Pablo's Dive Planner – Technical User Specification

OC and CCR decompression planner with bailout scenarios, gas analysis, and sensor modelling.

This document is structured in the same order as the planner UI: Dive Profile, Gases, Settings, CCR, and Outputs. It explains what is being calculated, which models are used, and how settings such as gradient factors, workload, gas share, CCR setpoints, and lost-gas scenarios affect the results.

Core Decompression Model

Bühlmann model and compartments

The planner uses a Bühlmann ZH-L16 style model with 16 tissue compartments. Each compartment tracks dissolved nitrogen and helium separately. At the surface, tissues are initialised to air: approximately 79% nitrogen and 21% oxygen at surface pressure.

For each time step, the planner updates tissue inert gas pressures based on the current depth, ambient pressure, and breathing gas. Nitrogen and helium are tracked independently, then combined into an effective “tissue pressure” for comparison against the Bühlmann M-values.

Gradient Factors, GF99, and SurfGF

The planner uses two gradient factors:

- **GF Low (GF_L):** controls deep conservatism and the depth of the first stop.
- **GF High (GF_H):** controls shallow conservatism and surfacing limits.

At each stop depth, an effective gradient factor between GF_L and GF_H is used. Deep stops use values closer to GF_L, while shallow stops approach GF_H.

Two key indicators are displayed:

- **GF99:** instantaneous gradient factor at the current depth, based on the most loaded compartment.
- **SurfGF:** gradient factor that would apply if you ascended directly to the surface at that moment.

These values are derived from the standard Bühlmann relationship between tissue pressure, ambient pressure, and the M-value for each compartment.

INTERPRETATION

> **GF99 max** in the summary is the highest GF99 reached during the ascent. **SurfGF** in the summary is the final SurfGF at the surface. Both are useful for comparing how "hard" different profiles load your tissues.

1. Dive Profile

1.1 Depth and time inputs

The Dive Profile section defines the nominal dive shape:

- **Planned depth:** maximum depth of the dive.
- **Bottom time:** planned time at maximum depth (plus any extra bottom segment).
- **Descent:** modelled using the configured descent rate from surface to bottom.
- **Ascent:** modelled using deep, mid, and shallow ascent rates between stops and to the surface.

1.2 Ascent and descent rates

The planner uses separate user-configurable rates:

- **Descent rate:** used from surface to bottom.
- **Deep ascent rate:** used from bottom towards mid-water (typically >30 m).
- **Mid ascent rate:** used between mid-depth and shallow (typically 6–30 m).
- **Shallow ascent rate:** used from shallow stops to the surface (≤6 m).

These rates are used to compute:

- **Descent time** to bottom.
- **Ascent time to first stop.**
- **Travel times** between stops and from the last stop to the surface.

> SUMMARY FIELDS
>
> The summary panel breaks the profile into:
>
> - **Bottom time:** planned time at depth (plus any extra bottom segment).
> - **Ascent to first stop:** physics-based time from bottom to first stop.
> - **Total deco time:** sum of all stop times.
> - **Final ascent:** time from the last stop to the surface.

2. Gases

2.1 Gas definitions

The planner supports:

- **Back gas:** a bottom mix with user-defined O_2 and He.
- **Deco gas 1:** typically a mid-range nitrox (e.g. 50%).

- **Deco gas 2:** typically a high-O_2 nitrox (e.g. 80%).

Each gas has:

- **O_2 % and He %** (N_2 is implied as the remainder).
- **Cylinder size (L)** and **fill pressure (bar)**.
- **Type:** "bottom" or "deco", which affects SAC usage and gas ordering.

2.2 Surface air consumption (SAC)

Two SAC rates are used:

- **Back Gas SAC:** used for bottom segments on open circuit.
- **Deco Gas SAC:** used for decompression segments on open circuit.

Gas usage for a segment is calculated as:

Gas used (L) = SAC (L/min at surface) × ambient pressure (bar) × time (min) × workload factor

For team gas calculations, additional stress multipliers and number of divers are applied (see the Gas Share section).

2.3 Gas density, EAD, and MOD

Gas density

For open-circuit gases, density is estimated using a weighted sum of component densities:

Density at depth (g/L) ≈ ambient pressure (bar) × (FO_2 × 1.43 + FHe × 0.18 + FN_2 × 1.25)

The planner highlights:

- Warning when density exceeds a moderate threshold.
- Critical when density exceeds a higher threshold.

Equivalent air depth (EAD)

For open-circuit gases, EAD is calculated from the nitrogen fraction:

EAD (m) = ((FN_2 × (depth + 10)) / 0.79) − 10

For CCR, EAD is based on the diluent nitrogen fraction at the current depth.

Maximum operating depth (MOD)

The planner displays MOD for each nitrox mix using:

MOD (m) = ((ppO_2 limit / FO_2) − surface pressure) × 10

Typical limits:

- 1.4 bar for bottom gas.
- 1.6 bar for deco gases.

3. Settings and scenarios

3.1 Gradient factors and decompression behaviour

The **GF Low** and **GF High** settings control how aggressively the Bühlmann model is applied:

- GF_L influences deep stops and the depth of the first stop.
- GF_H influences shallow stops and surfacing limits.

At each stop, an interpolated GF between GF_L and GF_H is used based on depth. GF99 and SurfGF are derived from these same relationships and are shown in the main table and summary.

3.2 Workload level

The **Workload Level** control has two styles:

- **Manual:** you choose "rest", "normal", or "hard".
- **AUTO:** the planner chooses a factor based on depth and whether you are on bottom or deco.

This factor is applied to:

- Metabolic oxygen consumption in CCR mode.
- CNS and OTU increments.
- Open-circuit gas usage when modelling workload-dependent SAC.

Workload mapping (AUTO)

Phase	Depth range	Workload factor	Interpretation
Deep working	> 35 m	1.30	High workload at depth
Moderate work	20–35 m	1.10	Moderate effort
Light work	≤ 20 m (bottom)	1.00	Normal swimming
Mid-water deco	15–20 m	1.00	Controlled deco
Shallow deco	6–15 m	0.90	Reduced workload
Final stops	≤ 6 m	0.80	Resting at final stop

This factor multiplies metabolic oxygen usage and CNS/OTU increments, and in open-circuit mode it also scales SAC-based gas consumption.

3.3 Gas Share (Team)

The **Gas Share (Team)** option models a situation where you are responsible for supplying gas to another diver in an emergency. When enabled:

- The planner assumes **two divers** (you plus one teammate).
- It applies **stress multipliers** to SAC during emergency phases.

- It adds a **problem-solving period** at depth for bottom gas.

Internally, the following constants are used:

- **STRESS_B:** stress factor for bottom gas (e.g. 1.5).
- **STRESS_D:** stress factor for deco gas (e.g. 1.2).
- **SOLVE TIME:** additional minutes at depth to resolve the problem (e.g. 2 min).
- **DIVERS:** number of divers sharing gas (typically 2).

For bottom gas in a gas-share scenario:

- Solo gas is still based on your own SAC and workload.
- Team gas multiplies SAC by STRESS_B and by the number of divers, and includes the solve time.

Gas Share affects:

- **Team gas requirement:** higher volumes needed for emergencies.
- **Gas cards:** they show both solo and team requirements, and flag insufficiency if team demand exceeds carried capacity.
- **Bailout scenarios:** scenarios are evaluated against team gas requirements when Gas Share is on.

Cylinder counts are still sized from **solo** requirements, but the planner checks whether those cylinders are sufficient for the **team** requirement. If not, the gas is marked as **INSUFFICIENT** in the cards and bailout matrix.

> READING THE GAS CARDS
>
> When Gas Share is enabled, the gas cards show:
>
> - **Req:** solo or team requirement (depending on context).
> - **Res:** reserve volume after meeting the solo requirement.
> - **[INSUFFICIENT]:** team requirement exceeds carried gas, even if solo is fine.

3.4 Lost deco gas – gases vs scenarios

Lost deco from gases (checkboxes)

In the main planner UI, there are checkboxes to mark individual deco gases as "lost":

- **Lost Deco 1:** removes the first deco gas from the nominal plan.
- **Lost Deco 2:** removes the second deco gas from the nominal plan.

When you tick these:

- The **nominal profile** is recalculated as if that gas is not available at all.
- Gas usage, TTS, and stops are all based on the remaining gases.
- This affects the main table, graph, and gas summary directly.

In other words, the gas checkboxes change the baseline plan itself.

Lost deco from scenarios (bailout matrix)

The **Scenarios** section provides a separate system for simulating “what if” cases without changing the nominal plan:

- Scenarios such as “Lost Deco 1”, “Lost Deco 2”, “Lost All Deco Gases”, “Bottom Gas Bailout”, etc.
- Each scenario is run as a separate full simulation derived from the same nominal configuration.
- The results are shown in the **Bailout Matrix** and **Bailout Gas Cards**.

Key differences from the gas checkboxes:

- The **nominal profile** remains unchanged and is still shown in the main table and graph.
- Scenarios are additional profiles used for comparison and risk assessment.
- Each scenario can have its own gas-loss pattern, even if the nominal plan still has all gases available.

> IN PRACTICE
>
> **Lost Deco from Gases:** “Plan the dive as if this gas does not exist at all.”
> **Lost Deco from Scenarios:** “Show me what happens if I lose this gas mid-dive, while keeping my nominal plan unchanged.”

3.5 Scenario engine and critical case

When you choose “All” or “Custom” scenarios, the planner:

- Runs the nominal profile once (using the current gas checkboxes).
- Runs additional full simulations for each selected scenario (e.g. lostD1, lostD2, lostAll, bailout_bottom).
- Collects TTS, max GF99, total gas volume, and gas sufficiency for each scenario.

The planner identifies a **critical scenario** as follows:

1. First, it looks for scenarios where any gas is insufficient (team requirement > carried gas).
2. Among those, the scenario with the **longest TTS** is chosen as critical.
3. If all scenarios have sufficient gas, the one with the **longest TTS** is chosen.

The critical scenario is highlighted at the top of the bailout matrix, with a detailed tooltip explaining:

- Why it is critical (gas insufficiency vs longest profile).
- TTS, max GF99, and total gas required.
- Which gases are insufficient, if any.

> KEY POINT

> Criticality is driven primarily by **gas survival** (can you finish the profile with the gas you carry?), not by GF99 alone. GF99 is reported, but gas insufficiency takes priority when ranking risk.

4. CCR mode, bailout, and sensors

4.1 CCR loop volume and diluent

In CCR mode, the planner models a fixed loop volume (4 L) and a diluent gas defined in Gases section by:

- **Bottom O_2 and He %** (N_2 is implied)

The loop is initialised with this diluent. During the dive, the loop composition changes due to:

- Metabolic oxygen consumption.
- Oxygen injection to maintain setpoint.
- Loop compression/expansion with depth (diluent usage on descent).

The planner tracks:

- **CCR O_2 usage:** metabolic oxygen consumption in litres.
- **CCR diluent usage:** gas used to maintain loop volume during depth changes.

4.2 Bailout inputs

The CCR engine includes a dedicated set of bailout-related inputs that determine how the system behaves when a bailout is triggered by sensors, controller logic, or loop safety limits. These inputs define the gases, configuration, and behaviour used once the diver leaves the loop.

- **Bailout O_2 % and He %:** Defines the open-circuit bailout mix used immediately after a bailout event. Nitrogen is implied as the remainder. This gas becomes the active mix for all post-bailout ascent and decompression calculations.
- **Bailout gas type:** Treated as an *open-circuit* gas regardless of CCR mode. SAC, workload, and gas-share rules switch to OC behaviour instantly.
- **Bailout setpoint:** Once bailout occurs, the CCR setpoint is ignored and ppO_2 is computed from $FO_2 \times$ ambient pressure. All CCR-specific CNS/OTU scaling is replaced with open-circuit rules.
- **Gas availability:** Bailout gas is assumed to be fully available unless a scenario explicitly removes it (e.g. “Lost All Deco Gases”, “Bottom Gas Bailout”). Scenario-driven bailout uses the scenario’s gas-loss pattern.
- **Transition point:** The bailout gas becomes active at the exact depth and runtime where the bailout trigger occurs. A “BAILOUT” row is inserted into the profile for clarity.
- **Ascent behaviour:** After bailout, ascent rates, stop depths, and GF logic remain unchanged, but all gas usage and CNS/OTU calculations follow open-circuit rules.

> NOTE
>
> Bailout inputs do not affect the nominal CCR plan. They only define behaviour **after** a bailout trigger or within bailout scenarios.

4.3 CCR setpoints

CCR operation is driven by:

- **Initial setpoint:** the starting ppO_2 at the bottom.
- **Setpoint table:** user-defined depth/setpoint pairs (e.g. 40 m → 1.3, 21 m → 1.4).

The planner:

- Sorts setpoint switches from deepest to shallowest.
- Detects when the ascent crosses a switch depth and updates the current setpoint.
- Logs a "Setpoint switch" row at the switch depth for clarity.

Safety checks ensure:

- Setpoint depth does not exceed planned depth.
- Setpoint does not exceed ambient pressure (ppO_2 cannot be higher than ambient).
- Setpoint does not exceed recommended limits (e.g. >1.6 bar).

4.4 CCR metabolic workload

CCR oxygen usage and CNS/OTU are scaled by the same **workload factor** described in the Settings section. In AUTO mode, deeper working phases use higher factors, while shallow deco and final stops use lower factors.

4.5 CCR loop safety checks

The planner continuously validates the CCR loop:

- Checks that O_2, He, and N_2 fractions remain finite and sum close to 1.0.
- Warns if loop ppO_2 is dangerously low (e.g. < 0.16 bar) or too high (e.g. > 1.6 bar).
- Warns if the setpoint is impossible at the current depth (setpoint > ambient pressure).
- Warns if the diluent is hypoxic at the current depth.

Any issues are reported as CCR warnings in the status area and in the CCR summary cards.

4.6 CCR technical specification

This section describes the internal computational behaviour of the CCR engine, including sensor modelling, controller thresholds, bailout triggers, and loop validation rules. These details reflect the actual logic used by the planner.

Loop model

- **Loop volume:** fixed at 4.0 L.
- **Initial composition:** equal to the selected diluent.

- **Metabolic O_2 use:** removed from loop each step, scaled by workload.
- **O_2 injection:** added when median ppO_2 falls below setpoint.
- **Compression/expansion:** diluent added/vented based on ambient pressure change.
- **Normalisation:** gas fractions renormalised to sum to 1.0.

Setpoint logic (internal)

- **Initial setpoint:** applied at bottom depth.
- **Setpoint switches:** sorted deepest → shallowest; triggered when ascent crosses depth.
- **Safety limits:** hard limit 1.6 bar; warning at 1.4 bar.
- **Impossible setpoint:** setpoint > ambient pressure is flagged.

Sensor model

Each of the three sensors starts from the true loop ppO_2, then applies noise and failure mode logic.

- **Noise:** Gaussian ±0.02 bar.
- **Stuck high/low:** ±0.2 bar offset.
- **Drifting:** ±0.005 bar per metre.
- **Oscillating:** ±0.1 bar sinusoidal variation.
- **Fail high/low:** fixed at 1.6 bar or 0.05 bar.

Voting logic

The three sensor readings are sorted and the median is taken as the voted ppO_2.

A sensor is marked **bad** if:

$|\text{reading} - \text{median}| > 0.10$ bar

Sensor-layer bailout: triggered if two or more sensors are bad.

Controller logic

The controller monitors rate-of-change, oscillation, and stability. Each sensor accumulates violations.

- **Rate-of-change violation:** $\Delta ppO_2/\Delta t > 0.20$ bar/s → +1 violation.
- **Oscillation violation:** peak-to-peak amplitude > 0.15 bar → +1 violation.
- **Lockout:** 3 violations → sensor locked out for remainder of dive.

Controller-layer bailout is triggered if:

- Two sensors are locked out, or
- Remaining sensors disagree by > 0.10 bar, or
- Median cannot be computed reliably.

Loop safety bailout conditions

- **Hypoxia:** $ppO_2 < 0.16$ bar.
- **Hyperoxia:** $ppO_2 > 1.6$ bar.
- **Diluent hypoxia:** $FO_2 \times$ ambient pressure < 0.16 bar.

- **Impossible setpoint:** setpoint > ambient pressure.

> BAILOUT SUMMARY
>
> Bailout is triggered by any of the following:
> • Two sensors disagree with median by >0.10 bar
> • Two sensors locked out
> • Rate-of-change or oscillation instability
> • Loop ppO_2 outside 0.16–1.6 bar
> • Diluent hypoxic at depth
> • Impossible setpoint

4.7 O_2 sensors and controller behaviour (UI view)

The planner models three independent O_2 sensors. For each sensor, a mode can be selected, such as:

- **Normal:** realistic reading with small random noise.
- **Stuck high / stuck low:** fixed offset from the true setpoint.
- **Drifting high / drifting low:** offset that increases with depth.
- **Oscillating high / low:** sinusoidal variation around an offset.
- **Fail high / fail low:** hard-coded extreme values (e.g. 1.6 or 0.05 bar).

For each time step:

- The planner applies noise and the selected failure mode to each sensor.
- It then sorts the three readings and takes the median as the "voted" ppO_2.
- Sensors that differ from the median by more than a threshold are counted as "bad".

If two or more sensors disagree strongly, the system triggers an automatic bailout to open circuit.

On top of the sensor model, a controller module simulates how a real CCR controller might behave:

- **Rate-of-change detection:** if a sensor changes too quickly (ppO_2 per second), it is treated as suspect.
- **Oscillation detection:** if a sensor swings too much within a short window, it accumulates violations.
- **Lockout:** after repeated violations, a sensor is locked out and no longer trusted.
- **Hysteresis:** the controller does not instantly follow every small change in median ppO_2; it only updates when the difference exceeds a threshold.
- **Lag:** the controller response is smoothed over time, simulating a slow-responding system.

If the controller loses redundancy (e.g. two sensors locked out), it escalates to bailout. The controller debug panel summarises:

- Whether bailout was required.
- Depth and median ppO_2 at the trigger point.
- Which sensors were locked out and why.

BAILOUT TRIGGER (UI)

Bailout can be triggered either by the sensor voting layer (two sensors disagree strongly) or by the controller layer (loss of redundancy due to lockouts). Once bailout is active, the ascent is treated as open circuit using the configured bailout gases.

5. Oxygen exposure and outputs

5.1 CNS calculation

For each segment, the planner:

- Determines ppO_2 (either from setpoint in CCR mode or from gas fraction × ambient pressure in OC).
- Looks up a NOAA-style maximum exposure time for that ppO_2 (e.g. 45 min at 1.6 bar, 150 min at 1.4 bar, etc.).
- Computes the fraction of that limit used by the segment.

CNS added (%) = (segment time / limit time) × 100 × workload factor

The planner accumulates CNS over the whole dive and displays:

- **CNS per segment** (in the table).
- **Total CNS** in the summary and gas cards.

5.2 OTU calculation

OTU is calculated using a standard power-law relationship for ppO_2 above 0.5 bar:

OTU added = time (min) × $((ppO_2 - 0.5) / 0.5)^{0.83}$ × workload factor

OTU is accumulated across the dive and reported:

- Per segment (for gas-specific totals).
- As a total OTU value in the summary and gas cards.

5.3 Main table and graph

- **Depth and runtime:** the full profile from descent to surface.
- **Gas used at each segment:** including switches and CCR vs OC behaviour.
- **ppO_2, EAD, density:** with warnings for high ppO_2 and dense gases.
- **CNS and OTU:** cumulative oxygen exposure.
- **GF99 and SurfGF:** decompression stress indicators.
- **TTS:** time to surface from each point, assuming you follow the schedule.

5.4 Gas summary cards

- **Per-gas requirements:** solo and team volumes, cylinder counts, and reserves.
- **O_2 loading per gas:** CNS and OTU per mix.
- **CCR summary:** total O_2 and diluent used, plus loop-related warnings.

- **Total gas volume:** overall solo gas requirement for the nominal plan.
- **Buoyancy swing:** weight lost due to gas usage (more positive at the end of the dive).

5.5 Bailout matrix and scenarios

- **Scenario-by-scenario comparison:** TTS, max GF99, total gas, and sufficiency.
- **Critical scenario:** the most demanding or gas-limited case, clearly highlighted.
- **Gas cards per scenario:** how each gas performs under that specific failure pattern.

This specification describes the behaviour of the planner from a diver's perspective and is aligned with the UI layout (Dive Profile → Gases → Settings → CCR → Outputs). It is intended to help you understand what the tool is doing, how to interpret its outputs, and how different settings (gases, gradient factors, workload, gas share, CCR behaviour, and scenarios) change the resulting profiles. It is not a substitute for formal training or real-world experience.