GEM4D DOCUMENTATION

Stope Flow Model

User Guide

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Contents

Part 1 — Getting started 3
1. What the Flow model does 3
2. Quick start: a box stope 4
Step 1 — Open the setup 4
Step 2 — Run 5
Step 3 — Play the draw history 5
Step 4 — Look inside with Markers 5
Step 5 — Plot the dilution curve 5
Optional — Add a tip point 5
3. Key concepts 5
3.1 The void is a grid of cells 5
3.2 What moves material 6
3.3 Rounds 6
3.4 Tonnes and cells 7
4. The Flow ribbon tab 7
Part 2 — Setting up and running 8
5. Preparing the meshes 8
5.1 What you need 8
5.2 Checklist for real meshes 8
5.3 Model size limits 9
6. The setup dialog 9
6.1 Container fill (mine RLs) 10
6.2 Flow parameters 10
6.3 Draw rate 11
6.4 The Drawpoints and Tip points grids 11
6.5 Saving and loading a schedule 12
6.6 Mesh roles and the fill order 12
7. Picking points in the scene 13
7.1 The scene markers 14
8. Tip points: what a tip can deliver 15
8.1 Where the tip starts: the search radius 15
9. Draw rates and scheduling 16
9.1 Tonnes say when a row stops; rate says how fast 16
9.2 Why Proportional is the default — a worked example 16
9.3 The calendar — Custom mode only 16
9.4 Tipping against drawing 17
9.5 Matching a real draw schedule 17
9.6 Snapshot spacing and the Round column 17
9.7 Staged runs: drawing and tipping in sequence 18
10. Cave zones 18

10.1 When intact rock fails 19
10.2 Bulking: why the cave is draw-controlled 19
10.3 The zone boundary is the caveability limit 20
10.4 Zone meshes, and several zones in one run 20
10.5 What you see 20
11. Running and the run report 21
11.1 During the run 21
11.2 The run report 21
11.3 Checks after the run 23
Part 3 — Results 23
12. Result meshes and snapshot playback 23
13. Cells to Markers 23
14. The dilution CSV 24
15. Saving, loading and clearing 25
15.1 Save flow 25
15.2 Load flow 25
15.3 Clear 25
Part 4 — Choosing parameters 26
16. Parameter guidance 26
16.1 Cell size and run time 26
16.2 Lateral flow spread — the calibration knob 26
16.3 Repose angle 26
16.4 Seed, and using the randomness 27
16.5 Snapshots 27
16.6 Cave zones — reading and steering the caving 27
17. Assumptions and limitations 27
Part 5 — Reference 28
18. Troubleshooting 28
18.1 Before the run starts 28
18.2 The run stops with a message 29
18.3 Notes and warnings in the run report 29
18.4 The results look wrong 30
18.5 Playback and files 31
19. Macros — recording and replaying flow runs 31
20. Glossary 32
21. References 33
Document history ..... **Error! Bookmark not defined.**

This guide shows you how to set up, run and read a flow model of broken rock in a stoping void: material drawn from drawpoints, tipped in from above, and caving in from the rock around it.

> **Scope and engineering responsibility.** The Flow model is an **indicative, kinematic** tool. It shows where broken rock moves and mixes as you draw and tip. It does not compute forces, loads or stability. Material never arches or hangs up, and caving is cohesionless; Chapter 17 lists every assumption. Use its dilution figures to compare options and as a starting point to calibrate against your own draw records — not as a forecast. What a result means for a draw plan remains the judgement of a competent mining or geotechnical engineer.

How to use this guide

If you want to…	Read
Understand what the model can do	Chapter 1
Get a first result quickly	Chapter 2 — a ten-minute walk-through
Learn the ideas behind the model	Chapter 3
Prepare meshes and set up a real run	Part 2 (Chapters 5–11)
View, export and save results	Part 3 (Chapters 12–15)
Choose and calibrate the parameters	Part 4 (Chapters 16–17)
Fix a problem, automate a run, or look up a term	Part 5 (Chapters 18–21)

Part 1 — Getting started

1. What the Flow model does

The **Flow** ribbon tab simulates how broken rock moves inside a stoping void. Material is drawn from drawpoints below and can be tipped in from above. Ore and waste settle, rill and mix as this happens. If you allow it, intact rock above the void caves in as the draw undermines it.

The model is fast and indicative, in the same spirit as the BEM module: colour-coded insight in seconds to minutes. It is not a research-grade granular simulation.

You supply three things:

1. **A container mesh** — the closed stope or void shape, loaded and visible in the scene. Several meshes can pool into one void.
2. **A fill** — ore and waste levels by RL, closed region meshes that fill with their own material, or both.
3. **Drawpoints and tip points** — where material leaves (East, North, tonnes) and where it enters from above (East, North, RL, tonnes).

You get back:

- one coloured mesh per material, inserted in the scene;
- snapshot playback of the draw history;
- a run report with the tonnes and waste percentage of each drawpoint;
- a dilution CSV with the curve of each drawpoint;
- the grid cells as Marker data, to colour by material, movement and displacement;
- a `.flow4d` file that reloads the result exactly.

Typical questions it answers

- Where does the waste above my ore report to when I draw? (dilution entry, waste fingering)

- How wide is the draw zone above each drawpoint? Do neighbouring drawpoints interact?
- How much can I draw before the waste percentage passes my cut-off?
- Where does tipped material end up, and what does the rill cone look like? How much can one tipping point place before it chokes?
- If I keep drawing under a caveable back or hangingwall, how much caves in? How far does the back advance, and what dilution does it bring? (Chapter 10)

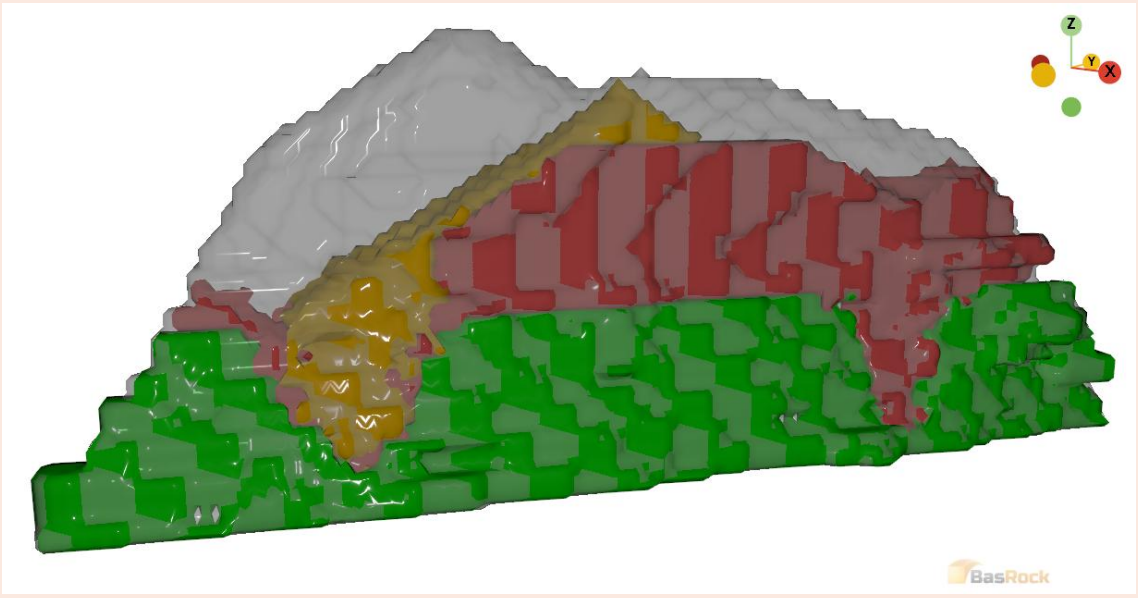


Figure 1 — A transparent stope container mesh with the coloured ore and waste bodies inside after a draw run, the drawdown cone above the drawpoint is clearly visible.

2. Quick start: a box stope

This walk-through runs a synthetic box stope from mesh to dilution curve. It takes about ten minutes.

Before you start

You need one closed box mesh, about 20 m × 20 m in plan and 60 m high. Any closed solid will do. GEM4D has no box primitive, so either:

- bring a closed box in from CAD as a DXF or OBJ solid; or
- click **Mesh › Save DXF-files › Save other › Scene bounding box**. This writes the bounding box of the visible meshes to a DXF file, as a closed solid plus a wireframe copy. Load the file back, delete the wireframe copy, and size the solid with the **Transform** panel.

Make sure the box is the only visible mesh.

Step 1 — Open the setup

1. Select the **Flow** tab.
2. Click **Run flow model**. The *Flow model setup* dialog opens.

On the first run of a session, the dialog fills in workable defaults from the box: a cell size of about 1 m, ore up to 40 % of the box height, waste up to 75 %, 20 snapshots, and one drawpoint at the centre of the box with about 30 % of its gross volume as tonnes.

If you have already run the flow model in this session, the dialog shows your last values instead. Check the two fill RLs against the box (§6.1). If the Drawpoints grid is empty, type one drawpoint at the centre of the box.

Step 2 — Run

1. Click **Run**. The progress label at the right of the ribbon counts up.
2. When the run finishes, GEM4D asks you to save the result meshes as a DXF. Save them.
3. Read the run report, then close it.
4. Hide the box in the Mesh panel. Inside is a green ore body with a red waste band on top, and air above.

Step 3 — Play the draw history

1. In the Snapshots group, click **Play steps**. The button reads **Stop play** while it plays.
2. Watch a drawdown cone form in the ore surface. It deepens, and the waste follows it down until red reaches the drawpoint. The report's waste percentage says how much waste came out with the ore.
3. Click **Stop play** to stop. Click **Final** to return to the end state.

Step 4 — Look inside with Markers

1. In the Actions group, click **Cells to Markers**.
2. Colour the markers by **Moves**. The draw zone above the drawpoint shows as a sharply bounded body of moved cells.
3. Colour by **DropM** to see how far each cell fell.

Step 5 — Plot the dilution curve

1. Click **Dilution CSV** and save the file.
2. In a spreadsheet, filter to DP1 and plot **CumTonnes** against **CumWastePct**. The curve stays at 0 % until the cone reaches the waste, then climbs. That is the dilution-entry curve.

Optional — Add a tip point

1. **Show the box again** in the Mesh panel, at a low opacity so you can still see inside. It must be visible to be the Container, and your click must land on its crown, not on the result surfaces.
2. Click **Pick tip points**, click once on the crown of the box, then click the button again to stop picking.
3. Click **Run flow model**. Give the tip more tonnes than the box can hold, and click **Run**.
4. Play the snapshots. An orange rill cone builds at the repose angle while the draw continues below. The report's `T1` line ends **choked**: the tip placed only the cone that fits under it (Chapter 8).

Where to go next

- Prepare a real stope mesh: Chapter 5.
- Schedule several drawpoints at real rates: Chapter 9.
- Add caving above the stope: Chapter 10.

3. Key concepts

You need only a few ideas to use the model well. This chapter explains them.

3.1 The void is a grid of cells

GEM4D divides the container into a uniform grid of cubic **cells**. Each cell holds one of:

- **air**;
- **wall rock** — immovable; everything outside the container;

- a **material** — ore, waste, tipped rock, or the material of a region mesh;
- **intact cave rock** — rock in a cave zone that has not failed yet (Chapter 10).

Each material keeps its identity as it moves. That is how the model can report where every tonne came from.

The cell size should be at least the mean fragment size of the broken rock. Cells finer than the real fragments imply a flowability the material does not have.

3.2 What moves material

Five simple local rules drive the model.

- **Draw.** A drawpoint removes one cell at a time. The gap it leaves — a "void" — climbs up through the pile. At each step it swaps with one of the nine cells above it, straight up or diagonally up, chosen at random with weights. Thousands of these random walks add up to the familiar draw ellipsoid, and mixing and dilution entry emerge from them. **Lateral flow spread** is the weight of the sideways steps: the single knob for how wide the draw zone grows.
- **Settling.** Material with air below it falls.
- **Toppling.** Material on a free surface sheds sideways while its slope is steeper than the **repose angle**. Tipped material builds rill cones at that angle, and drawn-down surfaces rill back to it. The rule looks two columns out, not only at direct neighbours, so repose angles down to about 20° are reproduced.
- **Tipping.** A tip point drops material into one cell, the **tipping point**. From there it falls and rills. The rill cone grows back up towards the tip. When it buries the tipping point, the tip **chokes**: nothing more goes in until drawing lowers the pile (Chapter 8).
- **Caving.** Intact rock in a **cave zone** stands like wall rock until it is undermined or its face is too steep. Then it fails, cell by cell, into broken material that bulks, falls and draws like any other (Chapter 10).

Every random choice comes from one seeded generator. **The same inputs with the same seed give exactly the same result.** Change only the seed to see another realisation of the same random process.

The method is a **stochastic void-diffusion cellular automaton** — the same family as FlowSim (Castro, University of Chile), CAVESIM and the stochastic-medium draw theory of Litwiniszyn and Mullins. The caving literature recommends this approach when speed and arbitrary geometry matter more than contact mechanics. Chapter 21 lists the references.

3.3 Rounds

The model advances in **rounds**. A round is an extraction step, not a unit of time. In every round, in this order:

1. **Each drawpoint that has not stopped draws its rate in cells.** Each cell drawn is a complete event: the cell leaves, its void climbs through the pile, and the surface settles before the next cell is drawn.
2. **Each tip that has not finished tips its rate in cells**, one at a time, each falling and rilling before the next. A choked tip tips nothing that round. It tries again next round, because a drawpoint below may have re-opened it.
3. **Each cave cell that is undermined or over-steep fails**, one at a time, each settling before the next. Cells newly exposed by the earlier failures fail too, so a collapse runs to its natural choke within the round. Caving comes after the draws, so a cave feeding a drawpoint's column refills it before the next round's draws.

The run ends when every drawpoint has stopped, every tip has spent its tonnage or is choked with nothing left to re-open it, and no cave cell is left undermined or over-steep.

Draw and tipping are, in effect, simultaneous. Draw comes first within a round, but a round moves at most 25 cells per row (the fastest row; Chapter 9 paces the others), against a grid of typically 10^5–10^6 cells. The two interleave far more finely than anything you would interpret. To tip first and draw later, or the other way round, run two stages (§9.7).

3.4 Tonnes and cells

All tonnages in the model are **broken tonnes**. One cell holds `(density ÷ swell) × cellsize³` tonnes. At 2.7 t/m³, swell 1.4 and 1 m cells, that is about 1.93 t per cell.

The tonnes you enter become a whole number of cells, rounded. Expect up to half a cell — about ±1 t at 1 m cells. Reported tonnages are cells × tonnes per cell.

How density and swell are used depends on whether the run has cave zones:

- **Without cave zones**, only the ratio `density ÷ swell` matters: the bulk density of the broken muck already in the void. Nothing swells while it flows; the porosity of flowing material does not change.
- **With cave zones**, each number matters on its own. An intact cave cell holds `density × cellsize³` tonnes. When it fails it becomes *swell factor* broken cells. That bulking chokes the cave and keeps it draw-controlled (§10.2).

So always enter the real in-situ density and swell factor. They are kept as two fields because those are the numbers most people have to hand. Entering a known bulk density with swell 1.0 gives the same result in a run without cave zones. **Never do it with a cave zone**: swell 1.0 means no bulking, so the cave never chokes and runs through its whole zone.

4. The Flow ribbon tab

The Flow tab has five groups, left to right: **Material flow**, **Snapshots**, **Save and export**, **Actions** and **Status area**.

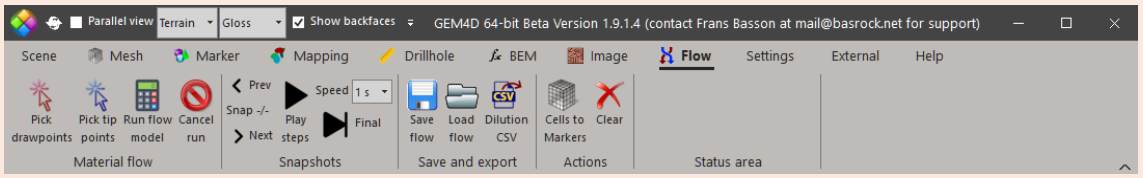


Figure 2 — The Flow ribbon tab with its five groups labelled, left to right: Material flow, Snapshots, Save and export, Actions, and Status area.

Group	Control	What it does	See
Material flow	**Pick drawpoints**	Toggle: click meshes to stage drawpoints (blue markers D1, D2, …).	Ch. 7
Material flow	**Pick tip points**	Toggle: the same for tip points (magenta markers T1, T2, …).	Ch. 7
Material flow	**Run flow model**	Opens the setup dialog; **Run** there starts the simulation.	Ch. 6, 11
Material flow	**Cancel run**	Stops the run in progress; no result is kept.	Ch. 11
Snapshots	**Prev**, **Next**, `Snap k/N`	Step through the snapshots. `Snap 0` is the state before any draw.	Ch. 12
Snapshots	**Play steps**	Plays the snapshots in a loop; reads **Stop play** while playing.	Ch. 12
Snapshots	**Speed**	Seconds per snapshot during playback.	Ch. 12
Snapshots	**Final**	Jumps to the last snapshot.	Ch. 12

Group	Control	What it does	See
Save and export	**Save flow**, **Load flow**	Save the solved result to a `.flow4d` file, or load one.	§15.1–15.2
Save and export	**Dilution CSV**	Exports each drawpoint's tonnes and waste-% curves.	Ch. 14
Actions	**Cells to Markers**	Loads the solved grid cells into the Marker panel.	Ch. 13
Actions	**Clear**	Resets the model and the drawpoint/tip schedule; result meshes stay.	§15.3
Status area	progress label	Shows the progress and outcome of a run.	§11.1

Run flow model and **Load flow** do not work in clipping mode. Leave clipping first. **Pick drawpoints** and **Pick tip points** leave clipping mode themselves.

Part 2 — Setting up and running

5. Preparing the meshes

5.1 What you need

Item	Required?	Notes
A closed ("watertight") container mesh	Yes	The stope or void shape, loaded and **visible**. Several visible meshes can pool into one container — a stope and its access drives, for example.
A fill	Yes, unless the run only tips into an empty void — a drawpoint needs material in its column at the start	RL layers (ore up to one RL, waste up to a higher one), closed region meshes with the **Ore fill** or **Waste fill** role, or both (§6.6).
At least one drawpoint or tip point	Yes	East and North in mine coordinates, and tonnes. A tip also takes an RL — the level where material enters. Type them in or pick them in the scene (Chapter 7).
Density and swell	Defaults 2.7 t/m³ and 1.4	They convert tonnes to cells (§3.4).
Cave zone meshes	No	Closed meshes of intact rock outside the void, with a **Cave zone** role. Up to 4 per run in total (Chapter 10).

5.2 Checklist for real meshes

Real stope and development meshes are messier than boxes. Before you trust a run:

- **Only visible meshes take part.** Hide survey strings and other clutter first.
- **The container must be closed.** The run report counts its open and non-manifold edges. A few are usually harmless on CAD meshes. Hundreds, or a void-cell count far from the stope volume ÷ cell³ (the report's `Grid:` line), mean the mesh needs repair: **Toolbox 1 › Mesh repair without remeshing**, or a watertight rebuild with **Toolbox 1 › Prepare meshes for BEM › Remesh for BEM analysis** (or **Create an encapsulating surface** for a hull) — or fix the CAD source.
- **Region meshes must be closed too**, and must sit inside the container (§6.6).
- **Hide old flow results** reloaded from an earlier session's DXF, or set them to **Ignore**: nested result surfaces corrupt the inside test. The current run's results are left out automatically.

- **Check the fill RLs** against this container's elevations (§6.1).

After the run, make the checks in §11.3.

5.3 Model size limits

- **At most 5 000 000 cells inside the container.** Cave-zone cells count toward the same cap. The count is made after the void is built, so only the stope's own volume counts. A long, skinny stope at 45° to East and North is not charged for the empty corners of its bounding box.
- **At most 100 000 000 cells in the grid box.** The grid is an axis-aligned box, and this separate memory guard applies to it. Only very spread-out geometry reaches it — for example, two containers far apart pooled into one run.

If either limit is exceeded, the run stops at once, and the message suggests a workable cell size. §16.1 shows how cell size drives the cell count.

What sets the size of the grid box: the **Container** meshes, plus any **Cave zone** meshes. Cave zones sit outside the void, so they extend the box and can push a run into the box guard on their own. **Fill regions never extend the box**: a fill mesh that reaches outside the container reaches outside the model.

6. The setup dialog

Click **Run flow model** to open the *Flow model setup* dialog.

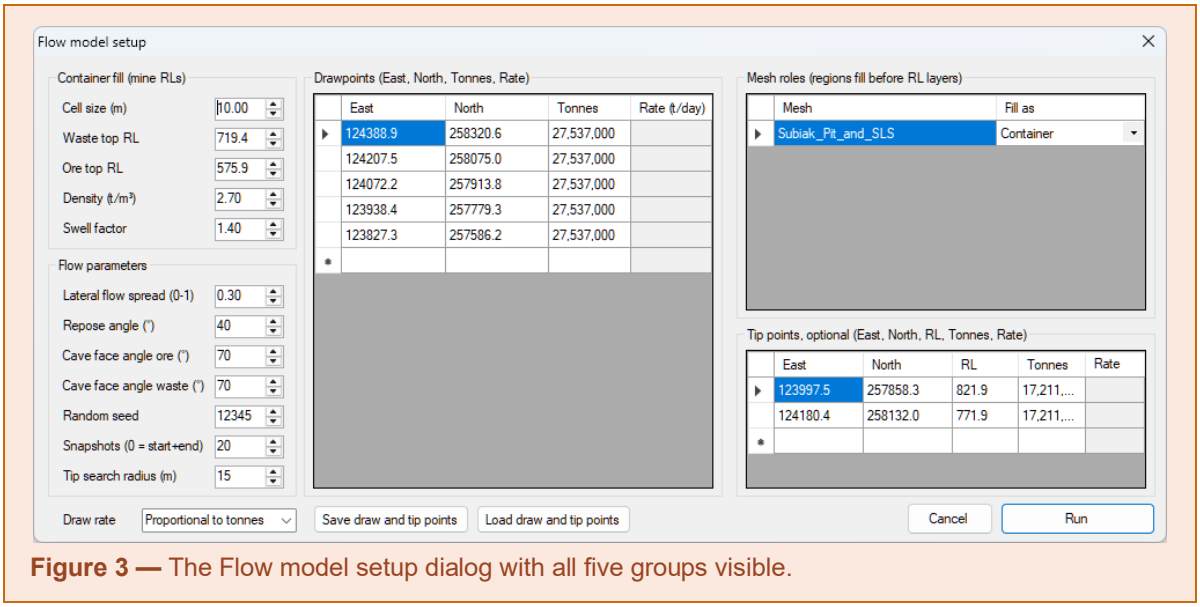


Figure 3 — The Flow model setup dialog with all five groups visible.

The dialog has five groups:

- on the left, **Container fill (mine RLs)** above **Flow parameters**, with the **Draw rate** drop-down below them;
- in the centre, the tall **Drawpoints** grid;
- on the right, **Mesh roles** above **Tip points**.

Along the bottom are **Save draw and tip points**, **Load draw and tip points**, **Cancel** and **Run**.

The dialog reopens with your last accepted values for the rest of the session; mesh roles are remembered by mesh name. **Run** checks your entries and starts the run — each rule is given with its field below, and §18.1 lists the messages. **Cancel** keeps everything as it was, including points staged with the mouse. Every control has a tooltip: hover over the label or the control for what it does and sensible values.

6.1 Container fill (mine RLs)

Field	Meaning	Range	Default
Cell size (m)	Edge length of the cubic cells. At least the mean fragment size, and small enough that the void is at least 20–30 cells across where flow matters.	0.05–100	About 1/60 of the largest extent of the visible meshes, kept between 0.25 and 10 m
Ore top RL	Ore fills the void from its floor up to this mine RL.	—	40 % of the height of the visible meshes
Waste top RL	Waste fills from the ore top up to this RL, with air above. Must be at or above the ore top; set the two equal for an ore-only fill.	—	75 % of the height of the visible meshes
Density (t/m³)	In-situ density.	0.5–10	2.7
Swell factor	Bulking on breakage. Broken density = density ÷ swell, so the same tonnes take more cells broken than in situ.	1–3	1.4

The RL layers always run, even when you also assign region meshes; they fill the air the regions leave (§6.6). To make the region meshes the only fill, set **both** RLs below the void floor. There is no separate off switch.

The RL defaults are set once per session, from the height of all the visible meshes on the first run. The roles are not chosen yet, so a visible drive, cave zone or old result shifts them, and the cell size too: hide everything but the stope before the first run. After that the RLs stay where you left them, even for a new container. When you move to a stope at a different elevation, **check both RLs**: too high, they flood the whole void; below its floor, they add nothing — and with no region mesh or tip either, the run stops with *"The RL layers and region meshes put no material inside the void…"*.

6.2 Flow parameters

Field	Meaning	Range	Default
Lateral flow spread (0-1)	The draw-zone width knob: how readily the climbing void steps sideways. 0 gives a vertical chimney straight above the drawpoint (piping); larger values widen and round the drawdown cone. Sensible values are 0.05–1.0 (§16.2).	0–1.5	0.30
Repose angle (°)	Angle of repose of free surfaces — tipped rill cones and drawn-down surfaces. Reproduced faithfully from about 20° to 60°; lower settings behave like about 20° (§16.3).	5–85	40
Cave face angle ore (°), **Cave face angle waste (°)**	How steep an intact cave face can stand before it unravels (§10.1). One angle for all **Cave zone (ore)** meshes, one for all **Cave zone (waste)** meshes. **90 = off.** An active angle cannot be flatter than the repose angle — checked only for a class that has cave-zone meshes.	45–90	70 / 70
Random seed	Same seed, same result. Change it to see another realisation (§16.4).	1–2 000 000 000	12345

Field	Meaning	Range	Default
Snapshots (0 = start+end)	How many intermediate states to record for playback. The state before any draw (Snap 0) and the final state are always recorded as well, so 0 gives a before-and-after pair (§16.5).	0–500	20
Tip search radius (m)	How far a tip may move sideways to find an opening when its own column has none (§8.1). Used at setup only. 0 = no sideways move.	0–1000	15

6.3 Draw rate

Draw rate is the drop-down at the bottom left of the dialog, below the *Flow parameters* group. It decides how fast each row draws or tips compared with the others:

- **Proportional to tonnes** (default) — every row finishes together. The Rate columns are blank, grey and locked.
- **Custom (t/day per row)** — you type a rate in tonnes per day for each row. This also gives the run a calendar.

Read Chapter 9 before you change it. Mixing up tonnage (when a row stops) and rate (how fast) is the most common reason a run does not look as expected.

When you switch to Custom, GEM4D fills every blank Rate with the t/day that finishes that row in **30 days** — very nearly the Proportional schedule, with a calendar added. Edit only the rows you want to differ. Rows you add later are filled the same way, and nothing you typed is overwritten. The 30 days only makes the numbers readable: halving every rate gives a 60-day campaign and the identical result (§9.3). In Custom mode every row needs a Rate greater than 0. Rates you typed are kept if you switch to Proportional and back.

6.4 The Drawpoints and Tip points grids

Each grid takes one row per point, in mine coordinates and broken tonnes:

- **Drawpoints:** East, North, Tonnes, Rate (t/day).
- **Tip points:** East, North, RL, Tonnes, Rate (t/day).

Rate is editable only in Custom mode (§6.3). Type a new row in the empty bottom row; to delete one, select its row header and press Delete. Points picked in the scene (Chapter 7) appear as pre-filled rows. Tonnes must be greater than 0. Tonnes and Rate show a thousands separator (`12,000,000`); type them with or without it.

Drawpoints. A drawpoint uses East and North only. It draws from the lowest cell of its column that holds material and keeps that cell for the whole run (§11.3). All drawpoints draw at the same time, each at its own rate, until each reaches its tonnes or stops for another reason (§11.2).

Tip points. A tip drops material into **one cell** at the East, North and RL you give, and each cell falls and rills from there (Chapter 8). Tipped material, `FlowTipped` (orange), counts as **waste**. Leave **RL** blank for *automatic*: the tip then sits at the highest opening above that East and North — the back of the void. A typo in RL is reported, not read as automatic.

How many drawpoints? There is no maximum. In practice:

- **One useful drawpoint per grid column.** Two rows with the same East and North are accepted, but they draw the same column, doubling its rate rather than adding a drawpoint.
- **Memory grows with drawpoints × snapshots.** 100 drawpoints at 20 snapshots take a few MB; at 500 snapshots, about 100–200 MB. Reduce the snapshot count if you need many drawpoints.

- **Readability.** The report has one `DP#` line per drawpoint. A few dozen is comfortable, a couple of hundred workable; a thousand becomes unreadable long before it becomes slow.

6.5 Saving and loading a schedule

Save draw and tip points writes both grids to a CSV file; **Load draw and tip points** reads one back and **replaces** both grids. Use it to prepare a schedule in Excel, to reuse it on another stope, and to keep it before you **Clear** (§15.3).

The file has one row per point:

```
Type,East,North,Tonnes,Rate_t_per_day,RL
Draw,1000.5,2000.0,20000,667,
Tip,1030.0,2050.0,40000,500,1245.5
Tip,1080.0,2120.0,20000,250,
```

- `Type` is `Draw` or `Tip`. Rate may be empty. RL may be empty (automatic); it is ignored on `Draw` rows.
- Numbers use a dot decimal whatever your regional settings, so files move between computers.
- A five-column file from an earlier build (no RL) still loads; its tips come back with RL blank.

When you load a file, blank lines, # comment lines and columns after the sixth are ignored. A row that cannot be read is **skipped and reported with its line number**. If the file has rates, Draw rate switches to *Custom*. The file replaces the remembered rows and staged picks, even if you then click **Cancel**.

6.6 Mesh roles and the fill order

Every **visible** mesh has a row in **Mesh roles**. Choose its role in the **Fill as** column. Divider lines in the drop-down group the roles: first the container and the fills that sit **inside** it, then **Ignore**, then the cave zones that sit **outside** it.

Role	Meaning
Container (default)	Part of the void. At least one is required. All Container meshes pool into one void (a stope plus its drives, say); with more than one, **Run** asks you to confirm. Run far-apart containers separately (§5.3).
Ore fill	A closed region mesh, filled with its own ore material: own name (`Flow_<meshname>`), colour and report line.
Waste fill	The same, counted as **waste**.
Ignore	Takes no part in the run.
Cave zone (ore)	Intact rock **outside** the void that caves in as its own ore material (Chapter 10).
Cave zone (waste)	The same, counted as **waste**.

The fill order. Each step fills only cells that are still air:

1. The **Container** meshes are turned into cells. Cells inside them become the void (air); all others are wall rock.
2. **Ore fill** and **Waste fill** regions fill, in row order. The top row wins where regions overlap.
3. **Ore top RL** fills the remaining air from the void floor up to that RL with `FlowOre`.
4. **Waste top RL** fills the remaining air up to that RL with `FlowWaste`. Air remains above.

So the RL layers never overwrite a region, even where it sits below both RLs: it keeps its own material, name, colour and report line.

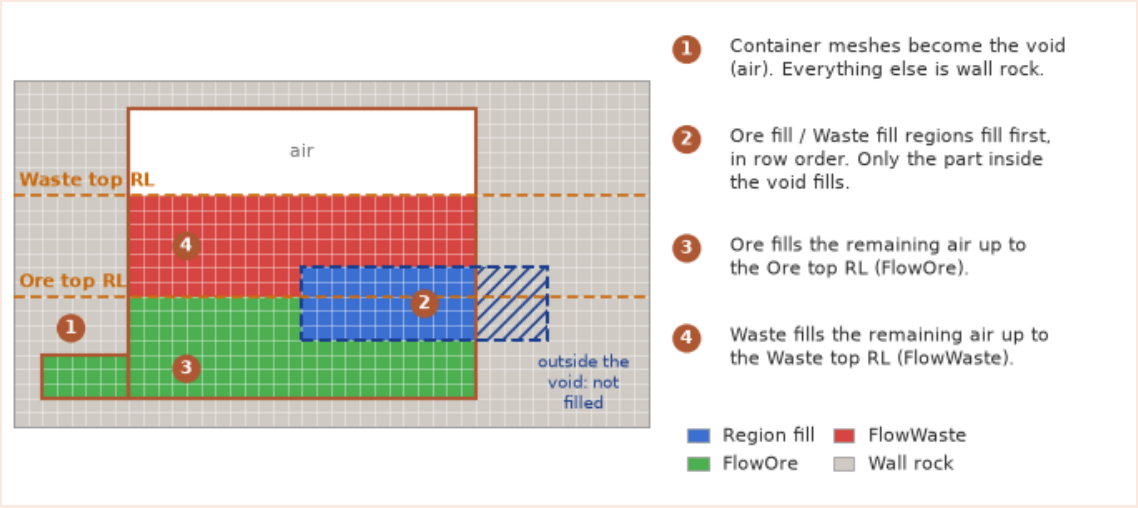


Figure 4 — The fill order, in a vertical section. The container (a stope pooled with its access drive) becomes the void. The region fill fills first, but only inside the void: its hatched part, outside the container, stays wall rock. Ore and waste then fill the remaining air up to their RLs. Schematic; cells drawn large.

Region meshes:

- They must be **closed solids**. Up to 200 are allowed, each in one of 8 display colours in turn (blue, teal, purple, magenta, olive, brown, steel, pink).
- They are placed exactly as drawn, without settling, and move only when the draw disturbs them.
- **Only the part inside the void fills.** A region mesh cannot extend the container, so **a region that overhangs it carries less tonnage than its mesh volume**. The report counts the lost cells on the region's line, and adds a `Note:` above about 5 % of the mesh. A thin rind along the walls is normal; a large count means the mesh is bigger than the stope. A region with no cells in the void stops the run with its name.

The current run's result meshes are left out of the role list automatically (to reuse them, see §9.7).

7. Picking points in the scene

Typing coordinates works, but picking is faster.

1. Click **Pick drawpoints** or **Pick tip points**. The button stays pressed and the cursor becomes a crosshair.
2. Left-click on any visible mesh. Each click stages a point and adds a numbered marker: blue **D1, D2, …** for drawpoints, magenta **T1, T2, …** for tips. Click as many as you need.
3. To remove the last staged point of the kind you are picking, press **Delete** or **Backspace**.
4. To stop, click the button again, right-click in the scene, or start any other tool.

Where to click

- **Drawpoint:** only East and North are used. The drawpoint finds its own level — the lowest material in its column — so a click on the stope wall at any height works.
- **Tip point:** East, North and RL are all used. The picked RL becomes the tipping RL, because that is where the tip chokes (Chapter 8). Click exactly where material enters: the brow, the raise collar, the crown opening. A tip picked low on a wall chokes early, which is the honest answer for a low opening. Clear its RL cell in the grid if you meant "wherever the back is".

The next **Run flow model** adds the staged points to the grids as new rows, rounded to 0.1 m, with a shared default tonnage. Edit the tonnes before you click **Run**. If you cancel the dialog, the staged points are kept for the next attempt.

New picks are **added** to the rows remembered from earlier runs. To start a fresh schedule, use **Clear** (§15.3).

7.1 The scene markers

Every drawpoint and tip in the current setup — typed or picked — shows as a numbered sphere with a faint vertical guide line through the full mesh height, scaled to stay visible at mine scale. The numbers match the grid rows. The markers stay through every run until the scene is cleared.

Where a sphere sits:

- **Before a run**, or after you edit the grids: drawpoints at the bottom of the mesh bounds; tips at their RL, or at the top of the bounds when RL is blank.
- **Staged picks:** exactly where you clicked.
- **After a successful run:** at the solved cell — the drawpoint's extraction cell, and the cell the tip actually tipped from. If a tip had to move to find an opening, you see where it ended up.

Check the markers before you run. In a side view it is easy to click a surface nearer the camera — an access drive, an old result mesh — instead of the wall you aimed at. The marker and its guide line then sit visibly away from the stope. Delete the pick (**Delete** or **Backspace**) and pick again, ideally from a view closer to plan.

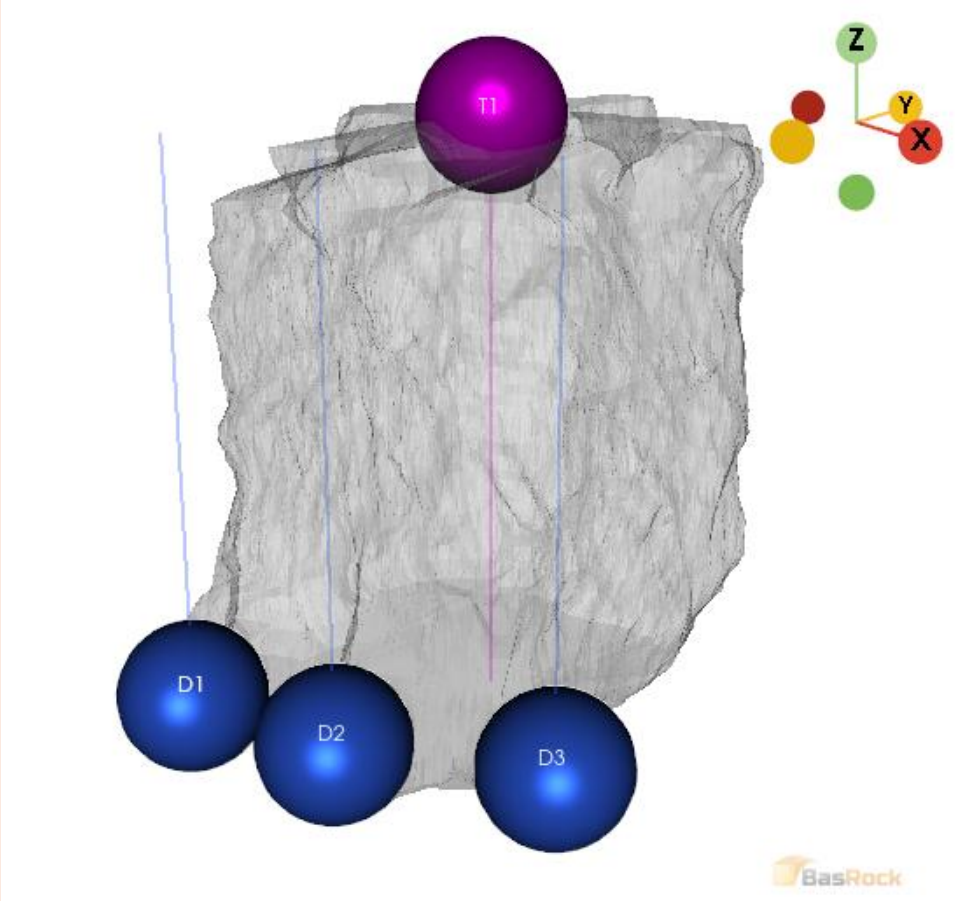


Figure 5 — A stope mesh with three blue drawpoint markers (D1–D3) and their guide lines along the trough, one magenta tip marker (T1) at the crown, and the Pick drawpoints button pressed.

8. Tip points: what a tip can deliver

A tip point is a point. Material enters the void at that one cell — a brow, an ore-pass mouth, the collar of a tipping raise. It falls to the surface below and rills outward at the repose angle. Nothing enters anywhere else.

A tip chokes when its cell is buried. The rill cone grows back up towards the tipping point. Once it reaches it, the opening is blocked and nothing more can go in. This decides how much one tip can place:

> **One tip fills the cone that fits under it, not the stope.** A tip *h* m above the surface below it places at most a cone of π h^3 ÷ (3 $\tan^2$ repose) — about 1 500 m³ at 10 m and 40°, half that against a wall — whatever the size of the stope. In an open void 22 m × 22 m in plan and 10 m high at 40° repose, that is about **30 %** of the void for a tip at the centre of the back, and about **15 %** for one against a wall. The rest of the stope stays open. To place more, add tip points, tip at a higher RL, or draw from below.

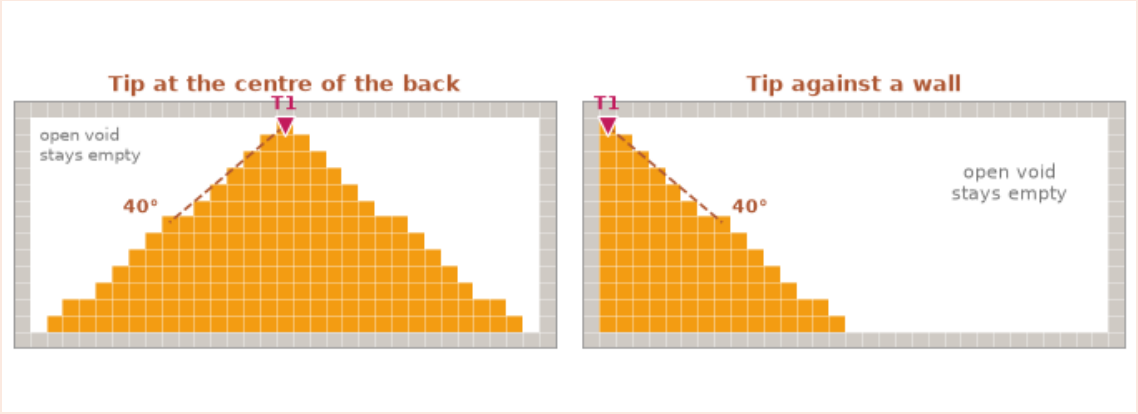


Figure 6 — A tip chokes when its rill cone reaches the tipping point. Left, a tip at the centre of the back; right, one against a wall, which seals much sooner. Schematic vertical sections at 40° repose.

A choked tip can re-open. A drawpoint working below lowers the pile, and tipping resumes the next round. So a tip and a drawpoint together deliver far more than a tip alone, and a tip's Tonnes is a budget, not a promise. The report says how much went in, how much did not, and how many rounds the tip was choked (§11.2).

A tip never puts material **above** its own RL, and never across solid rock into a void that merely lies above or below it.

8.1 Where the tip starts: the search radius

The **Tip search radius** (*R*) forgives an imprecise pick, at setup only; nothing moves a tip during the run.

- **The tip's cell is in rock:** GEM4D takes the nearest open cell in that column, searching **downward first** — so a pick on the crown surface drops into the void just below. The report notes a shift of more than half a cell.
- **The column has no opening at all** (a pick on a wall or pillar, a column filled to the roof, a position just outside the grid): the tip moves sideways to the nearest column with an opening, within *R* metres. The report notes the distance. With *R* = 0 there is no sideways move.

If there is no opening within *R*, the run stops before simulating and gives the distance to the nearest opening. A large distance almost always means the point was picked on the wrong mesh (§7.1).

9. Draw rates and scheduling

Read this chapter if a run has not behaved as you expected — especially with drawpoints of very different tonnages, or with tipping alongside drawing. The answer is usually here.

9.1 Tonnes say when a row stops; rate says how fast

Each drawpoint or tip row has two numbers:

- **Tonnes** — how much it draws or tips in total. It decides **when the row stops**.
- **Rate** — how fast it gets there.

By default (*Proportional to tonnes*) GEM4D derives every rate from the tonnages, so all rows finish together. Only *Custom* lets you set a rate independently of the tonnage.

The fastest row draws **25 cells per round**. Every other row is scaled against it:

Draw rate mode	Rate of each row	Use it when
Proportional to tonnes *(default)*	25 × its tonnes ÷ the largest row's tonnes	Normal use. Every row finishes together, which is what "drawing them all over one campaign" means. Fixes ratios only — no calendar.
Custom (t/day per row)	25 × its t/day ÷ the largest t/day	The tonnages alone do not describe the plan — for example, two drawpoints of equal tonnage where one is mucked twice as often. **Only this mode gives the run a calendar** (§9.3).

Drawpoints and tips are scaled against **one common maximum**.

Rates are fractional and exact: a row at 0.1 cells per round draws 1 cell every 10 rounds. The floor is a thousandth of the fastest row (0.025 cells per round), so even a tiny row still draws. The run report prints the mode and every row's rate.

9.2 Why Proportional is the default — a worked example

1 m cells at 2.7 t/m³ and swell 1.4 (≈ 1.93 t per cell), two drawpoints:

	DP1	DP2
Target	50 000 t	5 000 t
Cells	25 926	2 593
Same speed for both — rate	25 cells/round	25 cells/round
Same speed for both — stops at round	1 038	**104**
Proportional — rate	25 cells/round	**2.5 cells/round**
Proportional — stops at round	1 038	**1 038**

At the same speed, DP2 finishes 10 % of the way into the run and DP1 draws alone for the rest; the draw zones barely interact. Under **Proportional** they compete for the same material for the whole campaign, as they do underground. If a run shows little mixing between neighbours, or late dilution at the big drawpoint, check the `Draw rate:` line in the report.

9.3 The calendar — Custom mode only

Once each row has a rate in tonnes per day, rounds convert to days. The fastest row draws 25 cells and its t/day in the same round, so, for every row:

> **1 round = 25 × (tonnes per cell) ÷ (fastest row's t/day) days**

The run report then adds `Campaign: 62.4 days (1 round = 0.06 days)` and quotes rates in t/day, and the dilution CSV fills its **Day** column. In Proportional mode there is no absolute rate, so there is no calendar.

> **Only the ratios between rates change the simulation.** Double every t/day and the flow is identical, cell for cell; only the reported days halve. That is why Custom with the seeded rates (§6.3) gives very nearly the Proportional result, with dates attached. The seeded rates are rounded to three figures, so it is another realisation, not the same one cell for cell.

9.4 Tipping against drawing

The same rules govern tips. Drawpoints and tips share one common maximum, so in Proportional mode a 100 000 t tip beside a 10 000 t drawpoint tips at 25 cells per round while the drawpoint draws at 2.5, and both finish together.

The void's material inventory changes by:

> **(sum of active tip rates − sum of active drawpoint rates) cells per round**

Use **Custom** for a tip that deliberately outpaces or lags the draw — for example a 400 t/day tip against a 1 000 t/day drawpoint, where the void steadily empties although the tip never stops.

A tip's rate is a ceiling. A choked tip (Chapter 8) delivers nothing until the pile under it drops, and the cells it could not tip are **lost, not carried forward** — otherwise it would burst-fill the moment the draw re-opened it. A tip beside a slow drawpoint is therefore paced by the draw. The `T#` line says how many rounds it was choked.

9.5 Matching a real draw schedule

Concurrent draw — keep the default. *Proportional to tonnes* is right for most runs and needs nothing beyond the tonnages.

A real schedule — use Custom rates. Set **Draw rate** to *Custom* and give each row its tonnes per day:

East	North	Tonnes	Rate (t/day)	Runs for
1000	2000	20 000	1 000	20 days
1060	2000	20 000	500	40 days
1030	2050	40 000	500	80 days ← sets the campaign length

Rows now finish on their own dates. A **tip** row is the exception: if its line reports many choked rounds (`choked for k of N rounds`), the tip, not the schedule, set its delivery.

9.6 Snapshot spacing and the Round column

Snapshots are taken every *k* rounds, with *k* doubling as the run grows (§16.5) — **not** at equal tonnages. While every row is active the tonnage between snapshots is roughly constant. It drifts when a row **stops**, when a drawpoint draws **air**, and at the **final** snapshot, which falls wherever the run ended. For the exact tonnage at each snapshot, read `CumTonnes` in the dilution CSV (Chapter 14).

`Round` in the dilution CSV and the report is a **common scheduling clock, not tonnes**. Plot each drawpoint's `CumTonnes` against `Round` to see the campaign unfold — lines of different slopes, finishing together under Proportional or on their own dates under Custom.

9.7 Staged runs: drawing and tipping in sequence

There is no automatic run chaining. Every **Run flow model** rebuilds the grid from the container meshes and fills it again from the RL layers and region meshes, so it always starts from a freshly filled void. **Load flow** restores a solved state for playback and export only; it does not seed the next run.

You can still run a sequence by hand — draw, then tip into what is left; or draw level 1, then level 2. Stage 1's result meshes describe exactly the material that survived it, so feed them back in as region fills:

1. **Run stage 1** and save the result DXF when prompted. If you will want the stage-1 schedule again, click **Save draw and tip points** first — step 2 discards it.
2. **Click Clear** in the Actions group. While a result is loaded, its meshes are kept out of the role list; Clear releases them **without deleting them**, so they can be given roles. It also empties the point grids, ready for the stage-2 schedule.
3. **Reopen Run flow model and set the roles:** `FlowOre` → **Ore fill**, `FlowWaste` and `FlowTipped` → **Waste fill**. The stope stays **Container**.
4. **Put both fill RLs below the void floor.** Region meshes fill first and the RL layers then fill whatever air is left, so RLs left where they were would refill the space stage 1 just emptied.
5. **Enter the stage-2 schedule** in the empty Drawpoints and Tip points grids.
6. **Run.** The void now starts as stage 1 left it.

> If step 3 shows no `Flow*` meshes in the role list, you skipped the Clear in step 2.

10. Cave zones

A **cave zone** adds caving to the model. It is a closed mesh of **intact rock outside the void**: the crown, a hangingwall block, the ground over an undercut. Its cells stand like wall rock until the draw undermines them. Then they fail, progressively, into broken material.

Give the mesh the role **Cave zone (ore)** or **Cave zone (waste)** (§6.6). The role decides two things: whether the caved material counts as ore or waste, and which of the two cave face angles the zone uses.

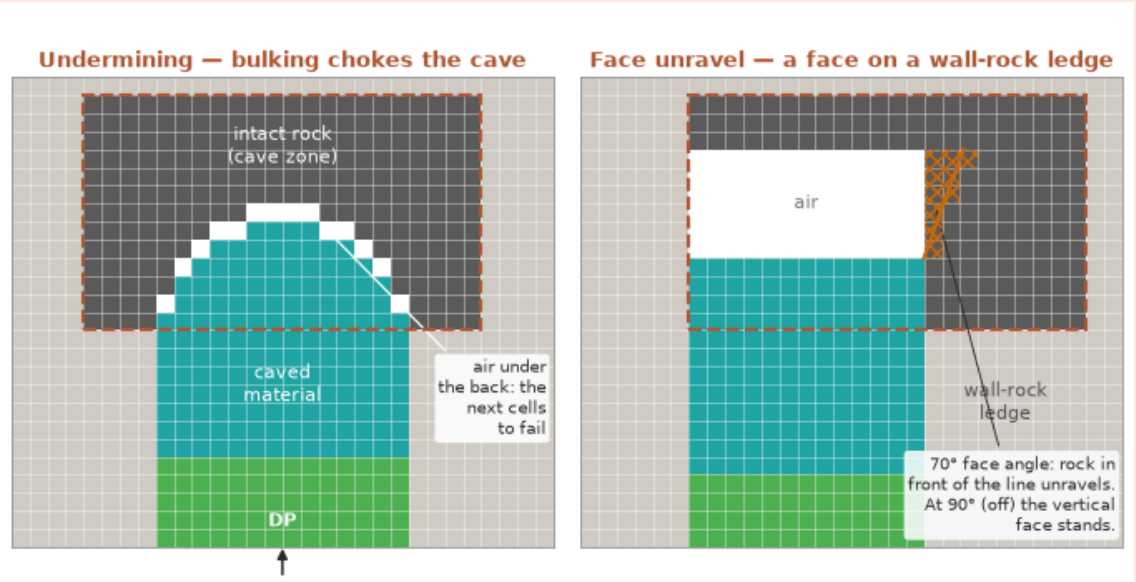


Figure 7 — How intact cave rock fails. Left: cells fail when air sits beneath them; the caved material bulks, fills the space and chokes the cave until the draw makes room. Right: a face resting on a wall-rock ledge is never undermined; the cave face angle unravels the rock in front of the angle line. Schematic vertical sections.

10.1 When intact rock fails

Two rules make a cave cell fail.

Undermining. A cell fails the moment **air sits directly beneath it** — cohesionless caving, with no stand-up strength, hydraulic-radius criterion or time dependence. The failed cell becomes the zone's broken material and falls, rills and draws like any other. As muck rills away from under the back, air works along its underside, so the cave grows sideways as well as up.

Face unravel. A cell whose column rests on something permanent — a wall-rock ledge, a solid step at the zone edge — can never be undermined. It would stand forever as a dark-grey pinnacle or overhang. The **cave face angle** closes that gap: a cell whose exposed face is **steeper than the angle** also fails.

- The test is the toppling rule with the face angle in place of the repose angle. The shed material bulks, piles against the face below and buries it, which steadies the face at the angle instead of consuming the zone.
- The default, **70°**, unravels sheer faces and overhangs but leaves benched profiles alone. **90° turns the rule off**: vertical faces stand.
- An active angle cannot be flatter than the repose angle — intact rock cannot stand flatter than its own muck.
- There is **one angle per role class**: ore zones use the ore angle, waste zones the waste angle. Set the weaker, ravelling mass flatter to let it cave more readily.

10.2 Bulking: why the cave is draw-controlled

A failed cell becomes *swell factor* broken cells (§3.4); a fractional remainder is carried forward, so the tonnes balance to within ±1 cell over a zone. That alone produces the behaviour the literature expects:

> **Bulking chokes the cave; draw drives it.** Each failed cell uses up a net `swell − 1` cells of open space. An undercut standing open under a zone collapses at once, but only until the air is used up — after about `open cells ÷ (swell − 1)` failures — and then chokes on its own muck. From then on the back advances only as the draw makes room: **cave advance ≈ draw ÷ (swell − 1)**. Stop drawing and the cave stops. Face unravel uses the same air, so it is draw-controlled too.

10.3 The zone boundary is the caveability limit

Caving stops at the mesh you drew. Rock outside every cave zone never fails, however much it is undermined. If the cave breaks through the top of its zone, the report says `zone fully caved`, and a stable cavity forms under the permanent rock above: the caveable volume you allowed has been used up.

Draw the zone as the volume you believe **can** cave. Its shape is your caveability judgement, not the model's.

10.4 Zone meshes, and several zones in one run

- Each zone must be a **closed** mesh. It may overlap the container: only its part in **solid rock** converts. A zone with nothing to convert — entirely inside the void, or entirely taken by a higher zone — stops the run with its name.
- A zone must touch the void, or ground the draw will expose; otherwise the report says `never undermined`.
- Zone cells count toward the 5 000 000-cell cap, and the grid box grows to cover them (§5.3).
- **Up to four zones per run in total** — ore and waste combined, not four of each. Four is a fixed limit of the model. To have more, pool neighbouring zones of the same role into one closed mesh; a zone need not be one connected body.
- **Zones are independent.** Each has its class angle, its own broken material (name, colour, report line, dilution column, ore/waste class) and its own bulking account, so one zone choking never holds up another. A 55° weathered hangingwall and an 80° competent block in one run is intended use.
- **All zones share one Swell factor.** With the two class angles, that is the model's whole strength vocabulary.
- **Where two zones overlap, the higher row wins**, as for fill regions.

10.5 What you see

- Each zone gets two materials: `Flow_<mesh>_Caved` (a region colour; ore or waste by role) and `Flow_<mesh>_Intact` (dark grey). Playback shows the grey body shrinking as the caved body grows — the cave back over time.
- The run report has two lines per zone (§11.2), Cells to Markers shows intact cells as MatID 251–254 (Chapter 13), and the dilution CSV has a `Flow_<mesh>_Caved_CumTonnes` column.

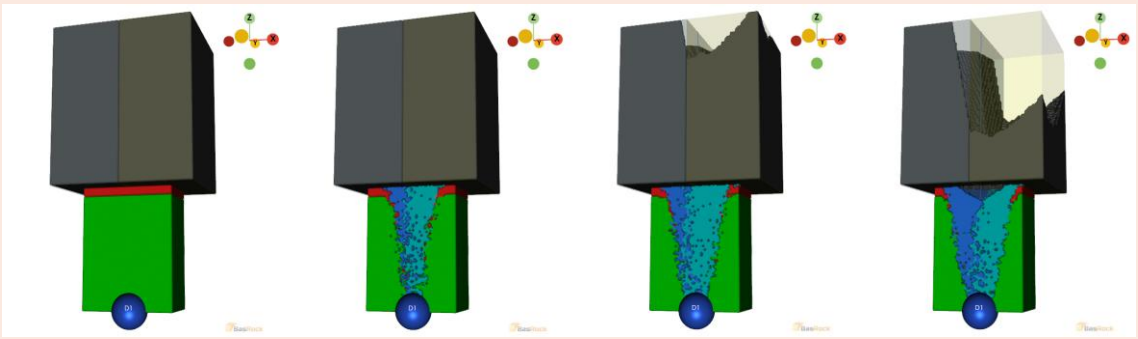


Figure 8 — A snapshot sequence of a stope with two different cave zone face angles on its crown — the grey intact body eaten upward as draw proceeds, the caved material building the muckpile, and the final choked state.

§16.6 explains how to steer the caving.

11. Running and the run report

11.1 During the run

Click **Run** in the dialog. The run works in the background: the rest of GEM4D stays usable, the loading spinner turns, and **Run flow model** is disabled until the run finishes.

The **Status area** on the ribbon shows:

- `Preparing grid…` while the grid is built and filled;
- `Run 34% — 1,234 / 3,600 cells` during the run — cells drawn plus cells tipped, against the run's total target;
- `Run complete — N rounds`, `Run cancelled` or `Run failed` at the end.

Cancel run stops the run. Nothing is inserted and no partial result is kept.

A run replaces the previous result only when it succeeds. After a failed or cancelled run, the earlier result still plays and exports while you fix the settings.

When the run completes, GEM4D asks you to **save the result meshes as a DXF**, as for any mesh it creates. The meshes then join the scene as ordinary meshes (Mesh list, filters, clipping, export). If you cancel the save, nothing is inserted, but the result stays in memory: Cells to Markers, Dilution CSV and Save flow still work.

11.2 The run report

The report appears when the run ends. Its lines, in order:

Line	Meaning
`Note: the container is not fully closed (N open, M non-manifold edges)`	Cells near the holes may be misclassified. A few are usually harmless on CAD meshes; many mean the container needs repair (§5.2).
`Note: region 'name' is not fully closed (N open, M non-manifold edges)` / `Note: cave zone 'name' is not fully closed (…)`	That mesh may fill or convert cells wrongly near its holes (§5.2).
`Note: region 'name' — N of its M cells (P %) fell outside the container void or were already claimed by an earlier region row`	Shown above about 5 %: the fill mesh is bigger than the void, so **its tonnage in the model is less than its volume suggests** (§6.6).

Line	Meaning
`Grid: nx x ny x nz cells at c m (N void cells)`	The grid, and the cells inside the container.
`Cleaned N stray void pockets (M cells)`	Absent on a closed container. If it appears, the container leaks: repair it (§5.2), and treat the results with suspicion.
`Fill: N ore + M waste cells`	The cells filled by the RL layers.
`Draw rate: <mode>`	The rate mode used (Chapter 9).
`Campaign: D days (1 round = d days)`	**Custom mode only** (§9.3).
`Region 'name' (Flow_name): N cells (M outside the void or already claimed)`	Cells filled by each region; the bracketed figure counts cells that did not fill (§6.6).
`Cave zone 'name' (Flow_name_Caved): N intact cells (M in the void or another zone, not converted)`	Intact cells in each zone. The bracketed figure is **not** a warning: a zone that overlaps the stope is normal use.
`Tip (E, N): snapped d m in plan to the nearest opening / the tipping point sits d m below (or above) the RL given`	The tip moved at setup (§8.1).
`Cave 'name': N of M intact cells caved (F by face unravel) = T t (+K bulking cells), R intact remaining`	Each zone after the run: cells failed, with their **in-situ** tonnage; how many by face unravel; the extra cells bulking made; and what still stands. `never undermined` and `zone fully caved` are explained in §10.3–10.4. A summary line names the face angle(s) used.
`DP1 (E, N) cell RL r: N cells = T t at R cells/round, waste w % — reason (air k)`	Each drawpoint: its extraction RL (`cell RL`), what it drew, its rate, its waste %, why it stopped, and how often it drew air.
`T1 (E, N) tip RL r: N cells = T t in at R cells/round, U t not tipped — ended choked: reason`	Each tip: the RL it tipped from, what went in and at what rate, what was left over, and whether it ended choked or how many rounds it was choked.
`Total drawn: N cells = T t (waste w %)`	All drawpoints together.
`WARNING: N settling cascade(s) hit the safety limit and were cut short`	Some surfaces were left partly settled (§18.3).
`Closed N diagonal-only contacts while building the material surfaces`	Cells touching only at an edge or corner would leave holes in a ragged surface, so one cell is added at each such contact. **Display only** — counts, tonnes and dilution come from the grid. Two bodies may overlap by one cell.
`A further N were left open because closing them would have put material outside the container mesh`	The same, declined where the only cell available was wall rock; those corners show a one-cell slit. Display only.
`Engine: R rounds, H void hops, S snapshots, E ms`	Run statistics.

Why a drawpoint stops

- `target reached` — it drew its tonnes.
- `only air at the drawpoint (cavity)` — 200 empty draws in a row. A stable cavity has formed above the drawpoint and nothing more can rill in.

A drawpoint with a bad East or North is refused before the run starts (§18.2).

Why a tip chokes

- `the pile reached the tipping point` — the normal reason (Chapter 8).

- `the tipping point is not inside the void` — the cell is wall rock. Check the T# marker and the tip's RL.

Waste percentages: `FlowWaste`, `FlowTipped`, Waste fill regions and Cave zone (waste) material count as waste; `FlowOre`, Ore fill regions and Cave zone (ore) material count as ore.

11.3 Checks after the run

- **Check each drawpoint's `cell RL`.** GEM4D finds the extraction cell by scanning the column **upward from the grid floor** to the first cell holding material. If that cell is not on the stope floor — a region fill floating above the floor while both RLs sit below it, or a pooled drive lower down in the same column — the drawpoint attaches there: part-way up the stope, or in the drive. Fills are not pre-settled, so this happens silently; `cell RL` tells you.
- **Check the tip notes.** "snapped 12 m in plan" or "sits 6 m below the RL given" means the picked cell was in rock. Make sure the T# marker now sits where material really enters.
- **The stray-pocket line should be absent** (§11.2).

Part 3 — Results

12. Result meshes and snapshot playback

A run inserts **one mesh per material**: `FlowOre` (green), `FlowWaste` (red), `FlowTipped` (orange), one `Flow_<meshname>` per region fill, and two meshes per cave zone (§10.5). **Hide the container mesh, or lower its opacity,** to see the material bodies inside; the report reminds you.

The **Snapshots** group plays the draw history through these same meshes.

- **Snap 0 is the state before any draw** — the void filled exactly as you defined it. Every run records it. Step to it first to check the fill, then forward to see what the draw did. `Snap 0/N` is the starting state and `Snap N/N` the final one; N is between the **Snapshots** value and twice it (§16.5).
- **Prev** and **Next** step one snapshot and wrap around at the ends.
- **Play steps** plays the snapshots in a loop and reads **Stop play** while running. Click it again, or **Prev**, **Next** or **Final**, to stop.
- **Speed** sets 0.25, 0.5, 1 or 2 seconds per step (default 1 s). It takes effect at once, also mid-play, and is remembered for the session.
- **Final** jumps to the last snapshot from wherever you are.
- **The meshes change in place**, so clipping, opacity and visibility settings stay through playback. A material fully drawn by the end keeps an empty mesh, so it still shows in earlier snapshots.

Stepping back changes only what the scene shows. Cells to Markers and the exports always use the final state.

13. Cells to Markers

Actions → Cells to Markers loads every material cell of the **final** grid into the Marker panel, through the standard CSV pipeline. It replaces the current Marker data. The columns are:

Column	Meaning
X, Y, Z	Cell centre, in mine coordinates.
MatID	The material: 1 = FlowOre, 2 = FlowWaste, 3 = FlowTipped, 4 and up = region fills, then caved materials, in dialog-row order; 251–254 = **intact** cave-zone rock (not yet failed, Chapter 10).

Column	Meaning
DropM	Vertical drop (m): how far below the level where its material first came to rest the cell now sits. 0 = never moved down. Caved cells measure from their **in-situ** position; intact cave cells read 0.
Moves	How many individual moves the material in this cell has made — the movement-zone picture.
Arrival	The round in which the material in this cell **last came to rest**. 0 = in place since the start (fill that never moved); tipped and caved material always reads 1 or more. Under Custom rates, multiply by the report's days per round to get a date — a calculated column does it in one step.

All the Marker tools apply: colour columns, legends (including Custom), filters, histogram, clipping and 3D shapes. Four useful views:

- **MatID** — mixing: where each material ended up. For one colour per material, right-click the **MatID** header and choose **Convert column to text**: every ID then gets its own colour and the scalar bar lists the IDs. A **Custom** legend with one band per ID also works.
- **DropM** — drawdown: the drawn cone shows as a chimney of high values.
- **Moves** — the **movement zone (IMZ)**. The width of the high-Moves zone above a drawpoint *is* the draw-zone width, the check for calibrating Lateral flow spread (§16.2).
- **Arrival** — sequencing: early arrivals are the settled base; late arrivals trace the last active flow paths and tip cones. Filter to one MatID to follow one material.

The export is limited to 3 000 000 material cells. Above that, run again with a larger cell size first.

14. The dilution CSV

Save and export → **Dilution CSV** writes the draw history of each drawpoint, recorded at every snapshot, as a tidy CSV file: one row per snapshot and drawpoint, plus a **Total** row per snapshot when there are several drawpoints.

Column	Meaning
Snapshot	The snapshot number. **The CSV counts snapshots from 1, while playback counts from 0**, so CSV Snapshot *n* is the scene's `Snap` *n* − 1. CSV Snapshot 1 is the state before the draw (Round 0), so every curve starts cleanly at zero tonnes.
Round	The round the snapshot was taken at — a common scheduling clock for all drawpoints (§9.6).
Day	Elapsed days at that round. Filled only when the run used **Custom** t/day rates; blank under Proportional, which has no calendar (§9.3).
Drawpoint	`DP1`, `DP2`, … in dialog-grid order, or `Total`.
East, North	The drawpoint position (blank on Total rows).
CumCells, CumTonnes	Cells and broken tonnes drawn by that drawpoint up to the snapshot.
IncrTonnes	Tonnes drawn since the previous snapshot.
CumWastePct, IncrWastePct	Waste percentage — overall to date, and within the increment. `IncrWastePct` is the sharper signal of dilution entry.
`<Material>_CumTonnes`	One column per material that reached any drawpoint: the broken tonnes of that material drawn to date.

In a spreadsheet, filter to one drawpoint and plot **CumTonnes against CumWastePct** — the classic dilution curve — or **CumTonnes against IncrWastePct** to read the point of dilution entry directly. All numbers use a dot decimal.

15. Saving, loading and clearing

15.1 Save flow

Save flow writes the whole solved state to one `.flow4d` file: the setup, the grid, the final state, every playback snapshot, and the draw tallies of each snapshot. Everything is stored in **mine coordinates**, so the file does not depend on the scene offset. Saving is blocked while a run is in progress.

When is saving worth it? The flow result is dropped whenever the scene is cleared or its last object is deleted, because the flow grid is tied to the scene's coordinate offset. The dialog settings survive for the session, but only a `.flow4d`, or a GEM4D project (`.gem4d`), which embeds one, keeps a *result* across scenes and sessions (Project Files manual, §7). Running again with the same seed also reproduces a result exactly; a `.flow4d` just skips the wait and fixes the inputs.

15.2 Load flow

Load flow restores a saved result. The result meshes are rebuilt and inserted (with the same DXF-save prompt as after a run), the snapshots play, the dilution CSV exports, and the saved setup becomes the dialog's remembered values.

- **It works on an empty scene.** The file carries its own coordinates and sets the scene offset if none exists yet. You can hand a `.flow4d` to a colleague as a complete, replayable result.
- **It restores the flow result only.** The container and geology meshes are not in the file; load them separately, before or after, if you want them in view.
- **A corrupt or truncated file is rejected before anything is touched.** The result in memory survives a failed load.
- **If a result is already loaded, Load asks before replacing it.**
- Files from builds before 1.9.1 still load; their **Arrival** column reads 0 (Chapter 13). Those builds cannot open a file saved by this one.

15.3 Clear

Actions → Clear resets the flow model to "nothing run yet". It removes:

- the grid, the result and the recorded snapshots, and resets playback;
- **the whole drawpoint and tip-point schedule** — the rows remembered from earlier runs, any staged picks, and their numbered markers.

It asks first, saying how many point rows will go, and works **during a run** (it stops the run first). To keep a schedule, save it with **Save draw and tip points** (§6.5) before you Clear.

Two things stay:

- **Your setup values** — cell size, materials, fill RLs and mesh roles.
- **The result meshes in the scene.** They are ordinary meshes; Clear only stops tracking them for playback. Delete them from the Mesh list if you want them gone.

When the scene is emptied (**Scene › Reset all**), GEM4D drops the result, the snapshots, the staged picks and the markers, as Clear does, but it keeps the remembered drawpoint and tip rows with the rest of the setup: they are back in the dialog at the next **Run flow model**. Click **Clear** to empty them.

Part 4 — Choosing parameters

16. Parameter guidance

16.1 Cell size and run time

The cell count grows with the cube of the refinement: halving the cell size gives 8 times the cells. A rough guide for a 50 × 50 × 100 m stope (cap: 5 000 000 cells inside the container, §5.3):

Cell size	Cells (approx.)	Feel
2.0 m	~31 000	Instant; coarse cones
1.0 m	~250 000	Seconds — the everyday setting
0.5 m	~2 000 000	Tens of seconds; smooth surfaces
0.35 m	~5 800 000	**Over the cap** — the message suggests a workable size

The dialog default (about 1/60 of the largest extent) is a good start. Refine only when the coarse answer is interesting, and never below the mean fragment size (§3.1).

Run time also grows with the tonnes drawn and the height of the void, because each drawn cell sends a void up the column. A tall void drawn heavily at fine cells is the slowest case.

16.2 Lateral flow spread — the calibration knob

This is the model's calibration knob for the draw zone (for caving, see the swell factor, §16.6). It sets how readily the climbing void steps sideways, and so the **width of the isolated movement zone (IMZ)** above a drawpoint.

Value	Draw behaviour
0.05–0.15	Narrow, chimney-like draw — fine, free-running material; piping
0.30 (default)	A mid-range ellipsoid — a reasonable uncalibrated start
0.6–1.0	Wide, strongly interacting draw zones — coarse, frictional caved rock (the literature links coarser fragmentation with wider movement zones)

To calibrate:

1. Run a **single central drawpoint** in a representative geometry.
2. Click **Cells to Markers** and colour by **Moves**.
3. Measure the width of the moved zone at a known height.
4. Adjust Lateral flow spread until that width matches what you expect at your operation — from draw-control markers, past dilution behaviour, or FlowSim/REBOP-style rules of thumb for IMZ width.
5. Keep that value for the real runs.

16.3 Repose angle

40° suits typical blasted ore and waste. The grid reproduces the angle well between about 20° and 60°. Values outside that band saturate: asking for 10° gives roughly 20°, and asking for 80° roughly 65°. The angle governs both tipped rill cones and how drawn surfaces flatten back during the draw.

16.4 Seed, and using the randomness

One run is one realisation of a random process. For screening decisions a single run is usually enough, since the model reproduces the average behaviour. Where a number matters — the tonnage at dilution entry, say — run 3 to 5 different seeds and look at the spread of the dilution curves. The same seed reproduces the same result, so a saved seed is a reproducible scenario.

16.5 Snapshots

The **Snapshots** value is the number of **intermediate** states to record. Snap 0 and the final state are always kept on top, so 0 still gives a before-and-after pair. 20 gives smooth playback and a well-resolved dilution curve.

Snapshots cost little run time; their cost is memory and file size, because each stores a compressed copy of the grid. Expect a bigger `.flow4d` for very large grids with many snapshots.

Recording paces itself: it records densely, then thins out as the run grows. The count you ask for therefore arrives evenly spaced whatever the run length, and a run that stops early — a drawpoint exhausts the material, a tip chokes — still delivers about as many. You may get up to twice the number requested. Snap 0 is never thinned; it is the reference, not a sample.

16.6 Cave zones — reading and steering the caving

Everything follows from one relationship: **cave advance ≈ draw ÷ (swell − 1)** (§10.2).

- **The swell factor is the main caving knob.** Every tonne drawn lets in about swell ÷ (swell − 1) tonnes of caved rock (in-situ tonnes, as the report's `Cave` line gives them): at 1.4, about **3 500 t** for every 1 000 t drawn; at 1.2, about **6 000 t**. By volume, that is 1 ÷ (swell − 1) m³ of intact rock for every m³ of broken muck drawn: 2.5 m³ at 1.4, 5 m³ at 1.2. If the caving looks too eager or too reluctant against your experience, calibrate the swell factor. It also changes the tonnes per cell, so adjust the tonnages to match.
- **The cave face angles are the second knob.** They decide how much intact rock *beside* the draw takes part. Steepen an angle if intact walls really do stand in your experience; flatten it towards the repose angle for weak, ravelling rock — a weathered hangingwall (waste) at 55° over a competent ore contact at 80°, say.
- **An open void under a zone collapses at once**, then chokes. If your back really stands open for a while first, the model cannot show that; it gives the picture *after the cave starts*.
- **Watch for `zone fully caved`.** After breakthrough the caved supply is finite and dilution changes character. If breakthrough is unrealistic, the zone mesh was too small (§10.3).

As everywhere else, run a few seeds where a caved-dilution number matters (§16.4).

17. Assumptions and limitations

1. **Indicative, kinematic model.** No forces, no stresses, no time. Use it for *where material goes and mixes*, not for rates, loads or support design.
2. **No arching, hang-ups or cohesion.** Flow never jams. Real coarse or cohesive material can hang where the model keeps flowing.
3. **Walls are rigid unless they have a Cave zone role**, and slough from ordinary walls is not modelled. Cave zones fail cohesionlessly: no stand-up strength, no hydraulic-radius criterion, no time dependence, so an undercut of any size propagates until bulking chokes it. The two class face angles are the only strength differentiation — no anisotropy, no per-mesh value and no variation inside a zone. Caving stops at the zone mesh (Chapter 10).
4. **No bulking change in the flowing pile.** A cave cell bulks once, when it fails; porosity does not change while material flows.

5. **Resolution.** Keep cells at or above the mean fragment size. Results within 1–2 cells of walls and drawpoints are dominated by the grid.
6. **One realisation.** One run is one sample; vary the seed where a number matters (§16.4).
7. **Drawpoints are cells, not equipment.** A drawpoint extracts from one column. It does not model brow wear, ore-pass geometry or loader reach.
8. **Repose fidelity is about 20–60°.** Lateral spread is a *calibration* knob, not a material property you can look up.
9. **Rates and dates, but no sequencing.** Each row can run at its own rate, and Custom mode converts rounds to days — but that is bookkeeping over your schedule; nothing in the flow depends on how fast it happens. A rate cannot change part-way through a run, there is no start date or downtime, and **runs cannot be chained** (§9.7).
10. **Extraction cells are fixed at the start.** A drawpoint attaches to the lowest material cell in its column at setup and stays there, even if the material beneath it changes during the run (§11.3).
11. **A tip is a single cell.** The tipping point has no width. A real brow is metres across and keeps taking material a little longer than one cell does, so the tonnage a tip delivers before choking is a conservative estimate at coarse cell sizes. The model also never tips material anywhere but at the point you set: no rilling onward down a drive, no filling a second opening. Model those as extra tip points (Chapter 8).

Part 5 — Reference

18. Troubleshooting

Find the stage where the problem appears, then the message or symptom.

18.1 Before the run starts

Message or symptom	Cause and fix
"No visible meshes — load or unhide the closed stope/void mesh first."	The model only sees visible meshes. Unhide the container.
"This function does not work in clipping mode"	Leave clipping mode first. Applies to **Run flow model** and **Load flow**.
"A flow model run is still in progress."	One run at a time. Wait, or click **Cancel run**.
"The waste (fill) top RL must be at or above the ore top RL."	The two RLs are the wrong way round. Set them equal for an ore-only fill (§6.1).
"Add at least one drawpoint or one tip point."	The run needs somewhere for material to leave or enter (§6.4).
"Drawpoint row N: …" / "Tip point row N: …"	The row named has a non-number in East, North or Tonnes, tonnes of 0 or less, a typed RL that is not a number, or (Custom) no Rate. Correct that row (§6.3, §6.4).
"Assign at least one visible mesh as the Container…"	No mesh has the Container role, and it defines the void (§6.6).
"Up to 4 cave-zone meshes are supported…"	4 zones per run **in total**, ore and waste combined. Pool zones of the same role into one mesh, or give the extras another role (§10.4).
"Too many region-fill meshes — the flow model supports up to 200 fill regions."	Pool some fill meshes, or set the extras to **Ignore**.
"The ORE / WASTE cave face angle cannot be flatter than the repose angle…"	Intact rock cannot stand flatter than its own broken muck. Raise that class's face angle, or set it to 90 to turn face unravel off (§10.1).

18.2 The run stops with a message

Message	Cause and fix
"The container holds … cells at … m, above the 5,000,000-cell cap. Use a cell size of about X m or larger."	The cell size is too fine for the container's volume. Take the suggested size; it comes from the stope's true volume, so it is a tight bound (§5.3).
"Void plus cave-zone cells (N + M) exceed the 5,000,000-cell cap…"	The container fits on its own, but the cave zones push the total over. Use a larger cell size or smaller zones.
"The grid box needs … cells, above the 100,000,000-cell box guard…"	The grid box spans every Container and Cave zone mesh together; far-apart containers, or a very long thin shape, make a mostly empty box. Take the suggested size, or run distant containers separately.
"No cell centres fall inside the container mesh — is it a closed solid at this cell size?"	The container is not closed, or the cells are too coarse for a thin void. Repair the mesh or reduce the cell size.
"Only isolated stray cells were classified inside…"	The "inside" answer was all noise; the container is effectively open. Repair it.
"Region mesh 'X' fills no cells inside the container void…"	The region lies outside the container, was fully taken by earlier rows, or is not closed.
"Region mesh 'X': no cell centres fall inside it — is it a closed solid at this cell size?"	The region itself became no cells: it is open, or thinner than one cell.
"Cave-zone mesh 'X': no cell centres fall inside it — is it a closed solid at this cell size?"	The zone itself became no cells: it is open, or thinner than one cell.
"Cave-zone mesh 'X' converts no wall-rock cells…"	The zone lies entirely inside the void (nothing solid to convert), or was fully taken by a **zone higher in the list**. Cave zones are intact rock **outside** the void (Chapter 10).
"The RL layers and region meshes put no material inside the void and no tip points were set…"	The ore and waste top RLs are below the container floor, and nothing else adds material. Check the RLs against the mesh (§6.1).
"Drawpoint (E, N): A drawpoint E/N falls outside the flow grid."	The position is outside the model altogether — usually a typo, East and North swapped, or a coordinate from another stope. Check the row against the container's extents.
"Drawpoint (E, N): A drawpoint column holds no material…"	The East/North is outside the void in plan, the fill sits at unexpected RLs, or the void is empty there at the start (a tip-only fill): drawpoints cannot wait for tipped material.
"Tip point (E, N): no open air within R m; the nearest opening is D m away…"	A **large D**: the pick almost certainly landed on another mesh — check the T# marker and pick again (§7.1). A **small D**: increase the tip search radius (§8.1).

18.3 Notes and warnings in the run report

The notes in the run report are explained in §11.2; the one warning is:

Message	Cause and fix
"WARNING: N settling cascade(s) hit the safety limit and were cut short"	A single extraction or tip is allowed at most 200 000 settling and toppling moves. Beyond that the cascade is abandoned and that surface is left partly settled, so it can show steep steps. Rare, and only on large grids with big free surfaces. Use a coarser cell size. The run is still usable: treat the affected surfaces as indicative rather than at repose.

18.4 The results look wrong

Symptom	Cause and fix
A new stope filled to the roof, or not at all	The fill RLs are remembered from the previous stope. Re-check both whenever the container changes (§6.1).
I assigned fill meshes, but `FlowOre` / `FlowWaste` appeared as well	The RL layers always run. Set **both** RLs below the void floor for a region-only fill (§6.1).
A fill region shows fewer tonnes than its mesh volume	Its part outside the container is skipped; its report line counts the cells lost (§6.6).
A drawpoint drew from higher up the stope than intended, or from a drive below it	The first material in its column is not on the stope floor. Check its `cell RL` (§11.3).
A small drawpoint seems to have had no effect on a large one, or **dilution reached the big drawpoint late**	The rows did not finish together, so the big one drew alone for most of the run. Check the rates in the report; *Proportional to tonnes* makes them finish together (§9.2).
A drawpoint stopped with `only air at the drawpoint (cavity)`	A stable cavity formed above it — the answer for this geometry. A lower repose angle or wider Lateral flow spread changes it.
A tip placed far less tonnage than I entered	It **choked** — the physical answer, not a fault. Add tip points, raise the tip's RL, or draw more from below (Chapter 8).
A tip's material all sits in one heap under its marker	That is what a tipping point does. To place material elsewhere, add another tip point (Chapter 8).
A tip does not keep up with the draw, whatever tonnage I enter	Tonnage sets when a tip stops, not how fast it fills. Give it a higher Rate in Custom mode, or add tip rows — unless the `T#` line reports many choked rounds, in which case the tipping point is the limit (§9.4).
A cave zone never caved	Its report line says `never undermined`: it must touch the void, or the draw must expose it. Check the zone sits on the container's back (§10.4).
Intact rock stands as pinnacles or ledges over the muck	The cells rest on wall rock or a solid step, and the face angle for that class is 90 (off). Set it, for the right class, to unravel steeper faces (§10.1).
Two cave zones behave differently	Check their roles: ore zones use the ore angle, waste zones the waste angle. Otherwise it is geometry — each zone caves only where *it* is undermined or over-steep, and the higher row owns any overlap (§10.4).
The whole cave zone collapsed between Snap 0 and Snap 1	The void under it stood open, so it failed at once, then choked; from there it advances only as the draw makes room (§10.2).
Floating cubes or specks in the result	The container leaks (§5.2).
The results are identical after changing something	Same seed and same inputs give the same result. Check the changed value was actually accepted.

18.5 Playback and files

Message or symptom	Cause and fix
"Run the flow model first — there is nothing to play back."	Nothing has been solved or loaded in this scene yet.
"The last run has only one state to show — nothing was drawn or tipped."	Every run records a before and an after state, so a single state means the run did no work. Check the drawpoint stop reasons and the tip choke reasons in the report.
"The flow result meshes are no longer in the scene — run the flow model again."	The result meshes were deleted or replaced, and playback needs them. Run again, or reload the `.flow4d`.
The Day column in the dilution CSV is empty	The run used Proportional mode, which fixes rate ratios only and has no calendar. Switch to Custom and enter t/day per row (§9.3).

19. Macros — recording and replaying flow runs

The **Macros** ribbon tab records and replays the flow module. With recording on, these actions become macro steps:

You do	Recorded step	On replay
Run flow model (dialog accepted, checks passed)	**RunFlow**, with the **whole accepted setup** — cell size, RLs, materials, rates, every drawpoint and tip row, and the mesh roles **by name**	Runs without the dialog: the roles are matched by name to the visible meshes, then the normal run pipeline follows
Save flow (completed)	**SaveFlow**, with the file path	Saves the solved state to that path
Load flow (completed)	**LoadFlow**, with the file path	Loads it, replacing any current result without asking
Dilution CSV (completed)	**ExportFlowDilution**, with the file path	Writes the CSV to that path
Cells to Markers (completed)	**FlowCellsToMarkers**	Reloads the Marker panel from the solved grid

- **Mesh roles replay by name.** At replay, the names stored in the macro are matched to the visible meshes; duplicate names map to successive rows, as in the dialog. A mesh the macro names that is **not visible stops the step with its name** — unless its recorded role was Ignore. Visible meshes the macro does **not** name are set to Ignore, so a bystander is never pooled into the container.
- **The DXF save prompt still appears** when a replayed run or LoadFlow inserts result meshes: the file destination is the one thing a macro cannot know. The run report box is not shown during replay; the macro progress dialog shows the run's progress.
- **Every number in the setup can be a parameter.** Open the saved macro JSON: the RunFlow step holds the setup as plain nested JSON. Replace a value with `"${name}"`, quotes included — for example `"seed": "${seed}"` or `"cell_size": "${cell}"` — and declare the parameter. Loading the macro then asks for it, so one recorded run becomes a template for seed sweeps or cell-size trials.
- The pre-flight check validates file paths up front. Scene state — is a flow result loaded, are the named meshes visible — is checked when each step runs, so order the steps as you would order the clicks.

20. Glossary

Term	Meaning
Air	An empty cell inside the void.
Arrival	The round in which a cell's material last came to rest (Chapter 13).
Cave face angle	How steep an intact cave face can stand before it unravels; one angle for ore zones, one for waste zones; 90 = off (§10.1).
Cave zone	A closed mesh of intact rock outside the void that fails when undermined or over-steep (Chapter 10).
Caved material	Broken rock from a failed cave zone, `Flow_<mesh>_Caved`.
Cell	One cube of the model grid. Each holds air, wall rock, a material or intact cave rock (§3.1).
Choke	A tip is choked when the pile buries its tipping point; a cave chokes when bulking has used up the air beneath it.
Container	The mesh role that defines the void. All Container meshes pool into one void (§6.6).
Draw zone, IMZ	The isolated movement zone: the body of material above a drawpoint that moves as it draws (§16.2).
Drawpoint	Where material leaves the model: an East/North column, drawn from its lowest material cell (§6.4).
DropM	How far a cell's material has descended, in metres (Chapter 13).
Face unravel	Failure of an intact cave cell whose exposed face is steeper than the cave face angle (§10.1).
Fill region	A closed mesh with the Ore fill or Waste fill role, filled with its own material (§6.6).
Intact cave rock	Cave-zone rock that has not failed yet; shown dark grey, MatID 251–254.
Lateral flow spread	How readily the climbing void steps sideways; sets the draw-zone width (§16.2).
MatID	The material number of a cell in Cells to Markers (Chapter 13).
Moves	How many moves the material in a cell has made (Chapter 13).
Repose angle	The slope that free surfaces of broken material settle to (§16.3).
Rill cone	The cone of tipped material that builds below a tipping point at the repose angle.
Round	One step of the model, in which every active row draws or tips its rate (§3.3). Not a unit of time.
Seed	The number that starts the random generator; the same seed gives the same result (§16.4).
Snapshot, Snap 0	A recorded state of the model for playback; Snap 0 is the state before any draw (Chapter 12).
Swell factor	Bulking on breakage: broken density = density ÷ swell (§3.4).
Tip point, tipping point	Where material enters the model: one cell at an East, North and RL (Chapter 8).
Void	The space inside the container meshes, where material can move.
Wall rock	Immovable cells outside the void.

21. References

The lineage this implementation follows:

- Castro et al. — *FlowSim* experiments and simulation, Caving 2018 (papers.acg.uwa.edu.au/p/1815_21_Castro/); FlowSim tool description, MassMin 2016.
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- Mullins, W.W. (1972). Stochastic theory of particle flow under gravity. *Journal of Applied Physics* 43, 665–678. With Litwiniszyn's stochastic-medium model, the mathematical ancestry of void diffusion.