The Recreational Dive Planner: History & Development

by Drew Richardson

The Recreational Dive Planner is the result of over three years of research, testing, development and cooperation among the scientists at the Institute of Applied Physiology and Medicine (IAPM), Dr. Raymond E. Rogers, creator of the original hypothesis and the original table designer; Diving Science & Technology Corporation (DSAT), a corporate affiliate of International PADI, Inc.; Dr. Michael Powell, in association with SeaUs; Dr. Richard Vann of H.G. Hall Laboratories at Duke University, in association with the Divers Alert Network (DAN), reviewer and consultant; and Karl Huggins, table design consultant.

The Rationale Behind the Recreational Dive Planner

The U.S. Navy tables are the most widely used tables by recreational divers in the United States, if not in the world. Statistics from the Divers Alert Network show that recreational divers use the U.S. Navy tables safely. So why new tables?

A Tailored Fit versus a Hand Me Down

Disadvantages of the U.S. Navy tables specific to the needs of recreational divers have been discussed for a number of years. The history of the U.S. Navy tables indicates they were developed in the 1950s to accommodate the introduction of scuba and to improve upon the old U.S. Navy tables initially published in 1937. There were no provisions for repetitive diving built into the 1937 tables.

The U.S. Navy tables were originally designed for decompression diving by military and commercial divers who were surface-supplied, that is, able to remain at a given depth on a single dive until completing a specific task. These tables were, and still are, truly decompression schedules, rather than recreational no-decompression tables.

Eventually, as military needs changed, it became necessary to create tables that would allow scuba divers to perform repetitive dives while on military missions and would account for off-gassing during the surface interval. In the decompression schedules developed by the U.S. Navy, the “surface interval credit table” was devised to allow repetitive dives. Because the original tables were intended for decompression diving on a long single dive, the ability to repetitive dive was an after-thought: the tables were modified to accommodate this.

Recreational dive patterns differ from commercial dive patterns. Recreational divers are constrained by the amount of air they are able to carry, thus limiting their underwater time. Because the recreational diver must return to the surface periodically to replenish his air supply, it is the nature of recreational divers to perform repetitive diving. Also, recreational divers move about the bottom and often change depths. The behavior of recreational and military divers diverges on these points. As a result, the U.S. Navy tables, which were designed primarily for single dives to a continuous depth, often impose needless restrictions on recreational divers. To address the behavioral differences of recreational divers, the Recreational Dive Planner took a ground-up approach in creating a no-decompression dive table.

Hyperbaric Scientists Petition for Research

During recent years, a general consensus in international medical conferences has begun movement away from the U.S. Navy tables, which have been the standard of the diving community since the late 1950s. Examples of this are found in publications by noteworthy physiologists and researchers within the hyperbaric community.

In the 1970s, Dr. Merrill Spencer of IAPM, using Doppler technology, discovered that divers who made dives within the U.S. Navy no-decompression limits developed venous gas-emboli known as “silent bubbles.” These small bubbles, even in large amounts, did not produce symptoms of decompression sickness in the diver. For this reason, venous gas-emboli are sometimes referred to as asymptomatic decompression sickness.

Dr. Andrew Pilmanis, of the University of Southern California’s Catalina Marine Science

Center, also using Doppler technology, published findings of venous gas-emboli detected on dives with the U.S. Navy no-decompression limits.

The discovery of the formation of bubbles on no-decompression dives spurred scientific discussions and reaction as to the adequacy of the U.S. Navy tables for recreational applications.

In 1982, Dr. Bruce Bassett of Human Underwater Biology Incorporated, in an attempt to minimize venous gas-emboli after no-decompression dives using the U.S. Navy tables, recommended more conservative no-decompression limits. These limits essentially represent shortened bottom times for each depth.

In response to the medical community's concerns associated with venous gas-emboli, the Divers Alert Network at Duke University in Raleigh/Durham, North Carolina wrote:

"It is now widely debated whether or not the U.S. Navy decompression schedules are appropriate for safe recreational diving. A concern is commonly expressed that some schedules may be too long, posing a higher risk for bends, and that other schedules may unfairly penalize a diver's time, therefore, being unnecessarily conservative."

Karl Huggins, a dive-table engineer affiliated with the University of Michigan, petitioned the recreational diving industry to address the issue of using the U.S. Navy tables by stating:

"...I also feel that instead of sitting around and waiting for a new set of 'sport-diving tables' to appear, we should encourage the certifying agencies to work together with diving physiologists, decompression experts and the Undersea [and Hyperbaric] Medical Society to produce a set of tables that are designed for the sport-diving community, not the military or commercial diving population."

The Recreational Dive Planner has accomplished exactly that.

The Hypothesis

The amount of gas loading in a tissue is expressed in gas partial pressure. The body is composed of numerous tissues that absorb (on-gas) and release (off-gas) nitrogen at varying rates, due to an array of variables.

In theory, optimal dive schedules would be afforded by tracking the gas partial pressures in each individual tissue as they on-gas during the dive and off-gas during the surface interval. Planning the next dive and its decompression obligation would be on the basis of the gas-loading in the so-called "controlling" tissue — the tissue closest to its maximum safe gas-level. This is what is done by many of the small, popular dive computers.

In calculating tissue-gas pressures, the concept of half-time is implemented. Half-time is the amount of time required for the gas pressure in a tissue to on-gas or off-gas halfway to the level of the gas pressure outside the tissue.

For the sake of simplicity, the U.S. Navy surface interval credit table is calculated on the basis of a controlling tissue with a 120-minute half-time. This covers all diving situations, including the most severe decompression dives encountered by the U.S. Navy's diving needs. The U.S. Navy's choice of a 120-minute tissue half-time was appropriate for military diving, but unrealistic for recreational use. For the recreational diver, this translates into repetitive dives that are unnecessarily conservative.

Recognizing the disadvantage to the recreational diver and in an effort to address the petitions of the scientists, Dr. Raymond Rogers began seeking a more appropriate controlling tissue for recreational diving profiles. In the early 1980s, Dr. Rogers used extensive computer analysis to find that a 40-minute half-time tissue met the needs for almost all dive profiles a recreational diver would make. He discovered, however, that a small percentage of profiles, primarily involving a series of long shallow dives, require a slower tissue than 40 minutes. With diver safety the primary concern, a 60-minute tissue half-time was chosen as the basis for the Recreational Dive Planner. The 60-minute tissue covers all the profiles, with only slightly shorter bottom times than a 40-minute tissue.

A theoretical tissue designated "60 minutes" was a new concept to many researchers who have used the traditional half-times of 5, 10, 20, 40, 80 and 120 minutes. Since half-times are mathematical concepts and do not correlate to any particular tissue, there is no reason that one of the traditional numbers must be used. As the mathematics of recreational diving depths and durations were evaluated, it became apparent that a tissue half-time of 60 minutes came closer to the theoretical needs of the recreational diver than any other half-time. The question remained to be answered as to how safe it would be to perform repetitive dives with the 60-minute tissue as the controlling tissue.

The Testing

The testing of the Recreational Dive Planner involved hyperbaric-chamber and open-water studies. Using Dr. Rogers' research and hypothesis, Dr. Michael Powell, Director of Hyperbaric Research at the Institute of Applied Physiology and Medicine (IAPM) directed testing toward dive profiles specifically designed for the recreational diver: multilevel and repetitive multilevel diving. The research was designed to validate or disprove Dr. Rogers' work.

As its objective, the testing at IAPM loaded the test subjects' bodies with nitrogen under pressure for a certain period and predicted the level of supersaturation that would be safely tolerated upon ascent. The study used a large group of volunteer divers following specified dive profiles in the hyperbaric chamber and in open water. A Doppler ultrasound flowmeter was the primary tool used in evaluating the test profiles through its ability to discern the early appearance of silent bubbles in the body. By minimizing silent bubbles, the probability of decompression sickness is minimized.

One consideration during testing was to effect maximum gas loading in the divers — much more than the gas loads that would be expected in the water by divers using scuba. Scuba divers with limited air could not come close to a comparable amount of nitrogen absorption obtained during the chamber tests. To maximize tissue on-gassing, the test subjects exercised on rowing machines and temperature control was used to increase blood-flow.

Test Description

In the hyperbaric-chamber tests, there were 79 male divers and 37 female divers. From Table 1, it is clear that this group reflects the recreational diver population in terms of age, gender distribution and percentage of body fat. For this study, there was clearly no effort made to recruit young, physical males as the diving subjects, but rather a full spectrum of the recreational diving population. Diver subjects were recruited from the recreational diving population of the Puget Sound area.

Table 1 – Test Subject Data

Average Ages		
	Male:	32.7 years (range 22-52 years)
	Female:	31.3 years (range 23-44 years)
Body Fat (Body Mass Index, Weight/Height)		
	Male:	22.1%
	Female:	27.4%
Average Length of Diving Experience		
	9.7 years (range 1-38 years)	

Dives were conducted at different times of day between 9:00 a.m. and 9:00 p.m. in a 4.5-foot (diameter) by 15-foot (length) chamber, using compressed air. The chamber temperature was kept between 75 and 77 degrees and carbon dioxide never exceeded equivalent concentration of .5% at sea level. Heart rate was increased by exercise on rowing machines with a cycle of two minutes on and two minutes off for dives under 30 minutes duration, and two minutes on and three off for dives of more than 30 minutes duration. The rowing frequency and spring constant of the rowing machines were fixed such that the workload measured at sea level was 1.2 liters of oxygen per minute. Ascents and descents were made at 60 feet per minute.

Following decompression, the divers exited the chamber and were Doppler-monitored for the presence of gas bubbles approximately 15 and 25 minutes later. Detected bubbles were graded on the scale first described by Dr. Spencer:

From numerous retrospective studies reported by Powell in 1982, using rats, and Powell and Johanson in 1985, using humans, it seems that the incidence of decompression sickness becomes very small when no larger than grade 1 is detected. This has been investigated by Dr. Richard Vann at Duke University in more than 800 human divers.

This is significant in the evaluation of repetitive diving practices and schedules designed for recreational divers. In a series of over 300 manned dives, such as in the testing of the Recreational Dive Planner, no cases of decompression sickness would be expected. To determine the "degree" of safety, one needs an objective measure, and Doppler detection offers the researcher that measure by allowing him to determine how close a test subject comes to a threshold likely to produce decompression sickness without actually developing symptoms. The use of Doppler affords not only practical considerations, but also has important medical-legal implications as well.

Table 2 – Doppler Bubble Grades

Grade	Description	Meaning
0 —	no bubbles detected	SAFE
1 —	less than 1 bubble per heartbeat	SAFE
2 —	1-5 bubbles per heartbeat	SAFE
3 —	10-20 bubbles per heartbeat	MODERATELY UNSAFE
4 —	gas bubbles more numerous than possible to count	UNSAFE

In addition to the chamber dives, a series of open-water dives was conducted in the Puget Sound. The divers wore either wet or dry suits, depending on their preference. Considering that the temperature of Puget Sound averages 55 degrees during the summer, the dive profiles were stressful.

Upon surfacing, subjects were Doppler-monitored on the boat or on shore. All Doppler readings were recorded and reanalyzed later in the laboratory. In cases where it was questionable whether bubbles were detected, it was resolved in the favor of a bubble. Thus, in some cases, a Grade 1 may have been decided where a Grade 0 may have been the actual case. Anatomical restrictions sometimes precluded optimization of a Doppler signal; when in doubt, it was assumed bubbles had been detected.

Test Results

No cases of decompression sickness were encountered in any test, either in the hyperbaric chamber or in open water. Occasional skin itching in the chamber subjects was reported (which is not unusual in chamber dives) and two cases of migraine headache occurred in one subject who was prone to this type of problem.

Doppler detectable bubbles were found in 4% of the profiles. In subjects who did deep knee bends during compression, bubbles were found in 12% of the profiles. The Doppler Grade in the subjects while resting was almost exclusively Grade 1. The after-exercise grades were mostly 1 and 2, with one subject having a Grade 3. Some of these grades could have been caused by objects in the bloodstream other than bubbles, but as mentioned previously, when in question, it was resolved in favor of gas bubbles and a higher grade.

Discussion

The results of these tests indicate that it is safe to make repetitive dives in which the 40- or 60-minute tissue is the controlling tissue, and that minimal gas phase (bubbles) follows the dives.

The testing clearly validated the science behind the new generation of dive tables: the Recreational Dive Planner.

New Tables/New Benefits

The tables by DSAT, using a much faster controlling tissue as the basis for a repetitive system arranged in a greater number of pressure groups, give credit for surface intervals much more quickly. Using these tables, the diver may change pressure groups in as little as 4 or 5 minutes. For example, following a 30-minute surface interval after a typical dive, the diver changes 5 to 8 pressure groups. This becomes especially dramatic when more than two dives are performed. Dives totally prohibited by the Navy tables can have reasonably long bottom times using the DSAT tables. The apparent contradictions stem from the use of a 60- minute halftime compared to a 120- minute halftime. In summary:

1. The tables by DSAT were designed for recreational diving and use conservative limits to minimize or avoid the formation of nitrogen bubbles within the body, even at levels that do not cause decompression sickness.
2. The tables by DSAT were extensively tested using state-of-the-art equipment not available when the Navy tables were developed
3. The tables by DSAT are based on a theoretical tissue that is much faster than that used as the basis for the Navy tables, creating realistic credit for surface intervals and longer repetitive dives.

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