BonnetRouge Dive-Planner: an Android application enabling advanced recreational divers to compute the maximal bottom time of a dive based on a Bühlmann algorithm supporting Baker's Gradient Factors

Author: Sandrine Sage

Abstract

The Android 6.0 Marshmallow BonnetRouge Bühlmann Dive-Planner is presented. Dive computers answer the need for a forward computation of the decompression problem. Namely, based upon a dive profile, they calculate a runtime as well as an expected gas consumption. The reverse decompression problem hasn't been fully explored. When a diver plans a dive with a given diving equipment, he must determine the longest time he can stay at the bottom, enabling him to return to the surface, after having applied the corresponding decompression protocol:

- *Within a specified lapse of time;*
- *Having respected his gas consumption constraints.*

This computation is currently handled through the diver's experience or by iteratively programming dives of increasing bottom-time on dive-computers.

BonnetRouge offers an integrated solution to that reverse decompression problem. It works with square dive profiles and supports normoxic Trimix dives with Nitrox and O_2 decompression. It may be used for altitude dives as well as for sea-level dives, in salty or fresh water. BonnetRouge also support repetitive dives. The user specifies a series of dive parameters and constraints: his material, his personal gas consumption and the dive profile. Based upon those, BonnetRouge uses Erik Baker's Gradient Factors and maximum %M value, as well as a Bühlmann algorithm, to compute the maximum bottom time fitting those constraints.

General idea behind gradient factors and maximum %M parameters

As the diver descends (fig. 1), he breathes gas mixes that dissolve in his tissues. The longer and deeper the diver is immersed, the greater the quantity of inert gases that will dissolve in his tissues. As the diver returns to the surface, inert gas is released from his tissues. He must follow a decompression protocol that aims at reducing the risk of decompression illness by managing the rate at which the gas is released from his tissues.

Optimal decompression occurs when the diver remains in the decompression zone that lies, for each tissue (compartment), between its M-value line and the ambient pressure line. The M-value line represents the threshold not to be exceeded. The ambient pressure line indicates the point where the pressure of the dissolved gas is equal to the ambient pressure.

The pressure of each inert gas in each compartment is computed throughout the entire dive. Computing a decompression protocol consists in first evaluating the inert gas pressure in the diver's compartments once he's about to leave the bottom. The diver ascends at a specific rate until he reaches the first ceiling. Computing a ceiling consists in calculating the maximum depth variation that each compartment can sustain. The ceiling is given by subtracting the smallest of those depth variations from the current depth. The diver stops at a ceiling until all of his compartments can sustain an ascent to the subsequent ceiling.

The diver leaves the bottom with an inert, dissolved, gas pressure of y1 in a compartment. The objective is to find x1, the first ceiling for this compartment, while applying Baker's Gradient Factors. The ceiling may lie anywhere within the decompression zone, between x2 and x3. Baker positions the ceilings at a specific relative distance between the ambient pressure line and the M-value line.

According to Baker, the Gradient Factor (GF) is expressed as the ratio of the inert gas pressure difference (y1 – y3) and the M-value difference (y2 – y3):

Equation 1. $$\boldsymbol{GF} = \frac{\boldsymbol{y1} - \boldsymbol{y3}}{\boldsymbol{y2} - \boldsymbol{y3}}$$

The value of GF is chosen by the user.
The M-value of the compartment at ambient pressure x1, y2, is given by the Bühlmann equation:

Equation 2. $$\boldsymbol{y2} = \frac{\boldsymbol{x1}}{\boldsymbol{b}} + \boldsymbol{a}$$

where a is the intercept at zero ambient pressure of the M-value line and b is the reciprocal of the slope of the M-value line, for a given compartment and for a given inert gas.
The compartment's pressure, y3, when it is equalized with the ambient pressure x1, is given by the ambient pressure line:

Equation 3. $$\boldsymbol{y3} = \boldsymbol{x1}$$

Replacing y2 by equation 2 and y3 by equation 3 in the gradient factor equation 1 results in:

Equation 4. $$\boldsymbol{x1} = \frac{\boldsymbol{y1} - \boldsymbol{GF} * \boldsymbol{a}}{\boldsymbol{GF} * \left(\frac{\boldsymbol{1}}{\boldsymbol{b}} - \boldsymbol{1}\right) + \boldsymbol{1}}$$

The first ceiling, x1, is computed using a low gradient factor (GF_L) and the compartments' pressure matrix. The low gradient factor (GF_L) is defined by the user. Divers commonly choose a GF_L value of 20%. The low gradient factor selects a deep ceiling, close to the ambient pressure line.

The successive ceilings are set at 3 meter intervals, from the first ceiling, until the diver surfaces. This, in order to follow commonly accepted conventions. At each ceiling, the stop duration is computed through Schreiner's equation for each compartment. This time lapse enables the pressure in the diver's compartment to decrease in such a way that he is able to ascend to a depth equal or shallower than the next ceiling. A high gradient factor (GF_H), chosen by the user, is used for computing those depths. Divers commonly choose a GF_H value of 85%. A high gradient factor constraint selects a shallow ceiling, close to the M-value line.

The maximum %M-value is another way of determining the first ceiling, based on how close the user wishes to be to the M-value line. It can be used in combination with the gradient factors. Baker defined the %M-value as the ratio of the inert gas pressure (y1) and the M-value (y2):

Equation 5. $$\%\boldsymbol{M} = \frac{\boldsymbol{y1}}{\boldsymbol{y2}} * \boldsymbol{100}$$

The M-value of the compartment at ambient pressure x1, y2, is given by the Bühlmann equation (equation 2).
Replacing y2 by its value into the %M equation results in:

Equation 6. $$\boldsymbol{x1} = \boldsymbol{b} * \left(\frac{\boldsymbol{y1} * \boldsymbol{100}}{\%\boldsymbol{M}} - \boldsymbol{a}\right)$$

Some combinations of low gradient factor, high gradient factor and maximum %M-value are incompatible. They result in compartments having ceilings that are deeper than the current ceiling. This would be the case, for instance, if:

- The low gradient factor is larger than the high gradient factor
- The maximum %M-value is smaller than the ambient pressure line

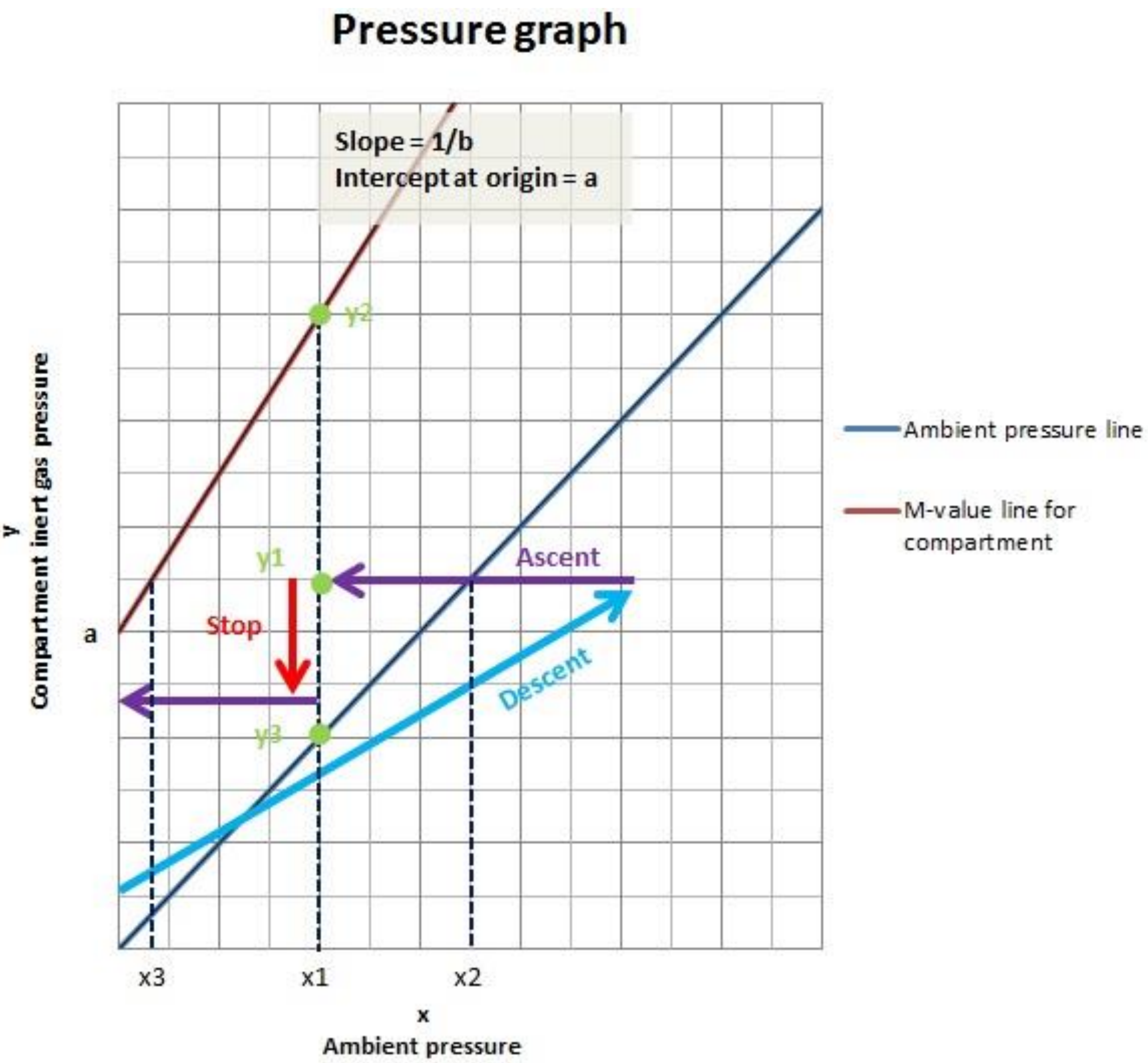

Figure 1. Variation of the pressure of an inert gas dissolved in a compartment during a dive

BonnetRouge algorithm

BonnetRouge computes dives of successively increasing bottom-times, until it finds a bottom time such that the dive matches the maximum dive duration or when one of the tank reserves, specified by the user, is reached (fig. 2).

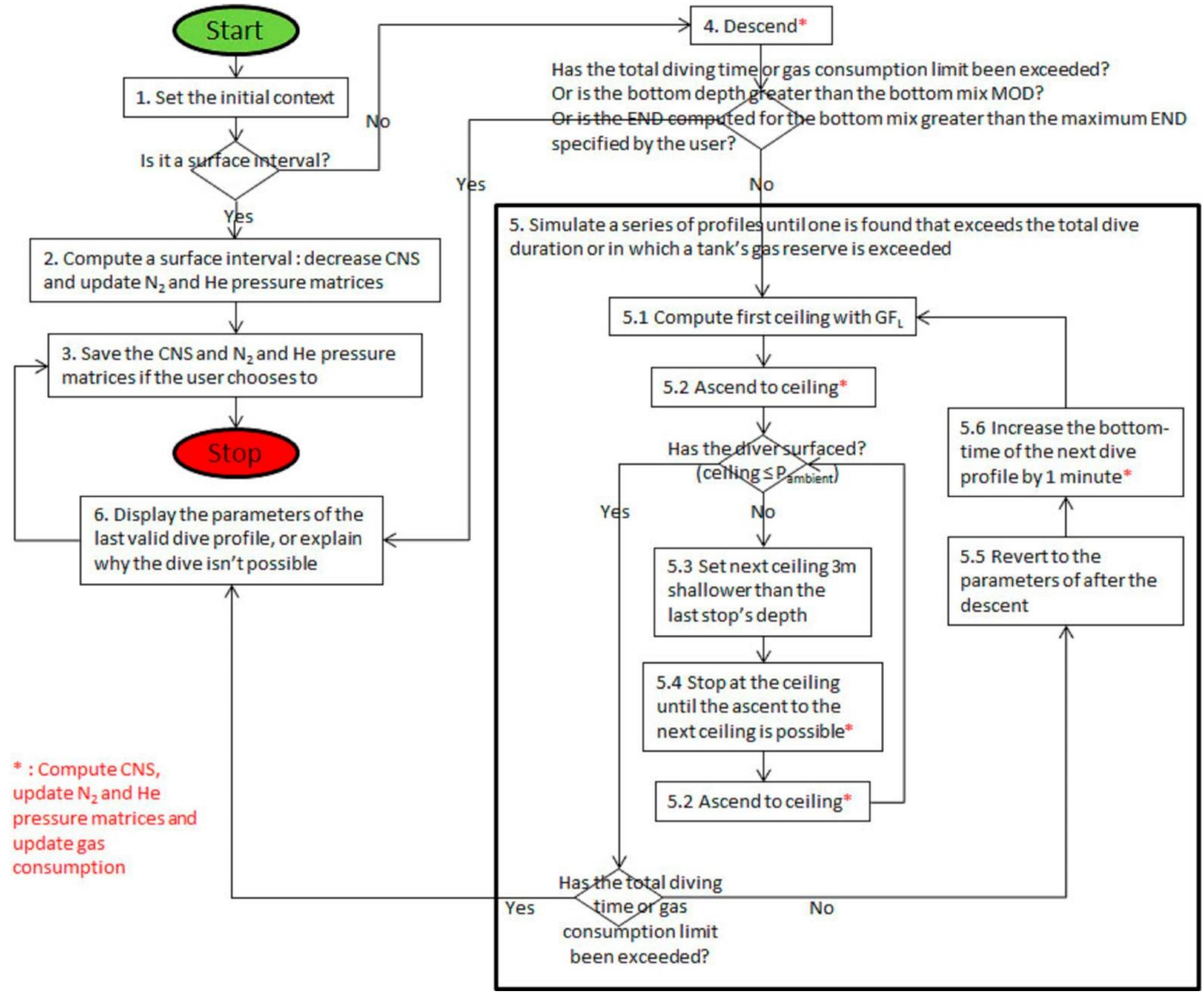

Figure 2. BonnetRouge Dive-Planner algorithm

1. Set the initial context

The following parameters are specified by the user:

- Ambient atmospheric pressure (bars): $P_{ambient}$
- Water specific gravity: waterSpecificGravity
- Gas usage constraints:
  - Maximum Equivalent Narcotic Depth (END) for the bottom-mix (bars): END
  - Maximum O_2 partial pressure for the bottom dive (bars): $PpO2_{bottom}$
  - Maximum O_2 partial pressure for the decompression (bars): $PpO2_{deco}$
- Decompression parameters:
  - Gradient factor high (%): GF_H
  - Gradient factor low (%): GF_L
  - Maximal %M value (%): M (a value of 0 indicates that the processing mustn't take this parameter into account)
- Dive material:
  - Gas composition, reserve, initial pressure and volume of the following tanks:
    - Bottom-mix tank (typically trimix)
    - Optional Nitrox decompression tank
    - Optional O_2 decompression tank

- Dive profile:
  - Bottom depth (m): this value is converted to absolute pressure units, P_{bottom} (bar), by multiplying it by $\frac{g*waterSpecificGravity}{100.00}$, where g: gravitational acceleration (9.81 m/s^2), and by adding $P_{ambient}$ to this result
  - Descent velocity (m/min): this value is converted to pressure per minute units, $velocity_{descent}$ (bar/min) , by multiplying it by $\frac{g*waterSpecificGravity}{100.00}$, where g: gravitational acceleration (9.81 m/s^2)
  - Ascent velocity (m/min): this value is converted to pressure per minute units, $velocity_{ascent}$ (bar/min) , by multiplying it by $\frac{g*waterSpecificGravity}{100.00}$, where g: gravitational acceleration (9.81 m/s^2)
  - Maximal total dive time (min): totalDiveTime
- Diver profile:
  - Respiratory Minute Volume (l/min): RMV
  - Dive companion's Respiratory Minute Volume (l/min), should the application plan for an incident where the dive companion requires full assistance at the time of starting the ascent to the surface: RMVPenalty

According to the user's preference, the diver's He and N2 pressure matrices as well as his Central Nervous System clock (CNS) are either loaded from previously saved values or initialized at the ambient conditions.
Initializing the CNS is done by setting it to 0. Initializing the He and N_2 pressure matrices is done by creating two matrices, pN2 and pHe, each of the size of the He and N_2 Bühlmann half-life and a/b coefficients tables. The N_2 pressure, pN_2, in compartment i, is expressed in bars and it is set to:

$$pN2[i] = fractionN2 * (Pambient - Pwatervapor)$$

Where:

- fractionN2 is 0.79
- $P_{ambient}$: ambient atmospheric pressure (bars)
- P_{water} vapor is the vapor water pressure in the lungs, at 37°C (0.06 bars)
- i varies from 1 to the total number of compartments supported in the He and N2 Bühlmann half-life and a/b coefficients tables

The He pressure, pHe, in compartment i, is expressed in bars and it is set to:

$$pHe[i] = 0.00$$

Where:

- i varies from 1 to the total number of compartments supported in the He and N_2 Bühlmann half-life and a/b coefficients tables

2. Compute a surface interval

When the user selects a 0 m depth dive, the application computes a surface interval:

- The diver's CNS is adjusted based on NOAA's CNS% surface interval credit
- The diver's He and N_2 pressure matrices, pN2 and pHe, are adjusted by applying Schreiner's equation to each compartment i:

  $$pN2[i] = (Pambient - Pwatervapor) * fractionN2 - ((Pambient - Pwatervapor) * fractionN2 - \mathrm{pN2[i]}) * e^{-(\mathrm{time} * \frac{\ln(2)}{\mathrm{N2CompartmentsTableHalfLife[i]}})}$$

  Where:
  - $P_{ambient}$: ambient atmospheric pressure (bars)
  - $P_{water\ vapor}$ is the vapor water pressure in the lungs, at 37°C (0.06 bars)
  - fractionN2 is 0.79
  - time: duration of the surface interval (min)
  - N2CompartmentsTableHalfLife[i]: half-life of compartment i for N_2

  $$pHe[i] = \mathrm{p}He[\mathrm{i}] * e^{-(\mathrm{time} * \frac{\ln(2)}{\mathrm{HeCompartmentsTableHalfLife[i]}})}$$

  Where:

- time: duration of the surface interval (min)
- HeCompartmentsTableHalfLife[i]: half-life of compartment i for He

The updated CNS is displayed and the user is informed that his pN2 and pHe pressure matrices have been updated:

3. Save the CNS and N_2 and He pressure matrices, if the user chooses to

The user may save those parameters, so as to use them as an input for a repetitive dive.

4. Descend

The bottom-mix is used during the descent.

- The END for the bottom mix is computed

  $$ComputedEND = \frac{Pbottom * \ fractionN2}{fractionN2Air}$$

  Where:
  - $P_{bottom:}$ bottom depth (bars)
  - fractionN2 is the N_2 fraction of the bottom-mix specified by the user
  - fractionN2Air is the N_2 fraction of air (0.79)
- The bottom-mix MOD is computed

  $$ComputedMOD = \frac{PpO2bottom}{fractionO2}$$

  Where:
  - PpO2bottom: O_2 partial pressure threshold for the bottom dive (bars)
  - fractionO2 is the O_2 fraction of the bottom-mix specified by the user
- The descent travel-time (min) is computed

  $$descentTime = \frac{(Pbottom - Pambient)}{velocityDescent}$$

  Where:
  - $velocity_{descent}$ (bars/min)
  - $P_{bottom:}$ bottom depth (bars)
  - $P_{ambient:}$ ambient atmospheric pressure (bars)

  The running total dive time is set to the descent travel-time.
- The consumption (l) during the descent is computed

  $$consumptionBottomMix = RMV * descentTime * \frac{(Pbottom + Pambient)}{2}$$

  Where:
  - descentTime: descent travel-time (min)
  - RMV: Respiratory Minute Volume (l/min)
  - $P_{bottom:}$ bottom depth (bars)
  - $P_{ambient:}$ ambient atmospheric pressure (bars)

  The bottom-mix pressure is decreased accordingly.
- The diver's He and N_2 pressure matrices, pN2 and pHe, are adjusted by applying Schreiner's equation to each compartment i:

  $$pN2[i] = \left(\left(\frac{(Pbottom+Pambient)}{2} - Pwatervapor\right) * fractionN2\right) + (velocity * fractionN2) * \left(\mathrm{time} - \frac{\mathrm{N2CompartmentsTableHalfLife[i]}}{\ln(2)}\right) - \left(\left(\left(\frac{(Pbottom+Pambient)}{2} - Pwatervapor\right) * fractionN2\right) - \mathrm{pN2[i]} - \left(\mathrm{velocity} * \mathrm{fractionN2} * \frac{\mathrm{N2CompartmentsTableHalfLife[i]}}{\ln(2)}\right)\right) * e^{-\left(\mathrm{time} * \frac{\ln(2)}{\mathrm{N2CompartmentsTableHalfLife[i]}}\right)}$$

  Where:

- $P_{bottom:}$ bottom depth (bars)
- $P_{ambient:}$ ambient atmospheric pressure (bars)
- $P_{water\ vapor}$ is the vapor water pressure in the lungs, at 37°C (0.06 bars)
- fractionN2 is the N_2 fraction of the bottom-mix, specified by the user
- velocity: descent velocity (bars/min) (positive for descents)
- time: descentTime (min)
- N2CompartmentsTableHalfLife[i]: half-life of compartment i for N_2

$$pHe[i] = \left(\left(\frac{(Pbottom+Pambient)}{2} - Pwatervapor\right) * fractionHe\right) + (velocity * fractionHe) * \left(\mathrm{time} - \frac{\mathrm{HeCompartmentsTableHalfLife[i]}}{\ln(2)}\right) - \left(\left(\left(\frac{(Pbottom+Pambient)}{2} - Pwatervapor\right) * fraction\mathrm{He}\right) - \mathrm{pHe[i]} - \left(\mathrm{velocity} * \mathrm{fractionHe} * \frac{\mathrm{HeCompartmentsTableHalfLife[i]}}{\ln(2)}\right)\right) * e^{-\left(\mathrm{time} * \frac{\ln(2)}{\mathrm{HeCompartmentsTableHalfLife[i]}}\right)}$$

Where:

- $P_{bottom:}$ bottom depth (bars)
- $P_{ambient:}$ ambient atmospheric pressure (bars)
- $P_{water\ vapor}$ is the vapor water pressure in the lungs, at 37°C (0.06 bars)
- fractionHe is the He fraction of the bottom-mix, specified by the user
- velocity: descent velocity (bars/min) (positive for descents)
- time: descentTime (min)
- HeCompartmentsTableHalfLife[i]: half-life of a compartment i for He

- The diver's CNS is adjusted for the descent by using the oxygen partial pressure and normal exposure time limits for a single dive from NOAA 1991 Diving Manual

5. Simulate a series of profiles until one is found that exceeds the total dive duration or in which a tank's gas reserve is exceeded

Each profile consists in a descent, a bottom stay and an ascent. Each simulated profile has an incrementally increasing duration at the bottom. The ascent is determined by the time spent at the bottom and by the decompression parameters specified by the user.

The very first simulated profile has a bottom-time of 0 min. The diver ascends immediately after he has reached the bottom. For each other simulated profile, the bottom-time is increased by 1 minute. In each profile, the diver ascends to the surface after having applied the required decompression protocol.

If the diver reaches the surface without having exceeding the dive's maximum duration or the tanks' reserve, the dive profile is valid and it is saved. Another dive profile is computed, increasing the bottom-time by one minute. The simulations are stopped when a profile is found that exceeds the dive's maximum duration or the tanks' reserve.

5.1 Compute the first ceiling with GF_L

The first, deepest ceiling is computed and rounded up to the deepest 3 m multiple. The deepest ceiling is the maximum value of all of the compartments' ceiling. The compartments' ceiling is the maximum value between the ceiling computed using the gradient factors constraint and the ceiling computed using the maximum %M constraint:

- Ceiling computed from the gradient factors constraint for compartment i (the Gradient Factor Low parameter (GF_L) is used), Pa[i], in bars

$$Pa[i] = \frac{(p[i] - a[i] * GF\_L)}{\left(1 + \frac{GF\_L}{b[i]} - GF\_L\right)}$$

- Ceiling computed from the maximum %M constraint for compartment i, Pa[i], in bars

$$Pa[i] = \left(\frac{p[i]}{M} - a[i]\right) * b[i]$$

Where:

- Pa[i]: compartment ceiling (bars)
- p[i]: compartment pressure (bars): sum of its He and N_2 partial pressures
- GF_L: gradient factor low, specified by the user
- M: maximum %M, specified by the user
- a[i]: weighted average of the Bühlmann 'a' parameter, for He and N_2:

$$a[i] = \frac{fractionN2 * aN2[i] + fractionHe * aHe[i]}{fractionN2 + fractionHe}$$

- b[i]: weighted average of the Bühlmann 'b' parameter, for He and N_2:

$$b[i] = \frac{fractionN2 * bN2[i] + fractionHe * bHe[i]}{fractionN2 + fractionHe}$$

Where:

- fractionN2: N_2 fraction of the bottom-mix
- fractionHe: He fraction of the bottom-mix
- aHe[i]: Bühlmann 'a' parameter, for He
- aN2[i]: Bühlmann 'a' parameter, for N_2
- bHe[i]: Bühlmann 'b' parameter, for He
- bN2[i]: Bühlmann 'b' parameter, for N_2

5.2 Ascend to the ceiling

- The consumption (l) during the ascent to the ceiling is computed. The tanks that the user will be using throughout this ascent are chosen according to their MOD. The running consumption (l) for each tank is computed:

$$consumptionTank[j] = (RMVPenalty + RMV) * ascentTimeOnTank[j] * \frac{(PStartTank[j] + PEndTank[j])}{2}$$

Where:

- RMV: Respiratory Minute Volume (l/min)
- RMVPenalty: Dive companion's Respiratory Minute Volume (l/min), specified by the user
- PStartTank[j]: total pressure at the depth where tank[j] started being used (bars)
- PEndTank[j]: total pressure at the depth where tank[j] stopped being used (bars)
- ascentTimeOnTank[j]: time spent breathing tank[j] (min)

The tanks' pressure is decreased accordingly.

- The duration of the ascent to the next ceiling is computed

$$ascentTimeIncrement = \frac{(PpreviousCeiling - Pceiling)}{ascentVelocity}$$

Where:

- ascentVelocity (bar/min)
- $P_{ceiling:}$ total pressure at the ceiling (or at the surface, as applicable) (bars)
- $P_{previousCeiling}$: total pressure at the previous ceiling (or at the bottom, as applicable) (bars)

The ascentTimeIncrement is added to the total dive time.

- The diver's He and N_2 pressure matrices are adjusted for this ascent step by applying Schreiner's equation to each compartment i:

$$pN2[i] = ((Paverage - Pwatervapor) * fractionN2) + (velocity * fractionN2) * (\mathrm{time} - \frac{\mathrm{N2CompartmentsTableHalfLife[i]}}{\ln(2)}) - (((Paverage - Pwatervapor) * fractionN2) - \mathrm{pN2[i]} - (\mathrm{velocity} * \mathrm{fractionN2} * \frac{\mathrm{N2CompartmentsTableHalfLife[i]}}{\ln(2)})) * e^{-(\mathrm{time} * \frac{\ln(2)}{\mathrm{N2CompartmentsTableHalfLife[i]}})}$$

Where:

- $P_{average}$: average pressure (bars): $\frac{(Pceiling + PpreviousCeiling)}{2}$
- $P_{water\ vapor}$ is the vapor water pressure in the lungs, at 37°C (0.06 bars)

- fractionN2 is the N_2 fraction of the bottom-mix, specified by the user
- velocity: ascent velocity (bars/min) (negative for ascents)
- time: ascent duration (min)
- N2CompartmentsTableHalfLife[i]: half-life of compartment i for N_2

$$pHe[i] = ((Paverage - Pwatervapor) * fractionHe) + (velocity * fractionHe) * (\mathrm{time} - \frac{\mathrm{HeCompartmentsTableHalfLife[i]}}{\ln(2)}) - (((Paverage - Pwatervapor) * fraction\mathrm{He}) - \mathrm{pHe[i]} - (\mathrm{velocity} * \mathrm{fractionHe} * \frac{\mathrm{HeCompartmentsTableHalfLife[i]}}{\ln(2)})) * e^{-(\mathrm{time} * \frac{\ln(2)}{\mathrm{HeCompartmentsTableHalfLife[i]}})}$$

Where:

- $P_{average}$: average pressure (bars): $\frac{(Pceiling+PpreviousCeiling)}{2}$
- $P_{water\ vapor}$ is the vapor water pressure in the lungs, at 37°C (0.06 bars)
- fractionHe is the He fraction of the bottom-mix, specified by the user
- velocity: ascent velocity (bars/min) (negative for ascents)
- time: ascent duration (min)
- HeCompartmentsTableHalfLife[i]: half-life of compartment i for He

- The diver's CNS is adjusted for this ascent step by using the oxygen partial pressure and normal exposure time limits for working dives from NOAA 1991 Diving Manual

5.3 The next ceiling is set 3 m shallower than the last stop's depth

5.4 Stop at the ceiling until the ascent to the next ceiling is possible

The diver will be cleared for ascending to the next ceiling, 3 m shallower than the current stop depth, when the deepest ceiling of all the compartments is equal or shallower than the next ceiling. This will be achieved by stopping a specific amount of time at the ceiling's depth.

The stop duration is increased by steps of 1 minute until the deepest compartment ceiling is equal or shallower than the next ceiling:

- The diver's He and N_2 pressure matrices are adjusted by applying Schreiner's equation to each compartment i:

$$pN2[i] = (Pceiling - Pwatervapor) * fractionN2 - ((Pceiling - Pwatervapor) * fractionN2 - \mathrm{pN2[i]}) * e^{-(\mathrm{time} * \frac{\ln(2)}{\mathrm{N2CompartmentsTableHalfLife[i]}})}$$

Where:

- $P_{ceiling}$: ceiling (bars)
- $P_{water\ vapor}$ is the vapor water pressure in the lungs, at 37°C (0.06 bars)
- fractionN2 is the N_2 fraction of the bottom-mix, specified by the user
- time: stop duration (min)
- N2CompartmentsTableHalfLife[i]: half-life of compartment i for N_2

$$pHe[i] = (Pceiling - Pwatervapor) * fractionHe - ((Pceiling - Pwatervapor) * fraction\mathrm{He} - \mathrm{pHe[i]}) * e^{-(\mathrm{time} * \frac{\ln(2)}{\mathrm{HeCompartmentsTableHalfLife[i]}})}$$

Where:

- $P_{ceiling}$: ceiling (bars)
- $P_{water\ vapor}$ is the vapor water pressure in the lungs, at 37°C (0.06 bars)
- fractionHe is the He fraction of the bottom-mix, specified by the user
- time: stop duration (min)
- HeCompartmentsTableHalfLife[i]: half-life of compartment i for He

- The compartments' ceiling is computed. A compartment's ceiling is the maximum value between the ceiling computed using the gradient factors constraint and the ceiling computed using the maximum %M constraint:

- Ceiling computed from the gradient factors constraint for compartment i (the Gradient Factor High parameter (GF_H) is used)

$$Pa[i] = \frac{(p[i] - a[i] * GF\_H)}{\left(1 + \frac{GF\_H}{b[i]} - GF\_H\right)}$$

- Ceiling computed from the maximum %M constraint for compartment i

$$Pa[i] = \left(\frac{p[i]}{M} - a[i]\right) * b[i]$$

Where:

- Pa[i]: compartment ceiling (bars)
- p[i]: compartment partial pressure (bars): sum of its He and N_2 partial pressures
- GF_H: gradient factor high, specified by the user
- M: maximum %M, specified by the user
- a[i]: weighted average of the Bühlmann a parameter, for He and N_2:

$$a[i] = \frac{fractionN2 * aN2[i] + fractionHe * aHe[i]}{fractionN2 + fractionHe}$$

- b[i]: weighted average of the Bühlmann b parameter, for He and N_2:

$$b[i] = \frac{fractionN2 * bN2[i] + fractionHe * bHe[i]}{fractionN2 + fractionHe}$$

Where:

- fractionN2: N_2 fraction of the bottom-mix
- fractionHe: He fraction of the bottom-mix
- aHe[i]: Bühlmann ‘a’ parameter, for He
- aN2[i]: Bühlmann ‘a’ parameter, for N_2
- bHe[i]: Bühlmann ‘b’ parameter, for He
- bN2[i]: Bühlmann ‘b’ parameter, for N_2

- The consumption (l) on the diver’s current tank is computed during the stop

$$consumptionTank[j] = (RMVPenalty + RMV) * stopDuration * Pceiling$$

Where:

- RMV: Respiratory Minute Volume (l/min)
- RMVPenalty: diving companion’s Respiratory Minute Volume (l/min)
- $stop_{duration}$: stop duration
- $P_{ceiling:}$ total pressure at the ceiling (bars)

The pressure on the diver’s current tank is decreased accordingly.

- The diver’s CNS is adjusted for the current stop by using the oxygen partial pressure and normal exposure time limits for working dives from NOAA 1991 Diving Manual
- The runtime is updated with the depth of this stop and its duration.
- This stop duration is added to the total dive time.

5.5 Revert to the parameters of after the descent

The CNS, N_2 and He pressure matrices as well as the gas consumption parameters are reset to the conditions of after the descent. The total dive time is also reset to the descent time.

5.6 Increase the bottom-time of the next dive profile by 1 minute

- The diver’s CNS is adjusted for the time spent at the bottom by using the oxygen partial pressure and normal exposure time limits for working dives from NOAA 1991 Diving Manual
- The bottom-mix consumption (l) at the bottom is computed

$$consumptionBottomMix = RMV * bottomTime * Pbottom$$

Where:

- RMV: Respiratory Minute Volume (l/min)

- $bottom_{time}$: time spent at the bottom (min)
- $P_{bottom:}$ bottom depth (bars)

The bottom-mix pressure is decreased accordingly.

- The running total dive time is set to the sum of the descent travel-time and the bottom time
- The diver's He and N_2 pressure matrices are adjusted for the stay at the bottom by applying Schreiner's equation to each compartment i:

$$pN2[i] = (Pbottom - Pwatervapor) * fractionN2 - ((Pbottom - Pwatervapor) * fractionN2 - \mathrm{pN2[i]}) * e^{-(\mathrm{time} * \frac{\ln(2)}{\mathrm{N2CompartmentsTableHalfLife[i]}})}$$

Where:

- P_{bottom}: bottom depth (bars)
- $P_{water\ vapor}$ is the vapor water pressure in the lungs, at 37°C (0.06 bars)
- fractionN2 is the N2 fraction of the bottom-mix, specified by the user
- time: bottom time (min)
- N2CompartmentsTableHalfLife[i]: half-life of compartment i for N_2

$$pHe[i] = (Pbottom - Pwatervapor) * fractionHe - ((Pbottom - Pwatervapor) * fraction\mathrm{He}) - \mathrm{pHe[i]}) * e^{-(\mathrm{time} * \frac{\ln(2)}{\mathrm{HeCompartmentsTableHalfLife[i]}})}$$

Where:

- P_{bottom}: bottom depth (bars)
- Pwater vapor is the vapor water pressure in the lungs, at 37°C (0.06 bars)
- fractionHe is the He fraction of the bottom-mix, specified by the user
- time: bottom time (min)
- HeCompartmentsTableHalfLife[i]: half-life of compartment i for He

6. Display the parameters of the last valid profile found or explain why the dive isn't possible

If no valid dive profile was found, the reason for that is displayed to the user.

The last valid dive profile is selected and the following parameters are displayed:

- the maximum time that the diver can spend at the bottom (fig. 3)
- the minimal pressure in the bottom-mix tank (fig. 3)
- the runtime (fig. 3)
- the CNS resulting from the dive (the font color is red when the CNS exceeds 50%) (fig. 3)
- the pressure graph displaying the leading compartment's pressure compared to its M-value, at a corresponding depth (fig. 4)

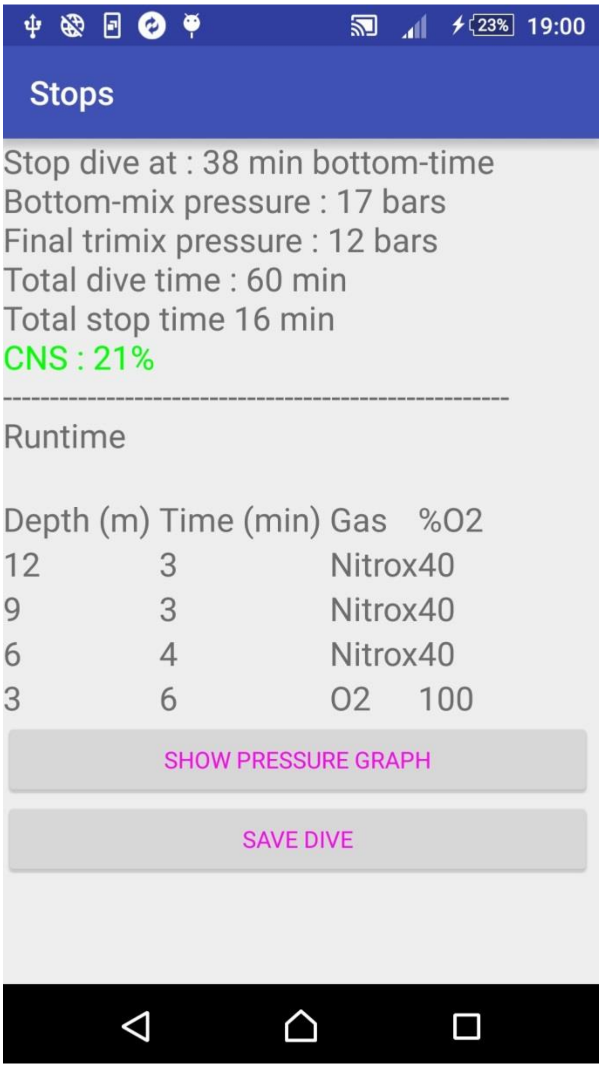

Figure 3. BonnetRouge Dive-Planner result display

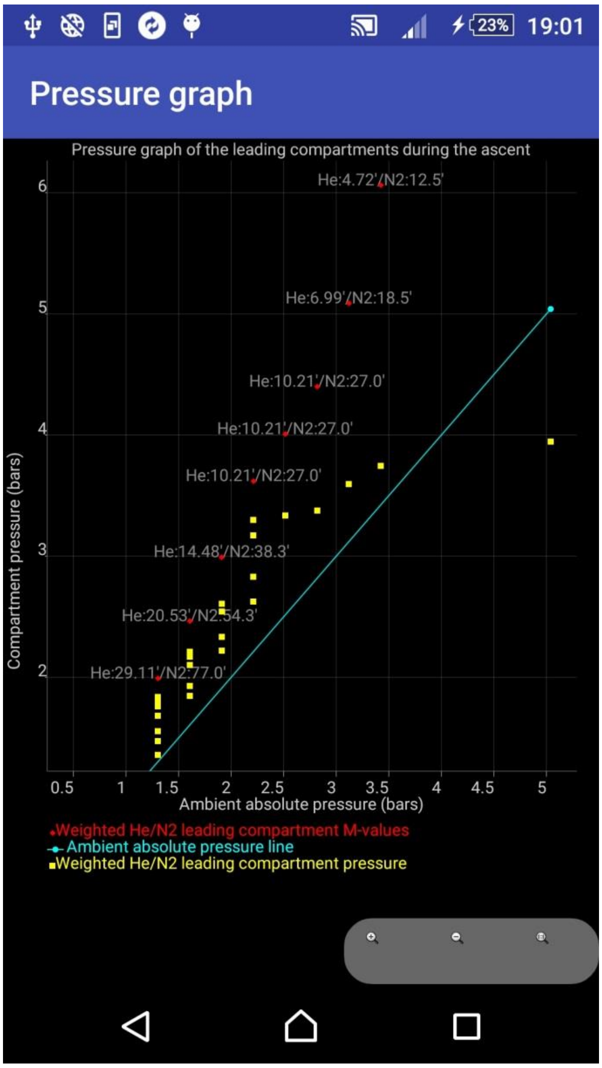

Figure 4. BonnetRouge Dive-Planner pressure graphs display

Conclusion

The Android 6.0 Marshmallow BonnetRouge Bühlmann Dive-Planner offers a solution to the reverse decompression problem: given a set of input parameters, it determines the longest time a diver can stay at the bottom, enabling him to return to the surface while respecting the given gas reserves and total dive time specified by the user, after having applied the corresponding decompression protocol. BonnetRouge is currently being tested.

The upcoming version of BonnetRouge will no longer impose square dive profiles. Rather, it will enable the user to freely define the geometry of his dive profiles.

Input tables

BonnetRouge works with the following input tables:

- Any Bühlmann half-life and a/b coefficients table, for He and for N_2 (both tables must have the same compartments)
- Any NOAA CNS oxygen exposure limits table
- Any NOAA CNS% surface interval credit table

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