The case
On August 22, 1986, Milla was returning to his village of Lower Nyos, Cameroon. He had spent the past week with his small cattle herd in the highlands, where grazing was much better at this time of year. It was early morning and Milla was slowly approaching the village. He looked forward to hearing the voices of his fellow villagers. It was rare to see, much less talk, with another person in the highland fields.

The last few months had been warm and dry in the lowlands, but now the temperature was cooling. In fact, it had been quite cool the past few nights and the late summer rains were returning. Milla could tell that it had rained hard the night before. The ground was still wet in places. But something was different. Usually when conditions were this wet, the insects, particularly the biting flies, were very active, but Milla hadn’t had to swat a single mosquito. Suddenly, Milla noticed an unusual sight just off the path. It was a lone cow lying motionless in the grass. Milla was sure it was dead, but he wanted to identify it so he could inform the owner once he arrived in Lower Nyos.

Milla’s own cattle had slowed down because of the wet ground, which gave him a chance to investigate. He often encountered dead animals along the commonly traveled paths but rarely cattle, and something was very strange this time. The carcass wasn’t warm, so it had been dead for some time, but there was no rotting smell, no swarming flies.

Milla began to worry. As he surveyed the area, looking for some clue that might help him understand this strange sight, it only got worse. He noticed another animal a few meters away. Same situation: a dead cow and no signs of decomposers. Ominously, he could see many more cattle lying on the ground.

Frightened, Milla began to run down the path. He knew that the Achirri family lived just outside the village. He would wake them and they would help him to understand this strange scene of death. As he approached the Achirri home, he repeatedly called out to them, “Achirri! Achirri! Please come see the cattle! They are lying dead in the fields. All of them!”

By the time he reached their door, he was short of breath. He was so upset he almost entered their home without permission. Again he spoke in breathless tones, “Please, Achirri, wake up and follow me into the upper field. They are dead. The cattle are dead and no life can be found!” But there was no response.

Looking through the doorway, Milla could see that the family was still in bed sleeping. He spoke louder, “Please wake, I have to show you the cattle lying dead in the upper field! Please wake up and come with me!” No one stirred.

Frantic, Milla went inside the house and began to shake the man in...
the bed nearest the door. “Achirri, you must wake! You must wake!” When there was no response, he leapt over to the other bed and tried to wake the woman, but with the same result.

With no regard to his own cattle, Milla ran into the village. Along the path he could see the occasional dog lying motionless. It appeared as if everything was dead. To his horror, the scene he had encountered by Achirri was repeated many times throughout Lower Nyos. Whole families were lying on the ground, as if they had lain down to sleep never to wake again. Many of them were noticeably blue around the lips.

Milla remembered the story his grandmother told of the myths of the Water Mammies—spirits of the dead who inhabited the lake’s depths and who, when angered, would come out and kill villagers. Surely this is what had happened, Milla thought. He must get to the elders who knew of such things. They stayed on the higher ground outside of the valley.

The elders were disturbed to hear Milla’s story of the death in Lower Nyos. Much to his surprise, however, they told Milla that it could be the lake that caused the death and not vindictive Water Mammies. These wise men had heard of a similar event that had occurred at neighboring Lake Monoun two years earlier. There, 37 villagers were found dead. Limnologists and volcanologists had determined that the lake was the source of a huge gas cloud that erupted from the lake and moved along the ground. Everyone in the vicinity died of asphyxiation. The cloud erupted because volcanic activity, which had created the lake, had also caused the lake to de-gas a huge amount of carbon dioxide that was stored in the bottom layer of water.

The elders had been visited just a few weeks earlier by an expedition of limnologists. The elders assured Milla that they would contact the scientists to see if they could help shed light on what had happened in Lower Nyos. In the meantime, word would be sent to neighboring villages to help bury the dead villagers of Lower Nyos.

Over 1,700 people died in Lower Nyos and thousands more in the region were left homeless and sick. In response, the international community sent doctors and relief workers, as well as scientists, to the region. When the limnologists finally arrived, they were taken out onto Lake Nyos (Figure 1).

The water of the lake had an odd rust color and large amounts of vegetation were floating on the surface. Once the scientists had reached a deeper section of the lake, the team leader dropped his Van Dorn bottle overboard and let it sink to the bottom of the lake (about 208 meters down). When the water sample was retrieved and the near ice-cold water poured into the sample jar, it looked as if an Alka-Selzer tablet had been dropped into the jar. Gas was violently bubbling out of the water. Immediately, the team leader ordered a vertical profile of temperature, pH, and conductivity. After reviewing the data, the limnologists went back to the village to discuss their results. When they learned that the victims were blue-lipped, suggesting asphyxiation, and that the victims were all from the area within the valley leading away from the lake, they believed that the lake was the cause of the deaths.

Do they have enough evidence to show that the lake is responsible for the deaths of the livestock and people?

Questions
- How are many of the lakes in this region of Cameroon formed?
- How else can volcanoes form lakes?
- What clue helps us determine that the people of Lower Nyos died of asphyxiation?
- What gases could be accumulating in the deeper waters of Lake Nyos?
- How might the volcanoes affect the gases in the lake?
- In limnological terms, where was the gas accumulating?
- What is meromixis, and what might it have to do with this story?
- What caused the reddish, rust color of the water?

Teaching notes
In this case study, students are presented with data on a particular lake that they must synthesize in order to determine the cause of an event that occurred in 1986 in Cameroon, Africa. Because this case is a dramatization of an actual event (all the names used in the case are fictitious), the horrifying result—over 1,700 people dead—is the intended “hook” into the case material. Thus, I have intentionally played up the emotions associated with the deaths that occurred.

The case is intended for use in a limnology or an aquatic biology course. Ideally, students would have been introduced to a few key concepts about lakes, including lake formation, thermal stratification (particularly in meromictic lakes), and dissolved gases. This background knowledge allows students to put together the necessary pieces of information. Thus, in a limnology course that follows the common textbook chapters (e.g., Wetzel 2001; Goldman and Horne 1994; Kalff 2001), students learn about geomorphology/basin morphology in the first few lectures, then move on to other physical topics (water properties, movement, light, and thermal aspects). If this progression is followed, this case could be used after thermal aspects are covered. Conversely, the case could be used to introduce any of these concepts, in which case students would read the case study without any previous exposure to the limnological concepts involved.

The original intent of the case was to introduce and reinforce the concepts of thermal stratification and use students’ curiosity about this event to get them to think about how layers of water develop. The case could also be extended to cover or review other concepts such as lake formation (in this case,
volcanism as a lake-forming process) or gas solution (in this case, carbon dioxide solution). The case could also be used throughout a limnology course because it deals with many aspects of the subject: lake origins, thermal stratification, gases, water movements, and applied limnology (remediation of problems). Instructors can introduce the case early in a course and refer back to it when each new topic comes up.

Objectives
Upon completion of this case, students should be able to:

- List the types of lakes that can be formed through volcanic activity and identify the characteristics of such lakes.
- Distinguish between holomictic and meromictic lakes.
- Describe the limnetic conditions necessary for meromixis to form in a lake.
- Identify the vertical zones of a meromictic lake.
- List the possible dissolved gases associated with lakes.
- List the sources of and factors affecting the quantity of dissolved gases in lakes.

Classroom management
The case is intended to be covered in a typical 50-minute lecture period but could be expanded into a 75-minute lecture period. Because the case narrative is not particularly long, it can be handed out for students to read in class. My limnology courses never have more than five students, but if your class is large enough, small groups may be used.

Students are given approximately 10 minutes to read the case. Then, with the instructor’s help, they are asked to identify the facts in the story. Board work from the instructor becomes important here. I recommend that you list the facts on the board under a heading such as “What We Know.” If students are having trouble generating the facts, the instructor may ask leading questions, such as:

- In what part of the world is the lake located?
- What is this particular region’s dominant geologic characteristics?
- Besides the villagers, what was affected by the event?
- What was the weather like at the time of the event?
- Why are the elders focusing on the lake as a cause?
- What samples were taken by the team of limnologists?
- How deep is the lake?
- Describe the water that came from the lake’s depth.
- Describe what the lake looked like when the limnologists arrived.

After about 10 minutes, ask students what data they want to have that will help them determine the cause of the event. Ideally, they will ask for the limnological data being collected, specifically the vertical profile data. The instructor can then hand out graphs of temperature, dissolved oxygen, pH, and conductivity (see Resources), depending on what variable they want to see. However, do not give out data that they have not asked for. This is the point in the class where the instructor will see if students are able to connect various types of concepts to actual data (connecting theoretical and applied concepts).

Give students several minutes to look at the data, and then ask them for their interpretations. The instructor may want to start another list on the board under the heading “Limnological Data Interpretation.” If students do not respond without prompting, ask questions such as:

- Is the lake stratified?
- What type of stratification do the data suggest?
- Which data are you using to determine this?
- What do the pH data tell you?
- What was the significance of the lake’s color?
- What is the origin of the gas in the deepest water layer?

Depending on time, each answer could be followed up with probing questions to make students reveal that they understand (or don’t) the physical properties involved. For example, the instructor can ask, “What type of stratification do the data suggest?” to which students would correctly answer, “Meromictic stratification.” The instructor can ask, “How is meromictic stratifi-
fication maintained?” to which students would correctly answer, “Through density differences.” The instructor can ask, “What is causing the density difference in that deepest layer?” to which students would correctly answer, “Often chemicals dissolved in the water, such as salts, increase the density.” Or the instructor can ask, “What is maintaining the density in this situation?” to which students would correctly answer, “Probably something to do with the gas that is bubbling out of solution, likely very high carbon dioxide concentrations. Soda water is denser than regular water.” Assessing the limnological data can take the remaining class period, but leave at least 10 minutes for a conclusion.

To conclude, when you feel that students have enough information present on the board, ask the million dollar question: “What happened here? Gases built up in the hypolimnion due to the meromictic stratification, but why did it bubble out of solution and eventually ‘burp’ a huge cloud of carbon dioxide?” If students are having trouble, ask them: “Why is this event called a limnic eruption, and a violent one at that?”

In working through the case, students tend to bring up the question of how the people died. I have given only one clue: the blue coloration around the lips, which indicates asphyxiation rather than overexposure to some poisonous gas. This leads to carbon dioxide. One of the original theories for such mass deaths was from exposure to the toxic gas hydrogen sulfide. That gas does tend to accumulate in hypolimnetic waters in strongly anoxic conditions, given a sufficient sulfur concentration, which would have been expected in a volcanic region. The reason that the carbon dioxide accumulates is because the monimolimnion does not mix annually. Regarding what caused the lake to mix, clues in the first paragraph indicate that the weather changed recently. It is believed that the storm that came through the area cooled the surface waters and weakened the thermal stratification. Then winds provided enough energy across the lake’s surface to mix the upper and lower layers of water. Once a small bubble of CO2 formed in the monimolimnion, it started a chain reaction that caused a massive degassing by “pulling” other bubbles with it.

Possible follow-up assignments
The assignments described below could be given to students to do outside of class. The instructor may devote another class period to discussing their answers, as both assignments can be used to further discuss limnology topics (tectonic lake versus glacial lake limnology). The second assignment can be used to bring in the concepts of applied limnology and engineering.

Assignment 1: Have students find other regions of the world where lakes are formed predominately from a type of geologic process. For example, the big lakes of the African Rift Valley (Victoria, Tanganyika, Nyasa) are mostly of tectonic origin; they are all graben lakes (a graben is the depression left by a shift in land due to tectonic movements; graben lakes are lakes formed by the filling in of these depressions). How does the origin of lakes affect limnological properties? Give specific details and examples to support your answers.

Assignment 2: Given the fact that follow-up sampling indicated that gases are continuing to build up in the lake and could possibly repeat this tragic event, how might scientists and engineers help the people around Lake Nyos?

A wealth of information is available on how the problem in Nyos was solved. A major degassing of the hypolimnion was the solution of choice. Additional information regarding the progress of the solution, as well as numerous pictures, can be found at perso.wanadoo.fr/mhalb/nyos/project/indexproj.htm.

References

Online resources
Continuous temperature profile in Lake Nyos and Lake Monou, November 1999—www.sciencecases.org/lake_nyos_a/handout1.asp
Selected data on water chemistry for Lake Nyos, November 1999—www.sciencecases.org/lake_nyos_a/handout2.asp
Temperature and conductivity profiles—www.sciencecases.org/lake_nyos_a/handout3.asp
Concentrations of CO2 species, hydrogen ion (pH), and TDS, December 17–18, 1988—www.sciencecases.org/lake_nyos_a/handout5.asp