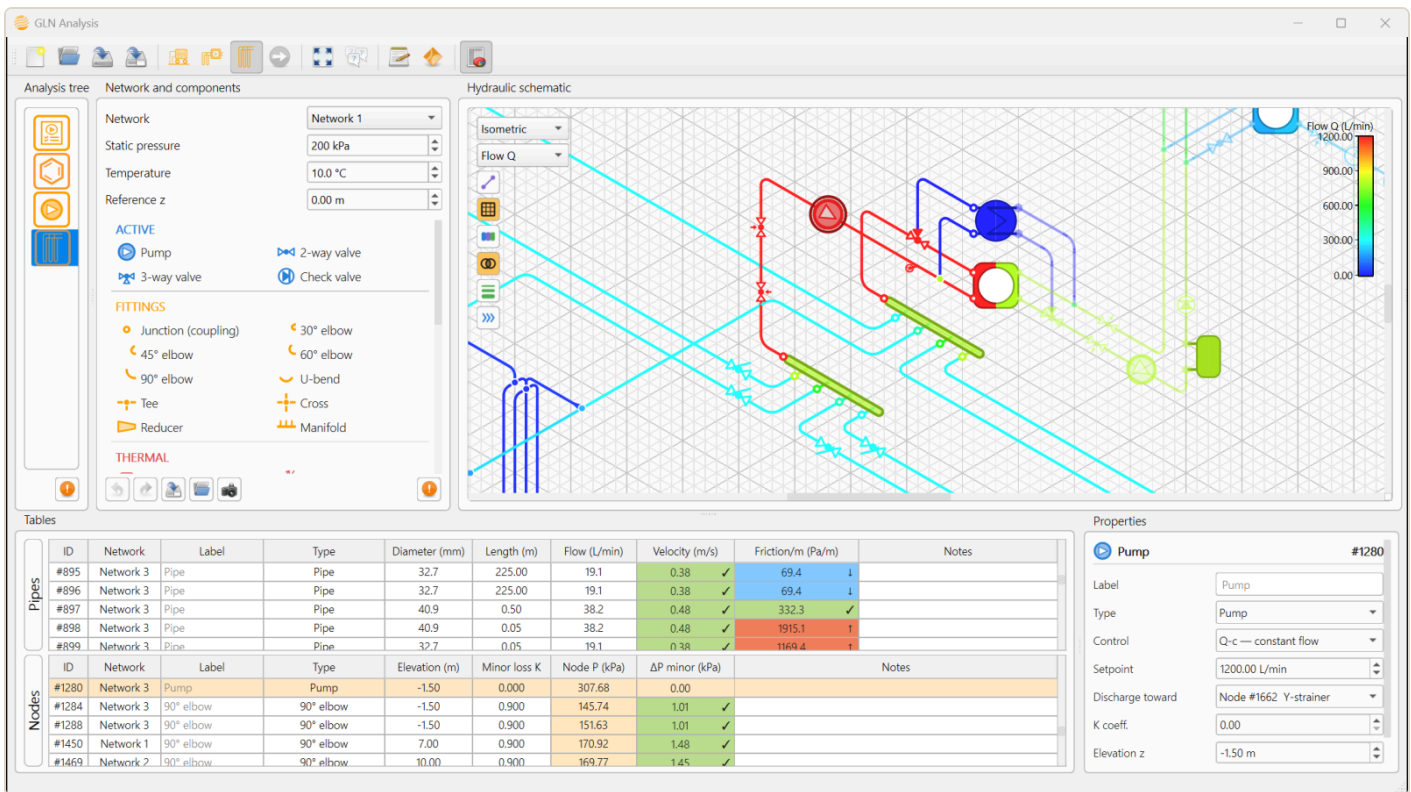


Figure 20 — The Nodes and Pipes tables at the bottom of the window, on their essential columns, with the input columns on white and the computed columns on a tinted background

COLUMN	KIND	WHAT IT IS
ID	computed	The identifier the drawing, the hover callouts and the console diagnostics all share.
Network	computed	Which independent network the node belongs to. It matches a console diagnostic to its loop on a drawing holding several.
Label	input	A short name of your own. Free text, carried into the hover callouts and the console diagnostics.
Category	computed	The palette family of the component. Hidden in the essential view.
Type	computed	The component type, with its kind where it has one, a two-way valve showing whether it is generic, balancing, purge or safety. Not edited here: the type is set in the inspector, and the table reports it.
Elevation	input	The height of the node above the datum. The solver drives the flow with the piezometric head, so this term decides the hydrostatic contribution of every pipe that reaches the node.
Minor loss K	input	The fitting loss coefficient, $\Delta P = K \cdot v^2 / 2$. Divided equally among the connected pipes, each applying its share at its own velocity.

COLUMN	KIND	WHAT IT IS
Fixed	input	Whether the node carries the pressure reference of its network. Only an expansion vessel, a reservoir or a fill connection may. Hidden in the essential view. Show it (right-click the header, <i>All columns</i>) to find where a network is pinned: the Network Builder may put the reference on a tee or an elbow, whose Properties page does not offer the box.
Node P	computed	The static pressure the solver found at that node.
Head	computed	The piezometric head, $P/(\rho g) + z$. Two nodes at the same head exchange no flow, whatever their pressures.
ΔP minor	computed + check	The pressure the fitting itself dissipates, and its own verdict : the cell is tinted and carries a symbol on its right-hand edge when the loss leaves the recommended 1 to 5 kPa . Left plain on a node without a fitting ($K = 0$), such as the two junctions at the head of a borehole.
Notes	input	Free text. Along with <i>Label</i> , the only other column you fill yourself.

Pipes table, column by column - One row per pipe, and only real pipes: the internal edges of a composite device are excluded.

COLUMN	KIND	WHAT IT IS
ID	computed	As in the Nodes table, the identifier shared with the drawing and the diagnostics.
Network	computed	The independent network the pipe belongs to.
Label	input	A short name of your own.
Type	computed	The catalogue entry the pipe was given, or <i>Custom</i> when its diameter is not one of the catalogue sizes. Set in the inspector.
Diameter	input	The internal diameter, the bore the fluid actually sees. Filled by picking a catalogue type, editable afterwards.
Roughness	input	The absolute wall roughness, seeded at 0.0015 mm for PE. Hidden in the essential view. A roughness larger than the bore blocks the pipe, and the network is then skipped.
Length	input	The real length, and the only way to set it : the drawing carries no distances. A small orange bar marks a pipe still carrying its seed length, the distance it happened to be drawn at. Sort on this column to list what remains to be checked.
P inlet / P outlet	computed	Static pressures at the two end nodes. Hidden in the essential view.

COLUMN	KIND	WHAT IT IS
ΔP	computed	The absolute difference of those two, what a differential gauge across the pipe would read. Not the friction : see the section just below. Hidden in the essential view.
Flow	computed	The volumetric flow the solver distributed to that pipe.
Velocity	computed + check	The mean velocity over the bore, and its own verdict : the cell is tinted and carries a symbol on its right-hand edge, reading the velocity against a recommended 0.3 to 2.5 m/s — fast enough to carry air and particles out, slow enough to keep the pumping energy reasonable.
Reynolds	computed	The flow regime. The column to watch on a glycol loop at its coldest condition, since that is where a borehole leg falls out of turbulence. Hidden in the essential view.
Friction	computed	The Darcy-Weisbach loss over the whole pipe: the energy the flow actually dissipates, which is what the pump has to supply. Hidden in the essential view.
Friction/m	computed + check	The same loss per metre. The pipe-sizing criterion , and the column to sort on when deciding whether a diameter is right. It carries its own verdict against a recommended 100 to 400 Pa/m : far above means a diameter one size too small, far below an oversized pipe carrying an unnecessary volume of antifreeze.
Notes	input	Free text.

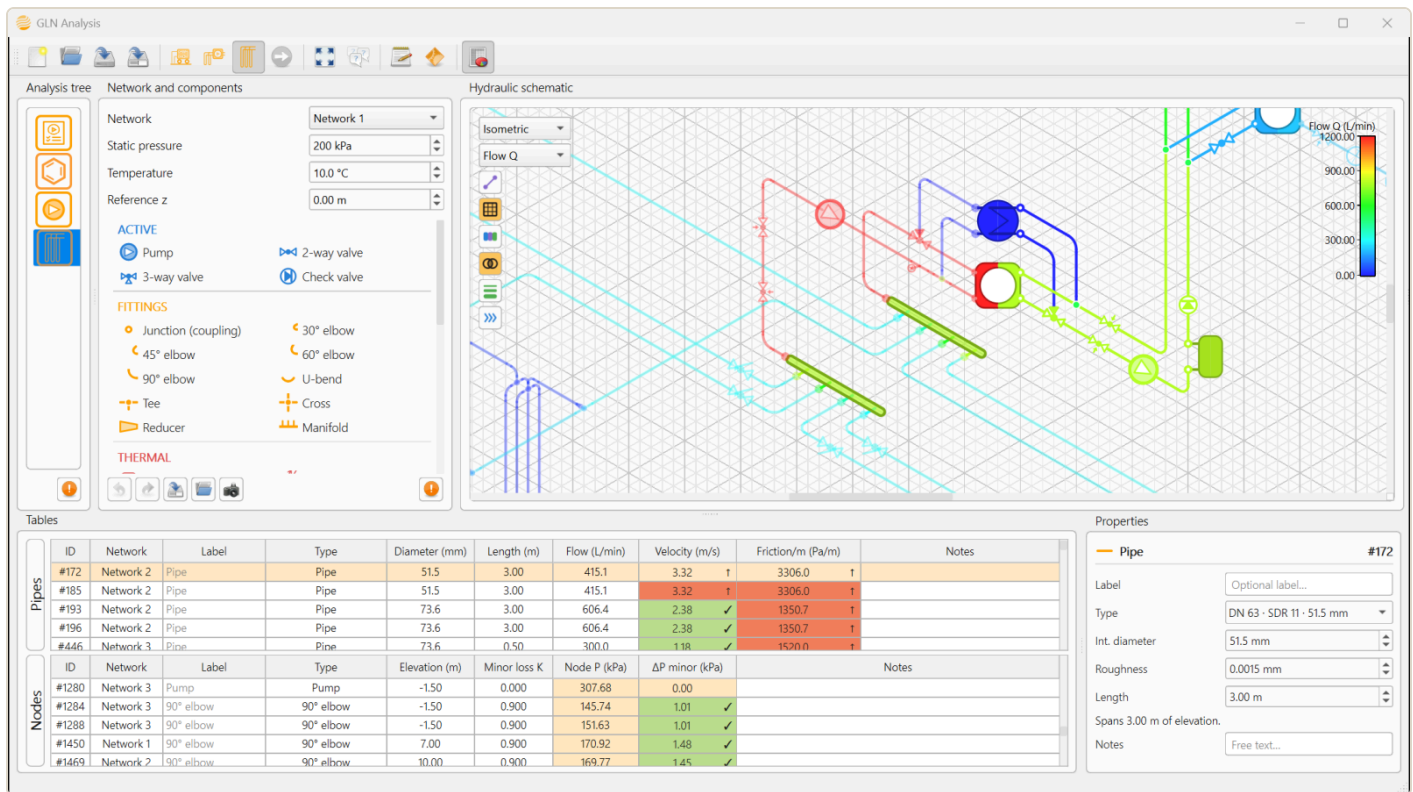


Figure 21 — The three advisory checks, each in the cell of the number it judges: the background carries the verdict and a symbol sits against the right-hand edge and stays when the row is selected

The three checks, *Velocity*, *Friction/m* and ΔP minor, are advisory: each compares a value with a window suited to an ordinary ground loop, which a design may leave for good reasons. The verdict is shown **in the cell itself**: blue background below the window, green inside, red above, with a symbol at the right-hand edge, ↓, ✓ or ↑. Selecting or hovering the row repaints the background, but the symbol remains. Sorting on one of these columns also sorts the verdicts.

Editing. A first click selects the row and shows the component on the drawing; a click on a row already selected, or a double-click, opens the editor.

Editing several rows at once. Select a set of rows, then edit one of them: the value applies to every selected row of that table. Setting one diameter on forty borehole legs is one entry, and one **Ctrl+Z** undoes the whole batch. If the row you edit is not part of the selection, only that row changes.

Selection is shared with the drawing in both directions: objects selected on the canvas are selected in the tables, and the reverse. Selected rows take the pale orange of the multiple-selection frame on the drawing.

ΔP is not the friction loss - These two columns answer different questions and coincide only on a horizontal pipe. ΔP is what a gauge reads between the two ends. *Friction* is the energy the flow actually dissipates, which is what the pump has to supply. The solver balances

$$(P_{\text{inlet}} - P_{\text{outlet}}) + \rho g \cdot (z_{\text{in}} - z_{\text{out}}) = \text{friction} + \text{minor losses}$$

so on a sloping pipe the two differ by the whole hydrostatic term. On a 150 m borehole leg that term dominates by more than an order of magnitude, and the sizing check therefore reads the *Friction* columns rather than ΔP . Across a

pump, the added head can even make the outlet pressure exceed the inlet's.

Borehole conditions - When the result tables are hidden, a **Histogram** panel appears under the console, its title giving the number of boreholes found. It shows how flow **Q**, velocity **v**, Reynolds **Re**, friction **Δh** , pressure drop **ΔP** and friction gradient **$\Delta h/L$** are spread over the boreholes, with the same symbols as the presentation selector. Boreholes are recognised by their **U-bend**, so a field drawn by hand is counted like one generated by the Network Builder. Each borehole contributes one value per quantity, taken over both of its legs: flow, velocity and Reynolds are averaged, friction and pressure drop are summed over the whole borehole, and the gradient is that sum per metre of **pipe**, both legs counted — so a 150 m borehole is divided by 300 m, which is the basis the 100 to 400 Pa/m criterion is written on.

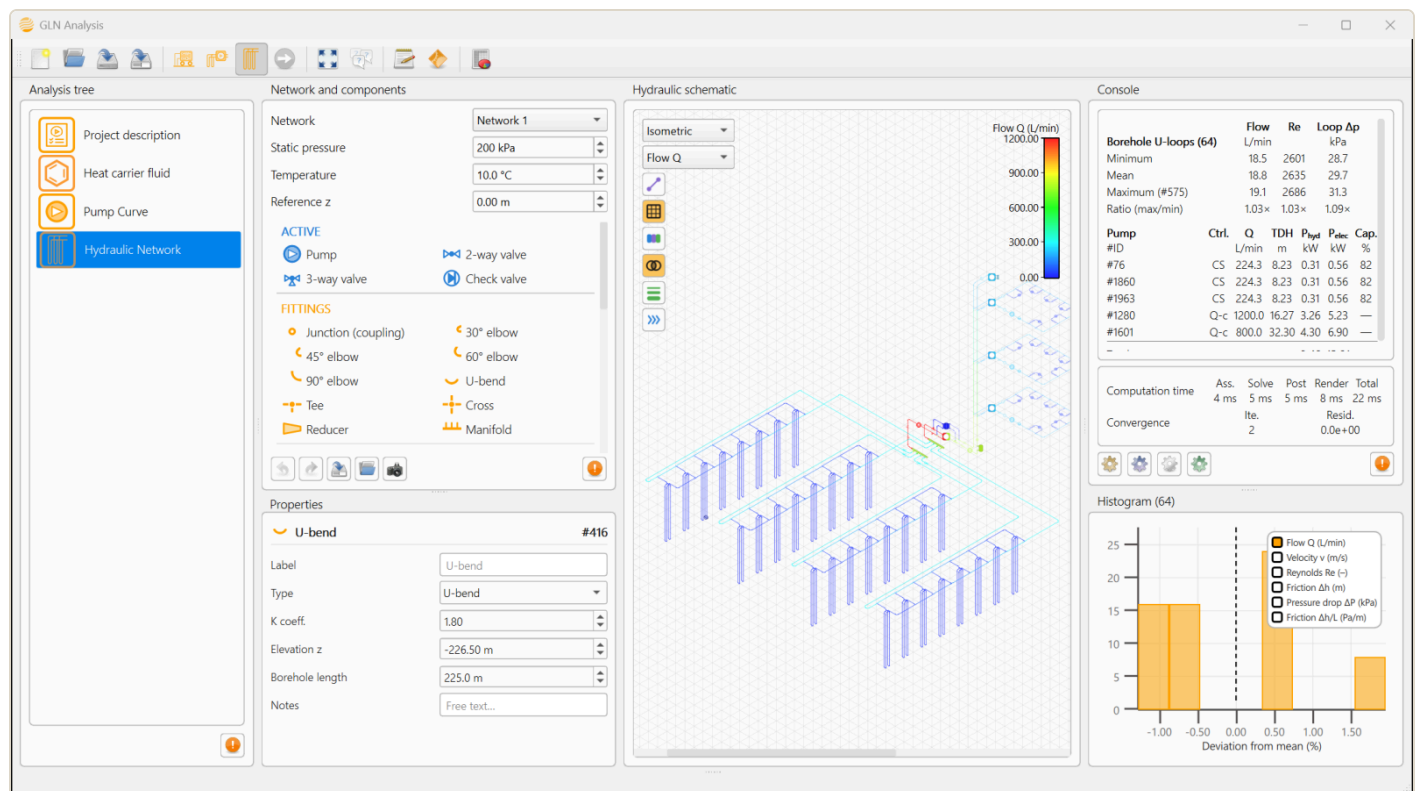


Figure 22 — The Histogram panel under the console: one bar per borehole, measured as a deviation from the field mean, with the dashed line at zero that a balanced field stacks its bars on



Showing the network

Two display options make a network easier to read: pipe strokes drawn to scale with the diameter , and an animation of the flow .

Drawing pipes to scale with their diameter - The **Draw to scale** button of the floating toolbar draws every pipe, and the arms of the fittings that continue it, with a stroke proportional to its diameter. Changes of size can then be read on the drawing, and a mistyped diameter, such as a header in 32 mm with a branch in 75 mm, stands out without opening the table.

Fittings follow, arm by arm. Each arm of a tee, a cross or a manifold takes the size of the pipe attached to it, so a 100 × 100 × 30 tee is drawn with a heavy run and a light branch. A reducer's cone shows the two sizes it joins, and each

take-off of a manifold the size of its own branch. A **U-bend** follows its two legs; its arc is only half a grid step wide, so a very large pipe is drawn wider than the bend and a step remains where they meet.

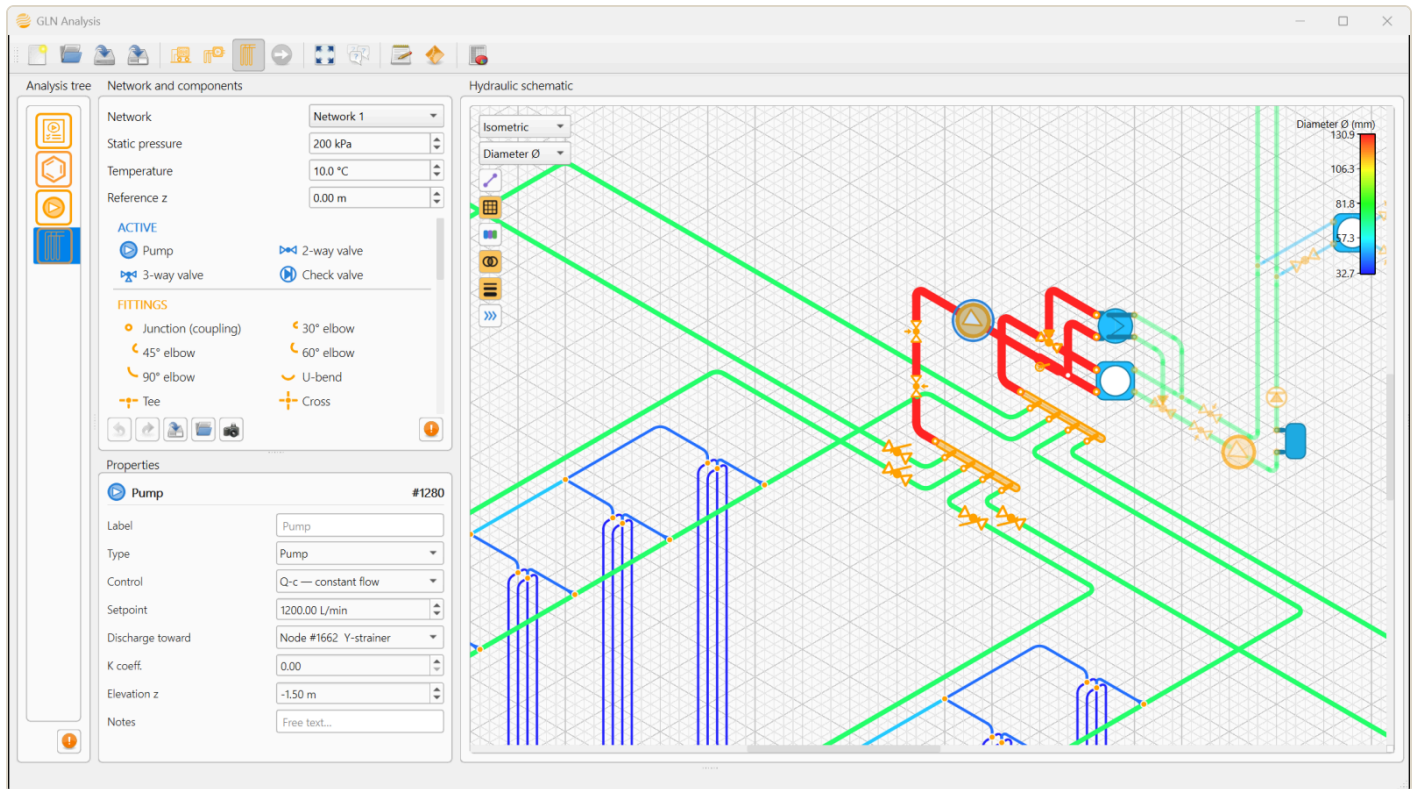


Figure 23 — The header and its branches drawn to scale with their diameter: the size change is read off the drawing rather than out of the table

»» **Animating the flow** - The last button of the floating toolbar animates the computed flow, and it **cycles through two ways of showing it**: click once for marching dashes, again for beads , a third time to stop. The icon and the tooltip show which mode is running. **Dashes** travel along each pipe in the direction of flow, at a speed proportional to the fluid velocity; a pipe carrying less than 2 % of the fastest velocity in the network is drawn **solid**. **Beads** add the flow rate. Each bead is a packet of fluid: its **area** is the flow it carries, its **speed** is the fluid velocity, and at a branch it **splits**, one bead per outgoing pipe, in proportion to their flow rates. Where two branches meet again, beads that catch up with one another merge back into one. The same 2 % rule applies: a pipe at rest carries no beads at all.

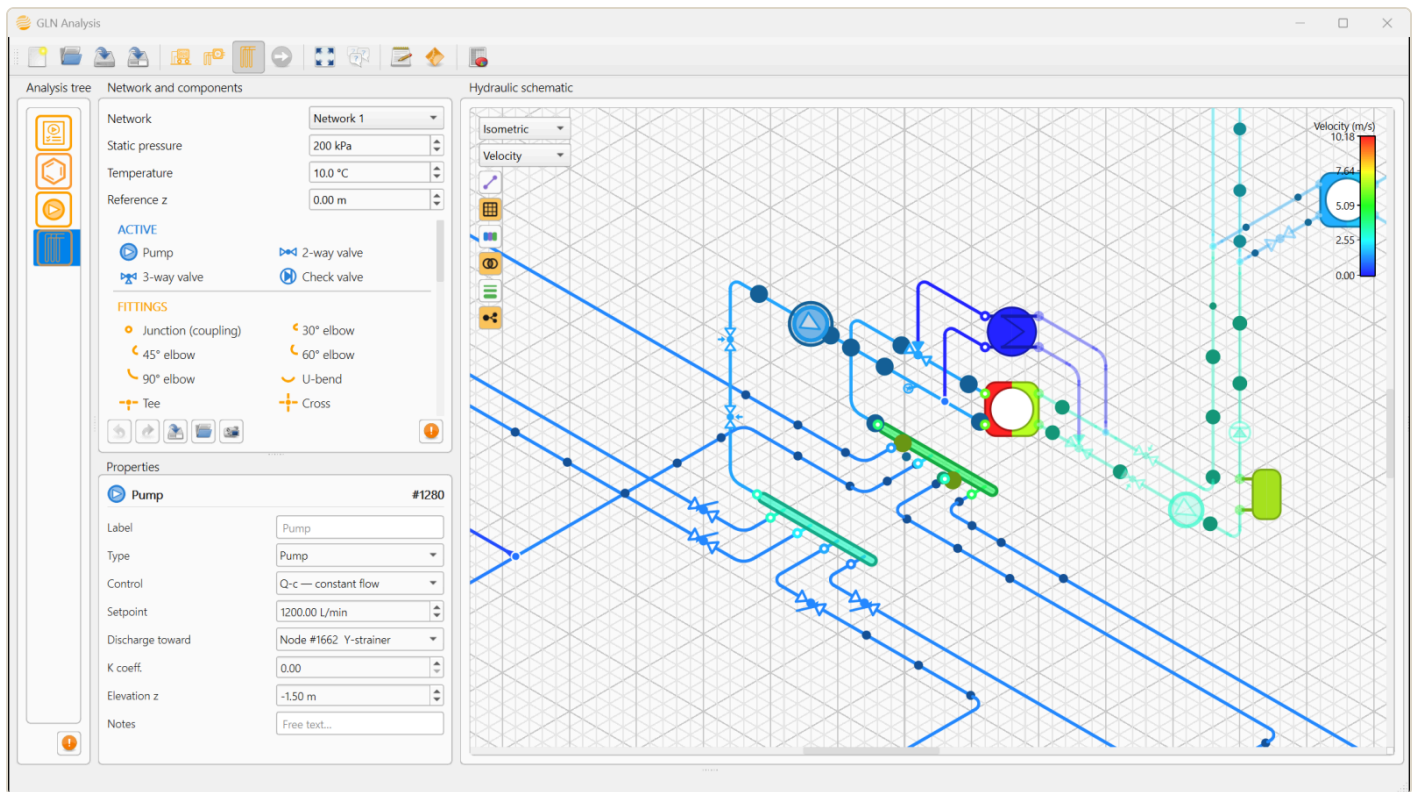


Figure 24 — A solved flow animated with beads, whose area carries the flow rate and which split at every branch; the other mode, marching dashes, carries the velocity

Capturing the view - The **camera** button of the bottom row saves what the canvas shows, with the same framing, zoom and colour mode. It writes a **PNG four times the size of the view on screen**, about 4000 × 2800 px for a 1000 × 700 view: enough for a full page at 300 dpi. The factor is lowered if the image would exceed 40 Mpx. The **colour scale is included**; the floating toolbars are **not**.

Recording a film. When the flow animation is running, the button shows a movie camera 📹 and records 30 s of the view as an **animated GIF** at 15 frames per second, up to 1200 px wide, which plays in a browser, a document or a slide. The animation is advanced frame by frame, so the film shows 30 s of flow whatever the speed of the computer. A progress dialog reports the frames and can stop the recording; a film cut short says how many seconds it holds.

GLN in practice: flow balance, turbulence at peak load and part-load operation

A sound ground loop satisfies two conditions: every borehole receives very nearly the same flow, and that flow keeps the fluid turbulent at the peak of the heating demand. Both are assumptions made by the thermal design, and both can be verified in this panel before anything is buried. The first is read on the *Histogram* panel, where a balanced field stacks its bars on the zero line; the second on the Reynolds column of the Pipes table, on a borehole leg, at the peak condition. Reynolds is not one of the essential columns and must first be revealed by right-clicking a header and asking for *All columns*.

Design for the heating peak. At peak heating demand the most heat must cross the borehole wall, and the fluid is at its coldest and most viscous. A leg that turns laminar then degrades the heat exchange when the design relies on it most, so turbulence at peak load is the first condition to secure.

Part-load operation. Away from the peak, reducing the flow is generally worthwhile: pumping power falls steeply with flow, and a loop held at its design flow all year uses energy it does not need. Reducing the flow may take the boreholes into the laminar range. This is acceptable as long as the fluid leaving the field still meets the needs of the heat pump at the load it serves: at part load there is less heat to move, so the poorer exchange of a laminar leg matters less. That condition is thermal and is checked in GHE Analysis. In this module, the peak and the part-load condition are two separate solves: the first confirms turbulence at the heating peak, the second shows how far the regime moves when the flow is reduced.

German guidance is stricter and requires turbulence at minimum pump power, which leaves much less room to trade flow for pumping energy.

Network first, pump second. Settle the friction gradients and the flow balance first, read the head the critical path demands, and only then select the pump. How margins added branch by branch push a pump far from its best efficiency point is discussed under *GLN in practice* on the *Pump curve* page.



The console reports the design-level results of a solve, the ones the per-element tables cannot show at a glance. It is organised as four pages, reached with the four buttons at the bottom of the panel, and the four share a footer giving the computation times and the convergence of the solver. The pages are filled when the solver runs, and they hold their contents until the next solve or until something invalidates them, such as a change of heat carrier fluid.

The console doubles as the help viewer: the help button ⓘ of any panel replaces the results with that panel's help page, and any of the page buttons brings the results back.

Every solve refills all four pages and leaves the one you were reading in front. If a solve fails to converge, pages 1 to 3 stay empty, the status bar reads *Convergence not reached* and the faulty nodes are badged on the drawing; page 4 gives the reason.

Page 1, pumping and operating point - Reached with the ⚙ button. The page opens with the borehole table described below, followed by one row per pump found in the drawing: the **#ID** of the pump node, its control mode, the flow **Q** in L/min, the head **TDH** in metres, the hydraulic power **P_{hyd}** and the electrical power **P_{elec}** in kW, and **Cap.**, the share of the pump curve's capacity used at this operating point. **Cap.** turns bold from 90 %, the level at which the solver issues a warning, and shows a dash for a pump in ΔP-c or Q-c: in those two modes the setpoint is the pump, and no curve is consulted. When the drawing holds more than one pump, a **Total** row sums the two power columns. An asterisk on the electrical total means that at least one pump is missing from it because its curve carries no efficiency; hover it to see how many.

TDH is the head H the pump delivers at its operating point, and the hydraulic power is $P = \rho g Q H$ at that point, with the density of the pump's own network at that network's temperature. The electrical power is $P_{\text{hyd}} / (\eta_p \cdot \eta_m)$, the pump and motor efficiencies coming from the Pump curve panel (Lamarche, 2023, Ch. 7); it shows a dash for a pump whose curve carries no efficiency. These are powers, not energies: the annual pumping energy also depends on the operating hours, which a hydraulic solve does not know.

The **Ctrl.** column gives the control mode with the acronyms used by circulator manufacturers, the same ones as in the **Control** list of the pump's Properties page. The setpoint of a ΔP-c or Q-c pump is read on that Properties page.

ACRONYM	MODE	WHAT THE OPERATING POINT IS
CS	Constant speed, on the curve	Where the pump curve meets the resistance of the circuit. The curve decides the answer.
ΔP-c	Constant head	A head the solver holds, whatever flow the circuit takes. No curve is consulted.
Q-c	Constant flow	A flow the solver holds, whatever head the circuit demands of it. No curve is consulted.

The **Borehole U-loops** table opens the page, since on a ground loop the first question is how much fluid reaches the least favoured borehole. A U-loop is recognised by its origin when the borehole was placed from the *Ground heat exchanger* family of the palette or generated by the Network Builder, whatever its orientation on the drawing. Otherwise it is recognised by its geometry: a 180° bend whose two legs rise nearly vertical and parallel. A U-bend with a third connection is never counted, since its two legs can no longer be told apart.

Three quantities are given for the boreholes of the field, each as a minimum, a mean and a maximum. **Flow** and **Re** are averaged over the two legs of a borehole. **Loop Δp** is summed over the two legs: it is the friction loss of the whole borehole, U-bend included, and therefore what the pump must overcome to push fluid through it. Like every friction figure of the console, it is $R \cdot Q^2$, not the difference between the pressures at the two ends of a pipe; see *ΔP is not the friction loss* in the *Hydraulic network* chapter.

Flow alone does not tell whether the field works: a well-supplied borehole can still drop into the transition band, which degrades the heat exchange without showing in any flow figure. The **Re** column is there to catch it; page 2 gives the flow regime over the whole drawing.

The **Ratio** row divides the largest value by the smallest in each column. A ratio close to 1 means a balanced field. At 1.5, the most favoured borehole receives 50 % more fluid than the most starved one, and correct sizing elsewhere will not compensate for it. The extreme boreholes are named in the row labels, as in *Minimum (#33)*, when the same borehole is the extreme of all three columns, which is the usual case on a field of identical boreholes. When the columns disagree, for instance on a field mixing bores or depths, the label reads *Minimum* alone.

Page 2, checks and balancing - Reached with the  button. This page sums up the design checks of the Pipes table over the whole drawing. Two columns, **Velocity** and **Friction**, give for the same pipes the recommended range, the maximum reached and the pipe where it occurs, the number of pipes below and above the range, and the number of pipes checked (the last three rows are labelled **Nb.**). A non-zero count outside the range is set in bold. Both checks are advisory: they count the pipes outside the usual design window, 0.3 to 2.5 m/s and 100 to 400 Pa/m. The internal edges of composite devices are not pipes and are not counted.

The **Friction** column is a gradient, $R \cdot Q^2$ per metre of pipe; a pressure difference would be dominated by $pg\Delta z$ and would flag every borehole leg. Below the range checks, **Flow regime** counts the pipes in each of the three regimes and gives the **share of the head loss** each regime carries. The share is the figure to read: thirty pipes in the transition band may be short connectors carrying almost no loss, while three pipes may carry most of it.

The transition row turns bold once it carries more than 1 % of the head loss. Between $Re = 2300$ and 4000 , the friction factor is not given by a correlation but interpolated between the laminar and the turbulent values. The interpolated factor is lowest at $Re = 2300$ and highest at $Re = 4000$, so within that band a colder loop can show a smaller head loss and a higher flow than a warmer one. This is an effect of the interpolation, not of the flow physics.

Page 3, networks - Reached with the  button. One **column** per independent network: the fluid actually used in the solve, the temperature and the density at which it was evaluated, the smallest and the largest pipe flow with their ratio, the critical head span, the delivered pump head, and the head-loss figures.

Min pipe flow, **Max pipe flow** and their **Spread** are counted over the pipes only, excluding the internal edges of devices and dead branches. The spread is a coarse indicator: a header naturally carries more than a branch, so a large ratio is expected and only says that the flows are not uniform.

Crit. ΔH is the difference between the highest and the lowest hydraulic head, $P/\rho g + z$, among the nodes of the network. Its meaning depends on whether the network holds a pump.

On a network with no pump, such as a loop between two pressurization points or a branch fed from a header, the span is the head that the boundary conditions impose on the circuit, and it is the figure against which a pump can be sized before one has been drawn.

On a network with a pump, the span is not an independent check on the pump. Hydraulic head is a potential, so the span between the lowest and the highest head is the head the pump adds between its suction and its discharge, less the friction of the pipe that joins the pump to its neighbour. It therefore follows the reported **TDH** by construction and sits slightly below it, typically by 0.1 to 2 %. A TDH lower than the span cannot occur, and comparing the two will never reveal an undersized pump. A large gap between them would point to a numerical problem in the solve.

To judge whether a pump is right for its circuit, read the head it delivers against the loss the circuit demands: **Total (kPa)** on this page for the whole network, and the **Loop Δp** of the worst borehole on page 1.

The last block splits the head loss of each network in two: **Friction loss**, dissipated by the pipes along their length, and **Minor loss**, dissipated by the fittings through their K. **Total**, under a horizontal rule, is their sum and the only row of the page that adds up. Friction is $R \cdot Q^2$ here, as on page 2. These figures are sums over all the pipes and fittings of the network.

Page 4, conservation and solver health - Reached with the  button. Whether the solve converged, in how many Newton-Raphson iterations, the flow residual it reached, and the largest nodal flow imbalance with the node where it occurs. The imbalance is recomputed from the published pipe flows rather than taken from the solver, so it is an independent check: it should be several orders of magnitude below the smallest flow in the network.

Nodes at imposed pressure are left out of this check: an expansion vessel, a reservoir, a fill valve, or the anchor the solver places itself on a loop that declares none. Imposing a pressure removes the node's continuity equation, so the node may feed or drain the circuit. What it exchanges is reported on its own line, **Boundary flow**, with the node concerned. On a closed loop that flow is zero; on a circuit open between two pressurization points it is the flow crossing the circuit, which is a design figure. **Solved at** closes the table with the time of the solve.

Below a thin rule come the messages about the solve, in order of priority: **Solver error**, in red (a pump not wired in series, a circuit with two pressurization points, a check valve carrying reverse flow), then the **networks left out of the computation**, in orange, each with its reason on the line below.

The solver log follows under **Details**; this is where a convergence problem is explained. Not every entry is a fault: a network with no expansion vessel, reservoir or fill valve receives a pressure reference at its lowest-numbered node, at the static pressure of the Network panel, and the log says which node and at what pressure. Flows, velocities and head losses do not depend on that choice.

Computation time and convergence - The footer shared by every page reports the wall-clock time of each stage: **Ass.** builds the equations from the drawing, **Solve** runs the Newton-Raphson iteration itself, **Post** reorients the pipes and computes the aggregates, and **Render** repaints the scene and the tables. **Total** is their sum. Beside them, **Convergence** gives the iteration count and the flow residual of the solve.

On a network of a few dozen elements the whole cycle is a few milliseconds. On a field of several hundred boreholes the solve stays in the tens of milliseconds, and the rendering of the drawing becomes the dominant term.

GLN in practice: reporting a hydraulic study

The main result of a hydraulic study is the pump head, but a head on its own says little. Report it with the flow it corresponds to, the pump control mode, the fluid and its temperature, the maximum velocity and friction gradient with the number of pipes outside the recommended ranges, and the borehole ratio of page 1. All of these values are on the four console pages, and a reviewer can check the pump selection from them without opening the model.

Check the inputs first. The console only reflects the model and cannot tell whether a diameter, a roughness, a K or a length matches the project. Start with the lengths: a pipe marked with an orange bar in the *Length* column of the Pipes table still carries its seed length.

The velocity and friction ranges of page 2 are guidelines. A short connection above 2.5 m/s is often acceptable, whereas a field where every borehole leg runs below 0.3 m/s deserves a closer look, even though nothing on the page is flagged. The borehole ratio is more important: once the field is buried, an imbalance can only be corrected by throttling the favoured circuits, which adds pumping head for the life of the system.

Published benchmarks help judge whether the pumping power of a design is reasonable. Kavanaugh and Rafferty (2014, Ch. 6 §6.2, *Impact of Pump Power*) grade commercial ground-source systems by the power drawn by the pump motors per installed ton of **cooling** capacity, for a circulation of **2.5 to 3.0 gpm/ton** (0.045 to 0.054 L/s per kW): **grade A up to 50 W/ton** (about 14 W per kW of cooling), B from 50 to 75, C from 75 to 100, D from 100 to 150 and F above 150. Page 1 gives the electrical power of each pump and their total, so the grade is simply that total divided by the installed cooling capacity. Converting a grade into a head requires the pump and motor efficiencies, which the table does not give.

Rhoda (2013) compares pipe-sizing criteria, piping configurations and pump control strategies on a simulated commercial building. Picard et al. (2017) derive the flow rate at which the extra pumping power offsets the gain in heat pump COP. For measuring and improving an existing pumping system, see U.S. DOE and Hydraulic Institute (2006).



Catalogues

This section gathers the three catalogues used to seed a drawing: components, fitting losses and pipes.

None of it is needed to build or solve a network, and most of it is shown on screen as you work: the palette is the component catalogue and the *Pipe type* list is the pipe catalogue. It is collected here for use away from the software, for instance to choose diameters, check a coefficient against a manufacturer's sheet or justify a figure to a client or a reviewer.



Component catalogue

Each entry shows the symbol drawn on the canvas, in the colour of its family, its name in the palette, the tables and the console, and its hydraulic role. The default K values are discussed under *Minor loss coefficients*, below.

ACTIVE

	Pump	A two-port machine: it must sit in series on a single line, with exactly one suction pipe and one discharge pipe; wired to three pipes or more, it is reported as an error in the console. Pump curve picks which curve from the <i>Pump curve</i> panel it follows; left unset, it falls back to the middle of that library. Discharge toward names the neighbour it pushes into, which reorients the two pipes so the symbol triangle and the computed direction always agree. Control is CS , constant speed, following the H-Q curve; ΔP-c , constant head; or Q-c , constant flow — the same three acronyms label the mode here and on the pumping page of the console.
	2-way valve	The general-purpose throttling/isolation element. Fully open, K starts at 0.3 for the gate / isolation kind, 0.05 for a full-port ball valve and 1.0 for a butterfly valve, and at 5 for the balancing kind. That 5 is only a seed: on a balancing valve K is the design variable, the one you adjust to distribute the flows, and a partly closed valve runs far higher — a manufacturer's K_v at the setting you intend is the figure to enter. Purge and safety valves are normally-closed branches rather than in-line resistances.
	3-way valve	Mixing or diverting. Assign the common port , then set the split with the slider: each branch's loss becomes K/a^2 with a the open fraction, so the flow split results from the solve, not directly from the slider position. It is solved as a true 3-way valve only with a common port assigned and exactly three pipes attached; failing either, it is solved as a plain fitting carrying its K — its position then has no effect at all — and the console names it and badges it on the drawing.

ACTIVE

	Check valve	$K \approx 2.5$ while it passes. Flow the other way is blocked: the solver closes the valve and says so. Its passing direction is the <i>Flow toward</i> row of the Properties panel.
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FITTINGS

	Junction (coupling)	A plain connection point, $K = 0$.
	30° elbow	$K \approx 0.2$ (fabricated).
	45° elbow	$K \approx 0.35$ (moulded).
	60° elbow	$K \approx 0.6$ (fabricated, two or more miters).
	90° elbow	$K \approx 0.9$ — the fitting where published sources disagree most; a swept bend can run as low as 0.4, a sharp socket-fusion elbow as high as 1.2.
	U-bend	$K \approx 1.8$ (two 90° elbows); the foot of a single borehole leg, placed automatically by the borehole archetypes of the <i>Hydraulic network</i> panel.
	Tee	$K \approx 1.5$, the branch value; flow continuing through the run costs about a third of that.
	Cross	Four-way fitting; can also carry a merged reducer on any one arm.
	Reducer	$K \approx 0.3$. Placed on its own between two pipe sizes, it is a component like any other. It can instead be merged onto one arm of a tee or a cross — the usual case when the reduction sits straight on a fitting with no pipe between them: pick the arm in that fitting's <i>Reducer on</i> field, or drop a reducer from the palette onto the fitting and it is merged instead of replacing it. The arm then carries the reducer's K on top of the fitting's own, and only on that arm; what is described is two pieces, the fitting at its own port size and a reducer to the branch pipe — the assembly usually stocked when a branch is several nominal sizes below the run. The arm is named by the neighbour it leads to: if that pipe is deleted or redrawn, the reducer loss is no longer applied, and the console names the fitting and badges it on the drawing.
	Manifold	The header of a ground heat exchanger — not a single component but one node per take-off , linked in series by short header segments, so every take-off appears in the Nodes and Pipes tables. Branches sets the take-off count. K per take-off is the minor loss of <i>each</i> take-off, applied to every one of them, not only the first. Take-off spacing , the real centre-to-centre distance between take-offs (0.10 to 0.30 m on a typical manifold, defaulting to 0.15 m), is a <i>physical</i> input decoupled from the drawing: the header segments carry it as

FITTINGS

		friction, while the canvas keeps a readable two-square spacing. Header Ø sets the internal diameter of every header segment at once, from the pipe catalogue; those segments are hidden on the drawing, so this is where they are sized. Size the header at least like the largest pipe it feeds or collects: it carries the full flow. Take-offs added later inherit it, and <i>Mixed</i> means the segments were edited to different sizes in the Pipes table. Rotation turns the whole manifold in 5° steps. Axis node at the other end moves the header's single axis connection from one end to the other, which is how the take-offs end up on the other side without redrawing.
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THERMAL

	Heat pump	Two forms, chosen by Kind. <i>Water-water</i> is what the palette places: two independent internal circuits, source and load, under one four-port body. <i>Water-air</i> has a single water circuit — its building side is air, drawn as two duct antennae and a finned coil — and therefore two ports instead of four. Either way it is a composite component: each port is drawn as an ordinary junction, but it belongs to the body — it moves with it and cannot be selected or retyped on its own. Selecting the device highlights it whole, every circuit included; the two circuits of a water-water unit never touch each other. Changing Kind converts the device, it does not merely rename it — see <i>Kind</i> on the <i>Hydraulic network</i> page.
	Auxiliary heat/cool	A boiler, chiller or other auxiliary unit added alongside the heat pump(s).
	Heat exchanger	Isolates two fluid loops — typically an antifreeze ground loop from a water building loop — as a composite component of its own, with two internal circuits and four ports. Plate, coaxial or shell-and-tube by Kind.
	Radiator	A terminal emitter on the building side, drawn as the convention draws it: a panel divided by its elements. Hydraulically it is an in-line component with two ports carrying a K, like any fitting. Like the rest of the module it computes no heat transfer : it is drawn so that the circuit feeding it can be sized. Its K starts at 5, the radiator valve rather than the panel dominating the loss, which is an order of magnitude and not a specification: an emitter is given by its pressure drop at nominal flow , so read it off the data sheet and convert it to K.
	Fan-coil unit	The other terminal emitter, where the air is <i>blown</i> across the coil; its symbol is a finned coil crossed by an arrow. Two ports and a K, like the radiator, with the same caution: the K starts at 30, because a finned coil typically loses 10 to 30 kPa at its nominal flow, but the data sheet gives the actual figure. Neither emitter carries a fan power or an air flow ; nothing in this module reads them.

GROUND HEAT EXCHANGER

	Single-U borehole	One circuit down and back — the standard configuration. Places the whole archetype (two legs, a U-bend at the foot) in one gesture. See <i>Placing a single borehole</i> on the <i>Hydraulic network</i> page.
	Double-U borehole	Two circuits in parallel down the same hole. Each carries half the total flow, so the borehole's pressure drop falls to roughly a quarter of the single-U value, not a half — the loss goes as the square of the flow. The Reynolds number of each leg halves with the flow, which is the number to check: a double-U is where a leg falls out of turbulence first.
	Coaxial borehole	A centre tube inside an annulus, drawn as two named legs. Measured field pressure drops depart from the textbook value — see Vautrin et al. (2024).

INSTRUMENTATION

	Flow meter	Confirms the design flow was actually achieved; standard placement is at the field connection.
	Temperature	Gauge (local dial) or transmitter (feeds a control system) by Kind, told apart on the drawing by the ISA sub-letter I/T.
	Pressure	Same gauge/transmitter convention as Temperature.
	Energy meter	Reads a thermal or electrical energy quantity at that point, for commissioning or monitoring.

STORAGE & SAFETY

	Expansion vessel	Absorbs the fluid's thermal expansion; normally carries the network's pressure reference (only the first one placed is armed). See <i>Fixed-pressure node</i> on the <i>Hydraulic network</i> page.
	Reservoir	An open, vented reservoir; may also carry the pressure reference.
	Buffer tank	Hydraulically decouples a variable-flow side from a constant-flow side. One water circuit, so two ports on the same side — its <i>Connections on the right</i> checkbox, on the device page, moves the vessel to the other side of them.
	Fill / make-up valve	Where the loop is charged and topped up; carries the pressure reference only while open, not by default.

TREATMENT		
	Y-strainer	Catches fusion beads, drilling debris and backfill before they reach the plant.
	Air separator	Removes dissolved air that a purge alone leaves behind — the air that surfaces after the first heating season.
	Dirt separator	Removes suspended solids circulating on a return line.

Minor loss coefficients

The loss through a fitting is written $\Delta P = K \cdot \rho v^2 / 2$, the loss-coefficient form used in the standard handbooks (Idelchik, 1994; Crane, 2013; ASHRAE, 2021). GLN gives every component a default K so that a network can be solved as soon as it is drawn. These defaults are generic values of the order found in the handbooks, not figures taken from one of their tables. For elbows and the U-bend they fall within, or very close to, the range of the thermoplastic data compared below. The tee takes the PPI value for flow into the branch, and the butterfly valve the PPI value for a fully open valve. The reducer and the check valve are on the low side of the published figures, and the ball and gate valves are not tabulated by either source. Crane and ASHRAE tabulate coefficients that vary with the pipe size and cover mostly steel, copper and PVC fittings: for a standard 90° elbow in threaded steel, ASHRAE gives 1.5 at 1 in and 1.0 at 2 in.

These values are only defaults. They exist to get a first solution, not to describe a particular installation. It is the user's responsibility to enter K values consistent with the components that will actually be installed on site, preferably from the manufacturer's data sheets, and to revise them whenever the equipment is selected or changed.

Published values for thermoplastic fittings. The table below compares the GLN defaults with two published sources, one American (PPI, for PE) and one European (GF, for PP and PVDF).

FITTING	GLN DEFAULT K	PPI, AS K AT F = 0.025	GF K _R
90° elbow (moulded, R/D ≈ 1.5)	0.9	1.00	0.4 swept · 1.2 sharp
60° elbow (fabricated, 2+ miters)	0.6	0.63	—
45° elbow (moulded)	0.35	0.53	0.3
30° elbow (fabricated)	0.2	0.20	—
15° elbow (moulded)	—	0.15	—
Tee, flow to the branch	1.5	1.50	1.3 (single value for a tee)
Tee, flow through the run	1.5	0.50	1.3 (single value for a tee)
Reducer (own node, or merged onto a tee)	0.3	—	1.0 reducer · 0.5 increaser
Check valve, swing, open	2.5	3.38	—

FITTING	GLN DEFAULT K	PPI, AS K AT F = 0.025	GF K _R
2-way valve, gate / isolation, open	0.3	—	—
2-way valve, ball, full port, open	0.05	—	—
2-way valve, butterfly, open	1.0	1.00 (> 8 in)	—
Globe valve, open	—	8.50	—
U-bend (two 90° elbows)	1.8	2.00	0.8 swept (2 × 0.4)

Sources: PPI values from Plastics Pipe Institute, *Handbook of PE Pipe*, Ch. 6, Table 2-2, which gives equivalent lengths, converted here to K at $f = 0.025$, and whose values PPI itself attributes to Crane TP-410 (in its 1957 edition, 410-C); GF K_r from Georg Fischer Piping Systems, *Technical Handbook*, p. 21, which covers PP and PVDF fittings and gives a single value for a tee; the PPI butterfly-valve figure applies above 8 in. Neither source lists a U-bend: its row is twice the 90° elbow, which is also how the GLN default was set. A dash means the source does not cover that fitting.

Where European practice tabulates these coefficients. In Europe the same quantity is written ζ (zeta) and is tabulated, fitting by fitting and by material, in the informative Annex A of DIN 1988-300, the DIN standard — also a DVGW code of practice — for sizing drinking-water pipework. ζ and K are the same number in the same equation, so a value taken from it can be entered in the K field unchanged. Two cautions before doing so: that standard covers **drinking water installations**, so its fittings are those of building services rather than a fused ground loop; and it presents its ζ as reference values, to be checked against the manufacturer's data once the actual product is known.

Reading the columns. The sources do not express quite the same quantity.

The PPI column is converted. PPI tabulates equivalent lengths in pipe diameters, not loss coefficients. They are converted here with a friction factor $f = 0.025$, representative of PE at the Reynolds numbers of a ground loop; at $f = 0.02$ the values would be a fifth lower.

The 90° elbow is where the sources differ most, because of the bend radius: PPI's 1.0 assumes a moulded elbow of $R/D \approx 1.5$, and GF distinguishes a swept elbow (0.4) from a sharp one (1.2). A socket-fusion elbow behaves like the sharp figure; a long sweep, or pipe simply bent to a radius, like the low one. The GLN default of 0.9 sits between them.

A tee is two coefficients, and GLN carries one. Flow through the run and flow into the branch differ by a factor of three (PPI: 0.5 against 1.5). The solver applies a single K per node, split across its pipes, and the default is the branch value, the one that matters at a manifold take-off or a reverse-return tee. On a tee that carries its flow mostly through the run, 0.5 is closer; in either case, check the result against a manufacturer's figure.

K depends on the flow regime. Handbook coefficients are usually given for fully turbulent flow. As the Reynolds number falls, which is what happens with a cold glycol mixture, the loss through a fitting becomes larger than a constant K predicts. Lamarche (2023), Ch. 7, mentions two methods that model this dependence, the two-parameter method of Hooper and the three-parameter method of Darby, and uses a simpler equivalent-length correction instead (his Eq. 7.21). In his worked example with propylene glycol at 5 °C, this correction raises the fitting losses by about 21 % for a 20 % solution and by 62 % for a 40 % one, by volume. GLN applies no such correction: it uses the K entered, whatever the temperature. How much this matters depends on the share of the fitting losses in the total, and that share varies

widely. In Example 3 of the *Examples and verification* window, a complete ground-source system, fitting losses are a small part of the loss in the borehole field, about a third in each fan-coil loop, and about half in the building loop, where the heat pumps and the plate heat exchanger sit. Where the share is large, enter a K already corrected for the operating temperature.

The pipe catalogue and its roughness

The catalogue is described where it is used, under *Pipe type* on the *Hydraulic network* page; what follows is where its numbers come from. The metric family takes its outside diameters and SDR series from ISO 4427 (EN 12201) and the imperial family from ASTM D3035 and F714. Every bore in the table is computed as $ID = OD \cdot (SDR - 2) / SDR$, so the same SDR reads the same way in both families: a dn 32 pipe is 24.9 mm inside in SDR 9 and 26.2 mm in SDR 11. That identity takes the wall as exactly OD/SDR , which is the convention of the geothermal design references; the bores of Lamarche (2023) agree with it within 0.1 mm. Manufacturers' tables give a slightly smaller bore. ISO 4427 tabulates a *minimum* wall, rounded up to the next 0.1 mm and followed by a tolerance (3.6 mm in SDR 9 and 3.0 mm in SDR 11 at dn 32), and for flow calculations the Plastics Pipe Institute (2022), Ch. 6, deducts twice the *average* wall, taken as the minimum plus 6 %, which gives 24.5 and 25.8 mm at dn 32. At a fixed flow, that bore raises the friction by about 7 % in SDR 11 and 9 % in SDR 9. Where that margin matters, enter the manufacturer's inside diameter.

The seeded roughness of **0.0015 mm** is the design value the Plastics Pipe Institute (2008) recommends for PE and the other thermoplastics — its Table 2-1 groups PE with the other thermoplastics, brass, glass and lead under a single *smooth pipe* entry at 0.000005 ft, and notes that any pipe at or below that figure behaves as one — drawn tubing included.

The same value seeds every pipe you draw, and it is the only roughness this module assumes: a ground loop is thermoplastic pipe, from the borehole legs to the headers. Two independent sources support treating PE as smooth — Lamarche (2023), whose Ch. 7 examples also serve as verification cases for this module, solves PE loops as hydraulically smooth ($\epsilon = 0$), while noting that a roughness of about 0.02 mm is sometimes suggested and would have a slight influence; and Javed and Spitler (2022) measured the pressure loss of four types of heat exchanger in a 200 m borehole and found the standard procedures adequate for smooth single- and double-U tubes.



References

The works listed below document the methods implemented in GLN Analysis: the Darcy-Weisbach formulation of distributed losses and the friction-factor correlations used to close it, the loss-coefficient treatment of fittings, the thermo-physical correlations of the antifreeze solutions, the reference cases against which the solver is verified, and the design practice the panel's advisory checks are drawn from.

1. ASHRAE, 2021. *ASHRAE Handbook — Fundamentals*, Ch. 22 "Pipe Design"; and ASHRAE, 2023. *ASHRAE Handbook — HVAC Applications*, Ch. 35 "Ground-Source Heat Pumps and Geothermal Energy". American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA. (The two volumes are issued on different years of the Handbook cycle; the chapter was numbered 34, and titled "Geothermal Energy", before the 2019 edition.) ↩
2. ASTM International. *D3035 — Standard Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Controlled Outside Diameter*, and *F714 — Standard Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Outside Diameter*. ASTM International, West Conshohocken, PA. ↩
3. Crane Co., 2013. *Flow of Fluids Through Valves, Fittings and Pipe*, Technical Paper No. 410. Crane Co., Stamford, CT. ↩
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