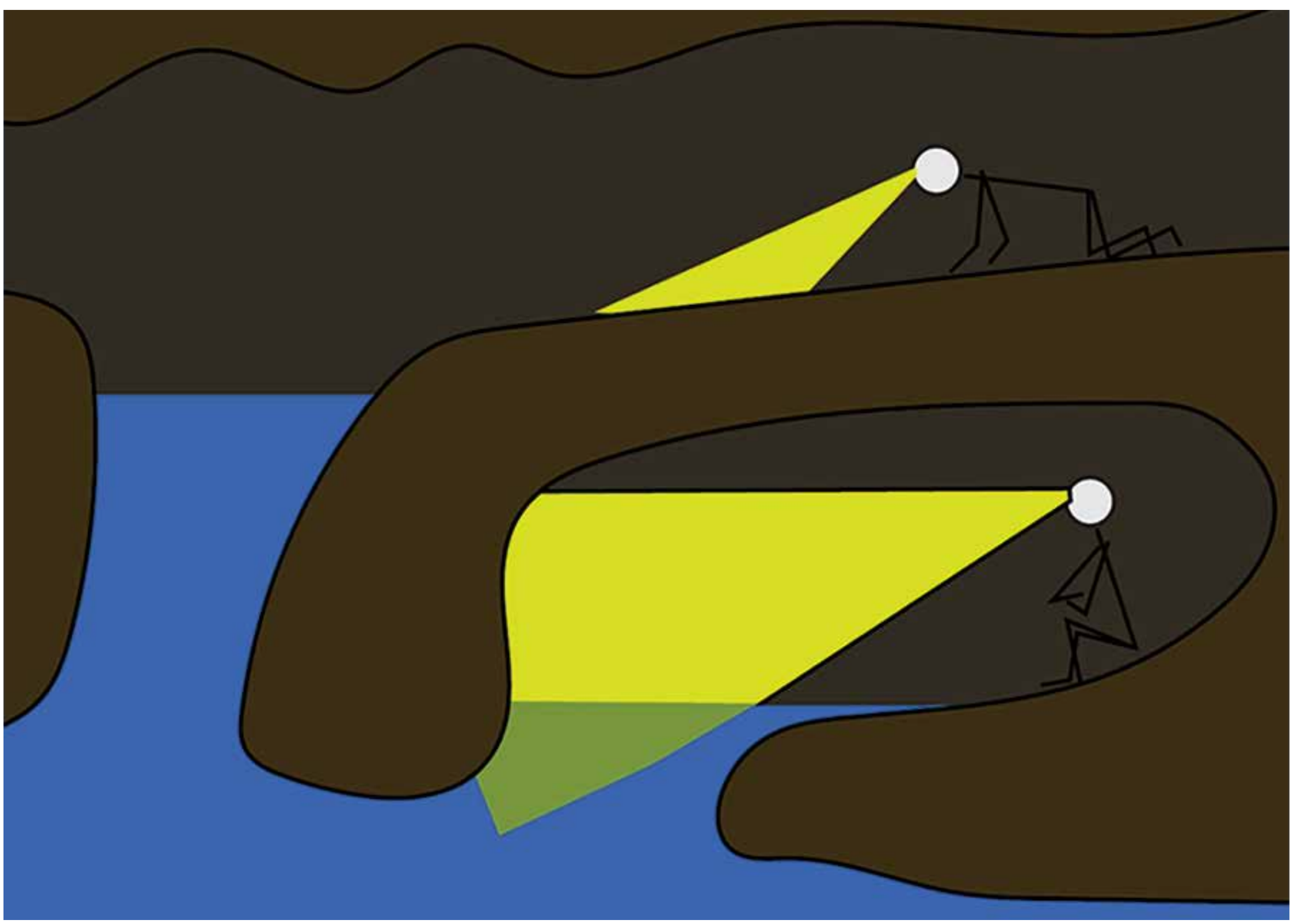
Conducting Rescues from Underwater Air Bells

by Michael A. Raymond

A friend of mine described a disaster situation he needed to plan for. A deep cave that he was exploring had the potential for massive flooding. He always kept an eye on the weather report, but wanted a contingency plan in case the cave started to flood while he was at its bottom. He presented his plan and wanted to know what I thought.

Near the bottom of the cave is a moderate-sized chamber. Its only opening is in the floor. He knew from historical records that the cave could flood to 60 m/200 ft above this chamber and that the water usually dropped all the way back down within four days. His contingency plan was to climb up into the chamber and wait out the flood. His hope was that since the air in the chamber had nowhere to go, it would be compressed but he would stay dry.

You can do the math of the situation at home. His decompression schedule is relaxed and safe. The problem is oxygen toxicity. He would spend a day with a pO_2 of 1.5 ATA. The author isn't positive of the effect, but doubts it is good.



Water in a typical underwater air bell is below the local water table. The elevated gas pressure in the chamber prevents the water level from rising. © Michael Raymond

There's another problem. Caves are where they are because that's where the weakest rock was. Limestone is a porous rock, and air leaks through it.

Each of us has noticed the air bubbling up from the sand as we've swum down the run toward the cave entrance at Ginnie Springs. It's the same air that was recently exhaled by divers in the cave tunnel below us. The same air that only momentarily formed a pocket on the roof of the cave. My friend's plan for surviving a flood was imaginative, but it would never work because the air in the chamber would leak right out of the ceiling.

There are several environments that would trap the air. Air bells are cavities with water at their bottom in which the only exit from the cavity is below the water level. In normal air bells, the water level sits at the same height as the local water table, and so the air in the cavity is not compressed. In underwater air bells, the water level in the chamber is below the local water table and is kept from rising by an elevated gas pressure in the chamber. Examples include diving bells and decompression habitats.

In this article we are going to look at rescuing people from underwater air bells. We will examine two mine rescues and two rescues from overturned ships. While neither of these environments are caves, techniques for sump rescue still apply here. By studying these incidents, cave divers can broaden their awareness of the factors involved in sump rescues and increase their ability to help others in a wider variety of situations.

Australia 1907

Modesto Varischetti was working 200 m/656 ft below the surface of western Australia in a gold mine. A major rainstorm caused a flash flood that swept into the mine and flooded the lower levels. Water filled from the twelfth level almost up to the ninth. Varischetti was working alone in a rise above the tenth level. He didn't notice the flooding until the water had risen almost 20 m/66 ft above his location, trapping him in an underwater air bell.

Once his fellow miners realized he was missing, they immediately initiated a rescue. They knew what part of the mine he was working in. They traveled to a spot directly above his location and were able to communicate with him by hitting the mine floor with hammers. They were mostly recent immigrants from northern Italy and used a tap code common to the region. The miners turned on the pump attached to the compressed air line going into his room. The line was normally used to power his tools, but in this case, it replenished his air supply.

The first attempt to use underwater breathing equipment for a sump rescue was in 1894, but Varischetti's rescue is its first known successful use. Hard-hat divers were brought in to ferry Varischetti supplies. The first diver reached him through low visibility and many entanglement hazards after Varischetti had been trapped for four days. Another diver helped manage the first diver's surface-supplied air hose.

The divers were able to regularly bring him meals, candles, and cigarettes. Some of the food had been peptonized (artificially partially digested) in order to help him in his weakened state. After nine days of captivity and hundreds of trips by the mine train hauling out water, Varischetti was able to leave his 7m/23 ft-long room. The lead diver carried him through now waist-high water in the tenth level to a ladder, where he was escorted from the mine.

Pennsylvania 2002

In July 2002, 18 miners were working in Quecreek Mine in Pennsylvania, evenly split into two groups. One group was working in an area they knew was near another long-abandoned mine, but they believed that the mines were still far apart. What they didn't know was that undocumented expansion had occurred at the other mine. They discovered this when one of their blasts broke into the other mine, which was at a higher elevation, and 75 million gallons of water starting gushing in.

This group immediately attempted to escape the area. First though, the men heroically took the time to contact the second group using the in-mine telephone system. This gave the second group enough time to escape the mine, though it was close. The first group, though, found its exit blocked by water and retreated to the highest elevation area it could reach. They were wet, cold, covered in coal dust, and without any supplies.

The rescue attempt started right away. Fortunately for the miners, the Quecreek mine was very well surveyed. Rescue personnel located the surface area above the most likely place the miners would have gone to, and started drilling a six-inch shaft 73 m/240 ft down to them. They also used seismic sensors to listen for hammer noise that the miners were trained to produce.

The 22-inch capsule used to rescue the Quecreek miners in July 2002. © Michael Raymond

Down below, the water was rapidly nearing the miners, and the oxygen in their area was running out. When the drill broke through the mine ceiling, the men used the pressurized air line that was powering the drill to refresh their air. Fortunately, the compressor was producing clean air, or their situation would have gotten even worse.

Something had to be done about the rising water. Huge pumps were brought to the mine, but they wouldn't be able to lower the water in time. The rescue team decided to seal the shaft they had bored, and pump in 90 psi of air. The sound was deafening to the miners, but the hot air helped keep them warm. Their part of the mine was at an elevation of 558 m/1830 ft and had a five-foot ceiling. Records show the water reached a maximum height of 560 m/1836 ft, which would have drowned them if it were not for the pressurized air preserving their air bell.

The rescue team then had to decide how to extract the miners. They considered using Navy divers, but this plan was rejected due to distance, route, and water condition. Their eventual plan was to drill a 26-inch shaft down to the miners and raise them in an old 22-inch rescue capsule. First, they bored down more six-inch shafts into deeper areas in order to add more pumps to the effort. The rescue team realized that decompression illness was a major threat.

To combat this, the Navy delivered 10 portable hyperbaric chambers to the incident site, and local engineers built a special compartment to go over the rescue shaft. The compartment would preserve the air pressure in the mine while the capsule was being raised and lowered.

The team decided that once the capsule reached the surface, they had 15 minutes to get the miner into a hyperbaric chamber. Part of the movement effort would involve cutting off the miner's clothing and washing him. Putting someone into a hyperbaric chamber while covered in coal dust was apt to lead to spontaneous combustion.

Fortunately, the chambers were never needed. By the time the rescue shaft was completed, the pumps had dropped the water level enough that the air pressure in the mine was back to normal.

All nine miners were successfully raised to the surface and flown at low altitude to the hospital. They were on the verge of hypothermia and very hungry after being in the mine for four days, but all fully recovered.

Pearl Harbor, Hawai'i 1941

When the Japanese attacked Pearl Harbor in December of 1941 and General Quarters was sounded, the Sailors of the U.S. battleship *Oklahoma* raced to their battle stations. Despite warnings about possible hostilities, the ship was awaiting an inspection, and all of its hatches were open. This meant that when it was struck by multiple torpedoes, it quickly began to flood.

Many Sailors stayed at their battle stations deep in the ship because they either had not been relieved, or because their leaders told them to stay there away from the falling bombs. This meant that when the ship rolled over and sank into the mud, they were trapped inside. The bottom of the ship was still above the water, but the compartments where the surviving Sailors were became underwater air bells.

The book *Trapped at Pearl Harbor* by Steven B. Young details his experience of being trapped in one of the turrets. He and the Sailors trapped with him were relatively warm. They had a few flashlights that they kept off most of the time to preserve the batteries. Their principal concern was that the water was rising, and they knew they were running out of oxygen.

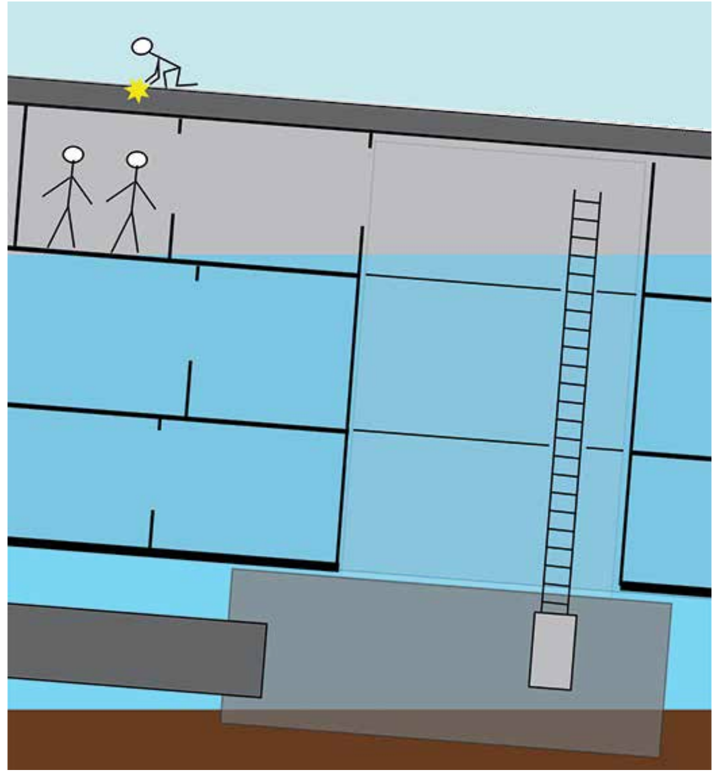
The Sailors were very familiar with their ship and knew there was an escape hatch at the top, now the bottom, of their area. Theoretically they could breath-hold dive down without any light, go through the hatch, swim along the deck of the ship, and then swim up to the surface. They didn't know if they could make it all the way, though.

At the start of their ordeal, several Sailors made the attempt. Some made it almost all the way to the hatch, thought better of it, and swam back up into the air bell. There was little talking, and no one shared that the way was clear. Other Sailors did make it all the way out of the ship and to the surface. Once on the surface, they were so exhausted from the effort that each one would have then drowned were it not for passing watercraft that saw them pop up and raced to retrieve them.

When people didn't come back, the Sailors inside didn't know if it was because they had made it, or if they had gotten stuck, which meant that the hatch would be even harder to get through. Eventually those who remained were in such bad condition from the bad air in the compartment that they collectively decided they did not have the energy for any more attempts.

Outside the ship, the rescue party working to save them had several complications. They could hear banging from inside the ship, but it was hard to precisely locate the source. They could not start cutting into the hull of the ship just anywhere. There were many fuel tanks in the hull, and cutting into one with a torch would ignite the fuel. Using a torch to cut into a small chamber also risked using up all the oxygen in the chamber and suffocating anyone inside.

The men inside the turret eventually broke open a door into a room beside theirs. With the tilt of the ship, it was higher and they could get out of the rising water. The expanded area also gave them more air to breathe. They were overjoyed to hear the rescuers cutting into the ship and getting closer.



Rescuers race against rising water in the U.S. battleship Oklahoma *at Pearl Harbor.* © Michael A. Raymond

When the rescuers began cutting into their room, a race began. When the first hole was made, their air bell was now broken. Air was escaping, which allowed the water to rise even faster. The Sailors didn't think to close the door in their new room and thus slow the rise. Eventually a man-sized hole was cut open. They padded it with mattresses, and everyone made it out of the ship before their area completely flooded.

Nigeria 2013

In June, 2013 the tugboat *Jascon-4* flipped over and sank nearly 30 m/100 ft to the bottom of the ocean. The ship had been helping to move an oil tanker off the coast of Nigeria while in high seas. The ship's cook, Harrison Okene, was unable to escape the ship and wound up trapped in an underwater air bell. None of the other eleven crew survived. The oil company immediately deployed divers to check the ship. They banged on the hull, and Okene banged back, but they didn't hear him.

Inside the ship, Okene worked to improve his situation. He tore apart the wall of the room he was in so that he could move to a larger area. He built a platform out of mattresses and the wall material so he could get out of the cold water. Okene was chubby, which helped keep him warm. He found one bottle of Coca-Cola to subsist on. He had two working flashlights, but they died after the first day. He could hear fish eating the remains of his fellow crew. When salvage divers encountered him on the third day, he was in very bad shape.

The oil company had hired salvage divers to remove the dead bodies from the tugboat. Their job was difficult for a number of reasons. The crew had locked all the doors as a precaution against pirate attack, and it took the divers an hour to break through them. The ship was upside down, full of debris, and slowly sinking into the ocean bottom.

After being trapped for 60 hours, Okene heard the salvage divers working on the ship, saw one diver swim past his position, and was fortunate to get a diver's attention the next time he saw a light. The video of their encounter is well known.

the temperatures of the air and water, the movement of the water, and the amount of time the persons have been there.

Can this equation be made simple enough to be useful to the incident response personnel? If not, we're left with our current rule of thumb that chambers with moving water replenish air "faster".

Moving water is likely a factor in Okene's survival in 2013. When experts ran the numbers for his situation after the fact, they found that he should have died at two and one-half days. This is the same amount of time that it took the salvage divers to get to him. His agitating water while struggling to stay on his small platform may have had a tiny benefit—water with more saturated O_2 and less saturated CO_2 may have then been exposed to the room.

Sump rescue skills translate to mining and shipwreck accidents. Special considerations include protecting the integrity of the air bell and having a decompression plan for the entrapped persons.

The salvage divers did a great job with rescuing Okene. When they found him, he was delirious, suffering from CO_2 poisoning, and short of breath. They fitted him with a diving helmet and harness and then gave him a 20-minute diving lesson. Okene remained calm throughout his extraction from the ship, which helped tremendously. The divers took him to a dive bell, which brought him to the surface where he was put into a decompression chamber for 60 hours. Okene fully recovered, though now he refuses to return to the sea and suffers nightmares of his ordeal.

Discussion

The sump rescue community needs a simplified way to calculate air replenishment for "small" chambers. Certainly the full solution can be calculated numerically. Take the volume of the chamber and factor in the respiratory rates of the trapped persons, the surface area of the water touching the chamber,

Movement by the trapped Quecreek miners probably had more of a negative effect. As the water rose, the miners struggled to build a series of barriers to keep it at bay. The water was rising so quickly that it quickly bypassed each of their attempts. They were following their training, but their physical exertion likely only exhausted their air.

An interesting additional issue is whether it is safe to use a Palmer Furnace or similar method to warm up your patient. The literature seems to suggest that in oxygen-enriched environments, fires are more affected by the percentage of oxygen than its partial pressure. Therefore, if you are in an area with compressed air then you should be able to safely operate a flame, whereas in an area full of nitrox or similar, it is recommended against. Most underwater air bells tend to be small areas though, and so fire should be avoided to prevent the depletion of oxygen and creation of harmful gasses.

Lessons Learned

Several lessons can be drawn from these rescues. In mine—and likely cave—rescues, the sooner you can start using pumps and the more pumps you can use, the better. Make sure that someone is watching and ready to react if one of the trapped people attempts to free dive out. Be prepared to deal with bad air when you encounter someone.

These rescues reinforce the first two parts of the ACME rescue acronym:

- **A**ir quality,
- **C**oherence as an indicator of the patient's mental status,
- **M**edical condition, and
- **E**xit plan.

Rescuers should step through this sequence upon coming up in an air bell and finding one or more of the missing persons. Remember, in cave rescue, it is almost always the cave environment that kills you, and not a debilitating injury.

Conclusions

Underwater air bells of sufficient size to shelter in are completely unknown in the caving world. They do happen in the worlds of mine and shipwreck rescue though. Sump rescue skills are applicable in these environments, but rescuers should be aware of the special requirements. These include:

- protecting the integrity of the air bell, and
- having a decompression plan for the patients.

Using this knowledge, cave divers can be able to assist their communities if these special circumstances arise.

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Michael A. Raymond is at work on a series that explores controversies and best practices in sump rescue. He is Associate Editor for Underwater Speleology.