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Use of Tethered Scuba for Scientific Diving

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Abstract

Many scientific diving entities face logistical challenges in their data collection including high currents, low visibility, and high entanglement areas. We will discuss standard practices for use of tethered scuba for scientific applications to enhance both efficiency and safety of the scientific diver. We will examine relevant regulatory requirements and applicable standards of the federal dive community (e.g., NOAA, EPA) relative to the application to scientific diving. Finally, we will make recommendations to advance this diving mode within the scientific diving community.

Keywords: contaminated water protocols, decontamination, EPA diving, federal dive programs, polluted water diving, tethered scuba

Introduction

Tethered scuba diving is a tended diving method where one diver in the water is line tended by surface personnel and directed to perform a variety of underwater tasks, which could include light work or scientific tasks. OSHA also requires that standby divers for working dives be line tended. This method is much like that of surface supplied diving in many ways other than the virtually unlimited air supply. Typical tethered diving equipment, personnel, and procedure is described below.

Methods

The tethered scuba mode requires particular equipment and protocols, further discussed below.

Equipment

Tethered scuba diving equipment nominally includes standard diver dress, e.g., wetsuit/drysuit, fins, and weight belt, as well as particular equipment to tethered diving needs. These other items include a full face mask with voice communications, strength member with quick release snap shackle tether, hardwired or wireless communications, and man-rated safety harness rated for lifting the diver from the water. In addition, a cutting device is recommended for the diver within easy reach, e.g., EMT shears mounted on the harness.

Full Face Mask

The full face mask allows for hardwired communication and in conjunction with a drysuit with hood and drygloves will give the diver some protection from polluted water, when using the positive pressure version to minimize leakage.

Figure 1. EPA diver prepares to conduct an outfall survey.

When diving in non-polluted water, a wetsuit may be utilized. Typically, the mask is used with an ear/microphone attachment, such that the diver may be in constant hardline communication with the surface.

Tether

While any kind of line may be used in conjunction with line signals, typically a comm. rope is used to allow for constant communications with the diver. Care must be taken in tending the diver when moving in arc patterns (discussed below), that the line is not hung up and frayed on sharp underwater objects. The tether should be fitted with a quick release snap-shackle to allow the diver to egress to the surface should the tether become irreconcilably entangled in bottom debris.

Figure 2. Tether deployed on an EPA dive operation.

The tether may also be marked in intervals for measuring distances used in search patterns, for example. Tethers can be made in most any length, though 200 and 300 ft tethers are typical for most dive operations. Generally, the tether required must be the distance from the dive platform added to the depth to the dive site multiplied by 1.5 (NOAA, 2009), e.g., 50 ft from the dive site at a 50 ft depth would be 150 ft of tether. A tether longer than 300 ft can present some span of control problems with a dive platform under anchor, in adequately fending off nearby vessel traffic in a timely fashion. The tether should be stowed in a bucket or bag of some kind, with the tender end going in first, diver end last, to keep it from being stepped on and damaged, and to avoid tripping/falling hazards on the dive platform. The container should allow for easy decontamination and segregation of contaminated line from other gear.

Communications Unit

The communications unit is utilized by the tender while tending the diver's line to maintain constant verbal communication with the diver and standby diver. The tender communications unit allows the tender to talk with the diver via a headset and belt clip communications unit. The tender unit typically uses replaceable batteries, which should be changed out on a daily basis to ensure constant communications. The vessel should have one set of batteries per day for the dive operation, plus one spare set. Care should also be taken when installing batteries in the unit, as the battery compartment soldering can be quite fragile. Rechargeable batteries are beneficial for this purpose to minimize waste generation from daily dive operations. When connecting the headset to the belt clip unit, a "squeal" should initially be heard as the unit powers on. Absence of this sound can indicate that the batteries are dead, or that the unit is otherwise not functioning. When the unit is not in use, the headset should be disconnected from the belt clip unit to conserve battery power.

Harness

A diver harness is necessary to connect the diver securing to the tether line. Buoyancy compensation device (BCD) D-rings are inadequate strength members for this task, as they cannot support the diver's entire weight and dynamic load when the tender needs to quickly retrieve the diver.

Figure 3. EPA diver with a harness on, preparing to dress in.

Breakage of a BCD D-ring could result in serious injury to the diver, as the diver's head is connected to the tether via the communications cable, absent the secure harness connection. The harness is worn underneath the BCD or backpack on top of the wetsuit or drysuit. The harness should be rated to pull the diver from the water, in the event of an emergency on the surface or beneath the water.

Emergency Gas Supply

An emergency gas supply (EGS) is necessary for tethered diving operations should the primary air supply be exhausted. The EGS supply is typically controlled through a manifold block, connected to the BCD. The manifold block should have a one way valve, such that opening the block does not equalize the primary and EGS cylinders. The EGS itself may be a pony bottle connected to a larger primary bottle up to a fully redundant scuba bottle, depending on diving depth, and should include an overpressure relief valve on the first stage (Barsky, 2007). The overpressure relief valve allows pressure to escape should the emergency gas supply first stage malfunction and send higher intermediate pressures down the hose to the manifold block, which could rupture a hose.

Figure 4. A yellow 30 ft^3 (cf) EGS bottle pictured on an EPA Superfund Site sampling project on the Willamette River, Oregon.

The EGS bottle is left open for diving, while the manifold block is in the closed position, such that the diver is breathing off the primary air supply, but may access the reserve supply by simply turning the manifold knob, similar to a surface supply configuration. This is different than a non full face mask (FFM) configuration, where the pony bottle is normally left off (e.g., NOAA mouthpiece reserve air supply system or RASS) to prevent a free flow from emptying the reserve supply. A smaller EGS may be adequate for shallow diving, while a 30 ft^3 or larger size tank could be used at or below 100 ft. The size of the bail-out bottle is determined based upon the type of water, i.e., contaminated vs. non-contaminated, working depth, type of equipment, i.e., FFM vs. helmet and the air consumption rate of the individual diver. The EGS should be mounted upside down such that the diver can reach the tank valve, should it accidentally be left closed or bumped while underwater. A submerged pressure gauge must also be in plain view of the diver so that they may see the current status of their EGS bottle. For example, if the manifold block is bumped, the diver may start breathing off the EGS without their knowledge. Frequent checking of the primary gas supply SPG, bail-out block and EGS SPG will help to ensure that the diver is continuously breathing off the primary air supply. Also, as tethered diving is often used for low visibility situations, analog gauges should be used as digital gauges cannot be read when pressing the gauge directly against the FFM in true blackout conditions. For diving with a drysuit, the inflator whip should be connected to the manifold block such that suit inflation may still be achieved when using the EGS.

Personnel

Typically tethered diving operations consist of a three person team, the diver, the standby diver, and the divemaster/tender. Each diver will be continuously tended while in the water.

Diver

The diver, unlike in the conventional scuba diving buddy system, will be diving alone. This takes some adjustment for the diver, and reminders from their divemaster that they will be in constant communication with the surface. While this is planned vs. unplanned, e.g., buddy diving in low visibility water where buddy contact is soon lost, taking the dive slowly and not rushing through tasks is key to avoiding panic, but also in minimizing air consumption. While the diver is still responsible for checking their air supply and reporting this to topside support, unlike surface supplied diving, other adjustments are needed. Often the dive may be controlled from the surface depending upon the task being performed. If the dive is primarily surface controlled, the diver will need to adjust to not being primarily in control of their dive, i.e., the divemaster will be in constant communication with them, and will instruct the diver what to do, and when to do it. As with all dives, the diver or divemaster may end the dive for any reason.

Tender/Divemaster

The divemaster/tender will assist the diver in dressing in, tending the line, and doffing gear at the end of the dive. The tender should also be a diver prepared to dive each day, especially for deeper dive profiles. Divemaster responsibilities are the same as generally defined for buddy type scuba operations e.g., the divemaster continues to be in charge of the overall dive, except that they can hear the diver throughout the dive, and should be monitoring the diver constantly for signs of anxiety.

Figure 5. An EPA Divemaster visually checks the location of his tethered diver during a sample collection project in the Willapa Bay estuary, Washington.

Breathing rate of the diver is a clue to their mental status. As needed, the tender should ask the diver to stop what they are doing, rest, and breathe (e.g., more deeply or slowly). As with all dives, the Divemaster must remain undistracted such that they can monitor the surface for danger from incoming boat traffic and any other hazards.

Standby Diver

All tethered diving operations require a standby diver. The standby diver must be ready to get into the water within several minutes, and be dressed in their drysuit or wetsuit either half way, or fully at the divemaster's discretion.

Figure 6. An EPA standby diver fully dressed in at left/tender at right, Cordova, Alaska.

Procedures

As noted above, the tethered diving operation normally involves at least three divers. This allows for safe and efficient diving by rotating through the crew of 3, especially for deeper dive profiles. The 3 person rotation allows for ample surface intervals for the diver who has just dived, and then becomes the Divemaster/Tender, the diver who has been out of the water for the duration of the last dive, who becomes the standby diver, and the diver, who has been out of the water for at least two dives worth of time.

Donning Gear and Water Entry/Descent

The tender and standby diver assist the diver in donning gear as needed. Special attention is paid to placement and setting of the manifold block/EGS and verification that the diver can reach the block and EGS valves easily, and without looking, as tethered diving is often used in low visibility environments. The primary and EGS tank pressures are checked and recorded. Communications checks are performed and volumes/ear piece placement adjusted as needed. The diver is deployed with an extra loop of line available (to avoid jerking the diver during descent) and the tender arrests their descent into the water via the tether line and holds them at the surface until they can complete a mask check.

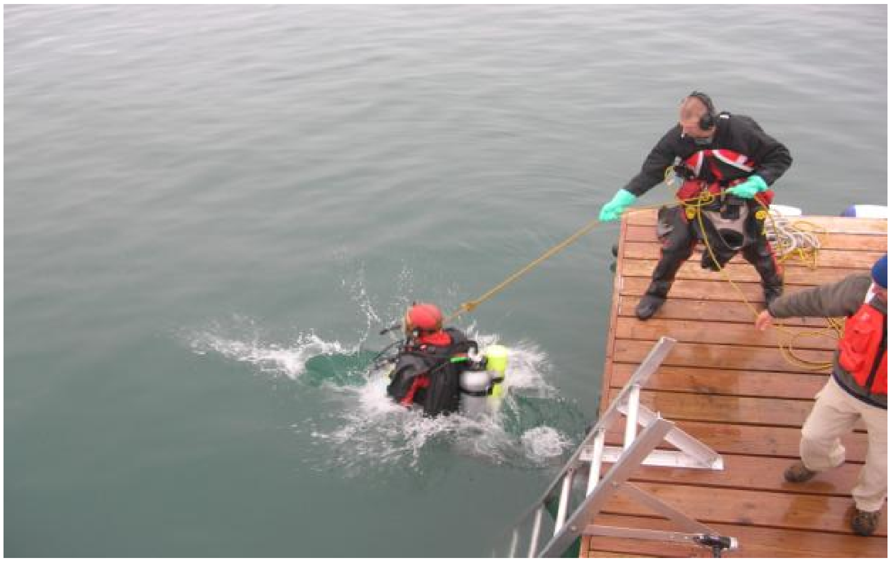

Figure 7. The tender uses both hands to arrest the diver's entry at the surface, with legs spread apart for balance.

The tender uses both hands to tend the line, so as to ensure that the diver is firmly held in place. The tether line is never wound around the tender in any way for two reasons: 1) the line may be contaminated, and this could leave polluted water and sediment on the tender, and 2), the tender could be pulled into the water with the line wound around them. The tender should use gloves to prevent chafing, and these should be covered by disposable gloves if there is any chance of contamination in surface water or sediment. Likewise, the tether should be managed in a portion of the dive platform considered to be the "hot zone" where it can be appropriately decontaminated and otherwise managed without tracking contamination throughout the vessel during tending at contaminated sites. The diver controls the rate of descent, including making requests for the amount and rate of slack given by the surface to ensure too much line is not paid into the water column, resulting in entanglements.

On the Bottom

Directing the diver is undertaken in a different manner than in buddy type scuba operations, where movements are relative to the tethered line itself. For example, the tender may instruct the diver to swim "toward the line," "away from the line," "take a 90 right," "take a 90 left," and so on. The diver trusts that the surface can direct them where they need to go, as in conducting a search pattern, "Hold line tension, and swim with the tether at your left." Surface may ask the diver to conduct search patterns via an arc, sweep, or out and back methods, using these line signals. Based on whether there is visibility on the bottom, this will determine the distance between diver sweeps (Hendrick, 2000).

Figure 8. An EPA diver prepares to withdraw a shallow groundwater sample from a Superfund Site on the Willamette River.

The surface will regularly ask for pressure checks from the diver, and the diver should also volunteer these to the surface. If asked during a crucial task for a pressure check, the diver should ask the surface to "standby." The surface will hold tension at all times, and release tension only when requested by the diver. Without tension, the surface loses good information on the status of the line, i.e., tangled or untangled, and may actually cause the line to tangle by allowing it to drag on the bottom. Absence of tension also prevents backup communications from happening as discussed in emergency procedures, below. Equipment may be conveyed to a stationary diver nearby the platform via a loop in the line. If this is done, tension should be maintained in the line should verbal communications fail. Once the tool is conveyed, all slack should be removed.

Ascent

The surface may control the diver's ascent, if the diver cannot control their own ascent due to weighting, currents, etc. Using the tether, the tender will give at least a 2 second count for every foot of line they pull in. When the diver nears the platform, the tender will instruct the diver to put up their hand for the last part of the ascent to protect their head from the hull of the vessel. The tender will remain on comm. until the diver is aboard and decontaminated, as needed. The line will be managed in the dive platform's "hot zone" with gloves such that it can be decontaminated at the end of dive operations, and otherwise managed to avoid material tracking throughout the vessel.

Doffing Gear

Decontamination (decon), such as a potable water decon, will take place as needed before other tasks, focusing on the mask and glove areas when conducting repetitive diving.

Figure 9. An EPA diver exits the water. Note the manifold block at picture center allowing the full face mask to be fed air from the primary or EGS tanks as needed.

The tender will ensure that the diver leaves the bottom with sufficient pressure to undergo whatever type of decon deemed necessary.

Vessel Operations

Vessel operations necessitate important tethered diving safety procedures, which include:

1. All boat/ship propellers must be deactivated prior to initiating dive operations.
2. A small boat must be on anchor before deploying the tethered diver.
3. Ships do not need to be on anchor for a ship husbandry dive, e.g., clearing a fouled propeller in deep water.
4. A bow and stern line should be available. While it is not required to be at a two-point or greater anchor configuration, sudden wind changes may necessitate a two point anchoring system to complete a dive safely.
5. If the boat were to swing on its anchor, it is important that sufficient slack is given and/or tension is kept on the diver to ensure they are not swept away in current, or subjected to sudden changes in pressure.
6. When operating near channel, a "Security" call should be made to all concerned traffic over VHF channel 16 and vessel traffic and channel 16 communications should be monitored to determine if large vessels are inbound.
7. An Alpha Flag (blue and white) as well as the standard diver down flag must be flown from the vessel during dive operations.

As the dive platform cannot fend off other boat traffic by means of physical presence, care should be given how far channel-ward a tethered diver is allowed to travel. Consideration of notice to mariners, broadcast of an encumbered vessel status either via VHF and/or automatic identification system (AIS) could also be considered.

Emergency Procedures

Before the tethered diver undertakes a working dive, it is important that they have practiced how to free an entangled line, disconnecting from the tether, unconscious diver rescue, and clearing a flooded mask in a training situation. During the dive briefing, backup communication line pull signals must be reviewed and memorized by the dive crew. See Table 1 for the US Navy Revision 6 Table 8-3 line pull signals. It is also important that the dive crew review what it sounds like for the communications cable wet connection for the hard line comm. to become disconnected underwater at the diver end. Absence of sound for the diver should indicate that they need to reconnect the plug, and/or begin using line pull signals to communicate their status to the surface. Consideration could also be given to taping the wet connection in place, to make it more difficult to become disconnected underwater. A fresh set of batteries should be on hand topside, in the event of communications loss, to ensure that voice communications can be re-established. A fully redundant tender headset and communications box might be kept on board in the event that these become flooded or cease operating.

Table 1. US Navy Table 8-3 (Revision 6) line pull signals.

Table 8-3. *Line-Pull Signals.*

From Tender to Diver		**Searching Signals (Without Circling Line)**	
1 Pull	"Are you all right?" When diver is descending, one pull means "Stop."	7 Pulls	"Go on (or off) searching signals."
2 Pulls	"Going Down." During ascent, two pulls mean "You have come up too far; go back down until we stop you."	1 Pull	"Stop and search where you are."
3 Pulls	"Stand by to come up."	2 Pulls	"Move directly away from the tender if given slack; move toward the tender if strain is taken on the life line."
4 Pulls	"Come up."	3 Pulls	"Face your umbilical, take a strain, move right."
2-1 Pulls	"I understand" or "Talk to me."	4 Pulls	"Face your umbilical, take a strain, move left."
3-2 Pulls	"Ventilate."		
4-3 Pulls	"Circulate."		
From Diver to Tender		**Searching Signals (With Circling Line)**	
1 Pull	"I am all right." When descending, one pull means "Stop" or "I am on the bottom."	7 Pulls	"Go on (or off) searching signals."
2 Pulls	"Lower" or "Give me slack."	1 Pull	"Stop and search where you are."
3 Pulls	"Take up my slack."	2 Pulls	"Move away from the weight."
4 Pulls	"Haul me up."	3 Pulls	"Face the weight and go right."
2-1 Pulls	"I understand" or "Talk to me."	4 Pulls	"Face the weight and go left."
3-2 Pulls	"More air."		
4-3 Pulls	"Less air."		
Special Signals From the Diver		**Emergency Signals From the Diver**	
1-2-3 Pulls	"Send me a square mark."	2-2-2 Pulls	"I am fouled and need the assistance of another diver."
5 Pulls	"Send me a line."	3-3-3 Pulls	"I am fouled but can clear myself."
2-1-2 Pulls	"Send me a slate."	4-4-4 Pulls	"Haul me up immediately."
ALL EMERGENCY SIGNALS SHALL BE ANSWERED AS GIVEN EXCEPT 4-4-4			

Figure 10. An EPA diver prepares to conduct a bottom search in the Toledo-Bend Reservoir, Texas.

A diver recall could also be kept on hand to supplement line pull signals should hard line communications be lost. The diver must also be prepared to disconnect from the tether, in consultation with the surface. The diver should not disconnect from the tether without first telling the surface, "going off comm." to ensure that the surface understands that communications will be lost for a period of time. Unplanned loss of communication (voice and line pulls) of the tethered diver should lead to immediate deployment of the standby diver unless the divemaster determines that conditions are too hazardous for rescue to be undertaken. For retrieval of an unconscious diver on the bottom, the standby diver would be deployed on tether, and follow the primary diver's tether to the bottom. Once with the unconscious diver, the victim should be oriented head up, and the surface notified that they may haul the pair up. For trapped diver situations, a "rescue bottle" could be maintained for the standby diver to convey additional breathing gas to a trapped primary tethered diver.

The rescue bottle could be outfitted with a quick disconnect coupling (female), so that the bottle may be connected underwater to the trapped diver's scuba bail-out block manifold quick disconnect fitting (male), along with a mouthpiece second stage and SPG.

Figure 11. A "rescue bottle" configured in sidemount fashion such that a standby diver mayferry additional gas to a trapped diver on the bottom. Note the brass quick disconnect fitting and mouthpiece regulator options for giving air to the trapped diver.

Discussion

Tethered scuba presents many advantages for the scientific dive program that must collect data in swift flowing water, low to zero visibility, or with a need for clear, constant voice communication for taking detailed scientific observations. Tethered scuba also offers advantages for emergency operations in deployment of the standby diver to effect an efficient and systematic search pattern for any missing diver in the buddy system. When deploying the tethered diver to rescue another tethered diver, it is understood exactly where the primary diver is due to their tether, making location of a tethered diver in trouble instantaneous. Use of the tethered diving mode allows collection of scientific data in areas that may be unsafe for standard buddy teams due to higher than usual amounts of entanglement hazards as a higher level of safety is achieved by knowing the diver's whereabouts and being able to constantly check their status. Tethered scuba also allows topside principle investigator/divemaster personnel to give specific, clear direction to a diver during data collection and even see what the diver is seeing when a camera umbilical is attached to the tether line.

Figure 12. An EPA diver conducts a video transect on a bottom dumping site. Both surface and diver observations are recorded during the survey.

Tethered scuba also allows topside personnel to pass tools to the scientific diver on the bottom rather than "bounce diving" to convey these tools to a standard buddy scuba buddy team, by looping an instrument to the tether and allowing it to slide to the bottom (within certain weight constraints). While the larger scientific diving community has been slow to embrace tethered scuba outside of ice diving/overhead diving environments, the NOAA diving program has been using tethered scuba for years now for a variety of tasks including ship husbandry and standby diver deployment. While NOAA tethered diving procedures are virtually identical to EPA procedures, NOAA has demonstrated the versatility of the tethered scuba diving mode in conducting various types of diving subject to different regulatory standards. On balance, the tethered scuba diving mode is a substantial advantage to any scientific diving program for the benefits to safety and efficiency of a wide variety of scientific missions.

Disclaimer: This paper is an illustration of steps to be taken to conduct tethered scuba diving operations and minimize the diver's exposure to polluted water conditions and is not the official view of the USEPA. Mention of any specific brand or model instrument or material does not constitute endorsement by the USEPA.

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