Lake Nyos Dam Assessment

Cameroon, September 2005

Joint UNEP/OCHA Environment Unit

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Cover: Overview of Lake Nyos, Cameroon

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Executive summary

Upon request from the Ministry of Territorial Administration and Decentralization of Cameroon, the Joint UNEP/OCHA Environment Unit deployed of an assessment mission to assess the stability of he natural dam in Lake Nyos, Cameroon. The main findings of the experts are summarized below.

- ***A breach of the natural dam in Lake Nyos, Cameroon, is imminent within the coming 10 years, with a high likelihood for this to occur within the next 5 years;***

- ***Such a breach will lead to severe flooding in the downstream Nyos Valley, affecting an estimated ten thousand people in Cameroon and Nigeria;***

- ***In addition, the breach will likely lead to a reoccurrence of the 1986 carbon dioxide eruption affecting a further unknown number of people;***

- ***It is strongly recommended that the Cameroon Authorities, at the highest level, decide on an approach to prevent the dam wall from breaking and facilitate the return of 12,000 displaced people from the 1986 disaster;***

- ***The proposed mitigation project includes the pumping of water from the deeper levels of the lake containing high concentrations of dissolved carbon dioxide. The water level should be reduced with 20 meters after which the dam wall can be removed using explosives. This will create a level outlet from the lake into the Nyos Valley;***

- ***A sustainable programme for the return of displaced people during the 1986 disaster should be developed and integrated into the Lake Nyos Mitigation Project;***

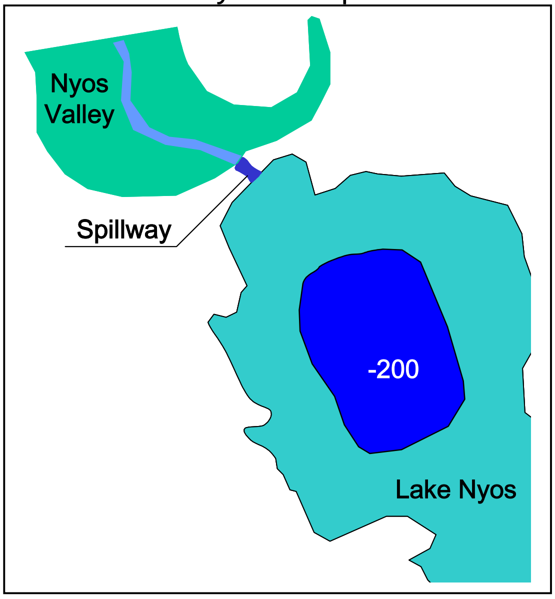
- ***The costs of the mitigation project are roughly estimated at 15 million USD and could be accomplished within 2 years;***

- ***Further design is required for the execution of the project.***

Introduction

This report is intended for decision-makers in Cameroon and potential donors interested in the problems associated with the dam/spillway of Lake Nyos in Cameroon. The report provides information and background to an assessment mission, organised by the Joint UNEP/OCHA Environment Unit in September 2005.

Continuing erosion of a natural dam wall in Lake Nyos has put the dam at a point of potential collapse. Lake Nyos is a 200-meter deep fresh water lake situated in Northwest Cameroon (see picture on front page). Its dam wall consists of (pyroclastic layers of) gravel, rock and mountainous soils and is subject to erosion from rain, wind and the lake waters. A collapse of the dam wall would not only result in floodings downstream, affecting an estimated ten thousand people in Cameroon and Nigeria, but also the collapse could lead to the release of carbon dioxide[1] that is dissolved in the deeper layers of the lake. Such a sudden release, or eruption, happened in 1986 and killed more than 1,700 people.



Media reports in mid-August alerted the Joint UNEP/OCHA Environment Unit (Joint Unit) to this potential disaster. Subsequently, through direct liaison between the Joint Unit and the UN Resident Representative, the Ministry of Territorial Administration and Decentralization of Cameroon requested, the deployment of an assessment mission. Through its brokerage mandate, the Joint Unit mobilized two experts from the Ministry of Transport, Public Works and Water Management of the Netherlands.

The experts conducted a technical and impartial assessment of the current status of the dam wall, evaluated the likelihood of a collapse and identified measures that can prevent a collapse and/or reduce its disastrous consequences. The assessment took place through a review of existing written material on Lake Nyos, interviewing academic and government officials as well as an on-site inspection. The mission was carried out in close cooperation with the Department of Civil Protection in the Ministry of Territorial Administration and Decentralization and the United Nations Development Programme in Cameroon. The findings and recommendations are based on

[1] Carbon dioxide is a colorless gas which, when inhaled at high concentrations, can cause asphyxiation (suffocation).

the experience and knowledge of the persons that have been interviewed, combined with the experience of the experts. The assessment mission took place between 22 and 29 September.

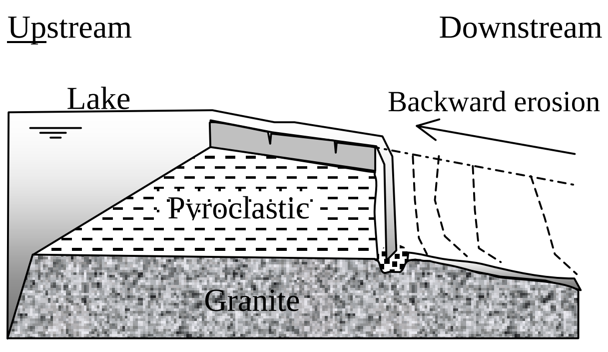
Current situation of the dam

The dam at the northern end of the lake has obviously receded since its formation some 400 years ago. The dam consists of (pyroclastic layers of) gravel, rock and mountain soil. The area surrounding the lake shows traces of nearly vertical landslides and rock falls. In addition, downstream of the dam old and recent landslides can be identified. There are even indications of landslides will occur at the section of the dam just east of the spillway. It is evident that landslides will occur in the coming years thereby seriously endangering the overall stability of the dam. Leakage is visible through the soil mass.

During the rainy season the lake drains over the spillway into the Northern dam. At the downstream end, the water runs over a cliff in a 40-meter high waterfall. At the spillway the dam at its most narrow point and below the spillway large boulders indicate earlier collapses of the front, causing the waterfall to recede. The chances for a breach are increased by erosion at the top, erosion at its base, hydrogeochemical erosion and piping. Yet, the dam is kept between the adjacent soil bodies and derives parts of its stability from these. Breaching of the spillway would always include failure of part of these soil bodies as well.

Vertical erosion (potholes, fractures, dissolution of the top) will lower the crest level of spillway gradually. This would very slowly reduce the lake water level over time, but it would not cause a breach. It is therefore not considered critical.

An on-site inspection of the lake and its spillway took place on 25 September. The spill was inspected from both its up- and downstream sides. Observations made during the inspection clearly showed the displacement of large boulders. In addition, deep cracks and potholes on top of the spillway showed the impacts of ongoing erosion. This erosion causes a regression of the waterfall toward the lake. Thereby the dam becomes narrower over time. This is not only at the spillway, but the whole dam has eroded in this way.



Cross section of the spillway

An important finding was that not the spillway, but the adjacent soil structures, appear to be the weakest spot in the dam area. The dense surface vegetation indicates an extremely humid soil, which further reduces the strength of the spillway. Also the roots of trees create little waterways, weakening the structure further. Caves in the soil structures at the lakeside were also detected leading to the conclusion that the stability of the spillway is affected from both sides and the soil structures, which hold the dam together, are far more likely to collapse first. Remaining questions include when a new rock fall will occur and if so, at which location this will take place. These questions will determine ultimately the strength of the dam.

Finally, seismic activities or another gas burst comparable to the one in 1986 (which reportedly caused a 6 meters flood wave over the dam) may induce a breach. Thus, the spillway constitutes a significant risk, but the adjacent soil structures, especially at the eastern side, are considered in far more critical condition.

Resuming, the risk of a breach is substantial and a breach is likely to occur in the coming 5 to 10 years, with a high likelihood of occurrence in the next 5 years. This might be tomorrow, the day after, or next year. A breach is more likely during the rainy season when the water level of the lake is elevated.

Carbon dioxide in Lake Nyos

National and international experts have studied the phenomenon of the carbon dioxide in Lake Nyos in great detail, since its deadly eruption in 1986. The lake is situated in a volcanic crater. This volcano releases carbon dioxide gases into the water at the bottom of the lake. The gas dissolves in water (like salt). However, on 21st August 1986 a gas cloud erupted from the lake causing the suffocation of more than 1700 people. The primary cause of death by gas is through suffocation as carbon dioxide displaces the normal air and oxygen. Carbon dioxide gas is heavier than air and travels like a cloud over the ground, until it dissolves. In 1986, such a cloud went down the valley killing people and cattle within 27 kilometres of the lake.

Variations in water pressure can cause (temporary) oversaturation of the dissolved gas. As a result, the gas may be released and, subsequently, the water containing the gas will rise and cause a gas eruption at the surface. Any tampering with the lake may induce a similar outburst of gas, which interferes with measures to reduce the risks of a dam breach. At the same time, a major dam breach will surely induce a very large gas burst.

In addition, variations in water level could also result from external distortions, such as avalanches (rock falls, landslides), small seismic activities, heavy rainfall, or human interference. In 2001, measures were effectuated to reduce the gas risk (see annex 2).

Displacement of affected people

As a result of the imminent risk of another gas burst, the population around Lake Nyos have been evacuated to areas distant to the direct vicinity of the lake. To date, an estimated 12,000 people have been displaced and reside in shelters at higher areas in the hills. They have been displaced for almost 20 years. There is a strong desire from the displaced population to return to the Nyos Valley and surroundings of the Lake. As they are currently situated at higher altitudes, their lives would only be threatened in case of a considerably larger gas burst, which is very unlikely.
The Nyos valley is still unsafe for people to live in. However, people are gradually returning to the valley to grow crops and graze their cattle. Some of them are also living in the valley, contravening official policies. There are also cases of people moving into the valley and claiming land of the originally displaced people. Therefore, it is important that a long-term solution will include the safe return of the affected people and provide safety for the population further downstream.

During the assessment mission, the Buabua-Kimbi Lake Nyos Suriovivors Cultural and Development Association and the Nyos Cultural and Development Association made official humanitarian pledges for further assistance.

Suggested approaches

The current degassing project has a life expectancy of 30 years (see annex 2) and strengthening of the dam wall should not wait till the accomplishment of this project. By that time, the dam will already have breached and the affected population will already have been displaced for 50 years.

A controlled breach of the dam would be a possible way to reduce the pressure in the lake. The top water layer would be drained off leading to an abrupt reduction in the water pressure at the bottom of the lake, which will induce a gas burst. This scenario would result in a catastrophic flood wave, followed by a suffocating gas cloud.

Relocating the affected population will be a time-consuming and complex operation. Any relocation should preferably be carried out in the primary interest of the affected population and should involve sufficient participation. Further, such relocation will require extensive government commitment and involvement at administrative, legal and political levels. Humanitarian interest groups will most likely also be involved. Therefore, a suggested programme for the return to the Nyos Valley should be undertaken simultaneously with the dam safety project.

For the medium and long term, strengthening the dam would be a logical solution, but this is hardly feasible, very costly and considered uneconomical. Leaving the situation ‘as is’ implies endangering the lives of some ten thousand people in the downstream area of Cameroon and Nigeria. This leads to the recommended solution of reducing the level of the water by 20 meters and siphoning the carbon dioxide rich water from the bottom of the lake using semi-giant pipes. As reducing the water from the top of the lake means that the gas will burst out, it is not considered an option. The lowering of the water level will considerably reduce the pressure of water on the dam, minimizing in this way the risk of any future collapse. After the water level has dropped by 20 metres, the top of the dam can be removed, providing the lake with a natural and level run off. This project would imply a temporary risk for a gas burst, which requires additional measures.

A sustainable relocation programme for the resettled population should accompany the lowering of the water level. In addition, improvements are needed on access road to Lake Nyos for the efficient implementation of the technical components of the proposed project.

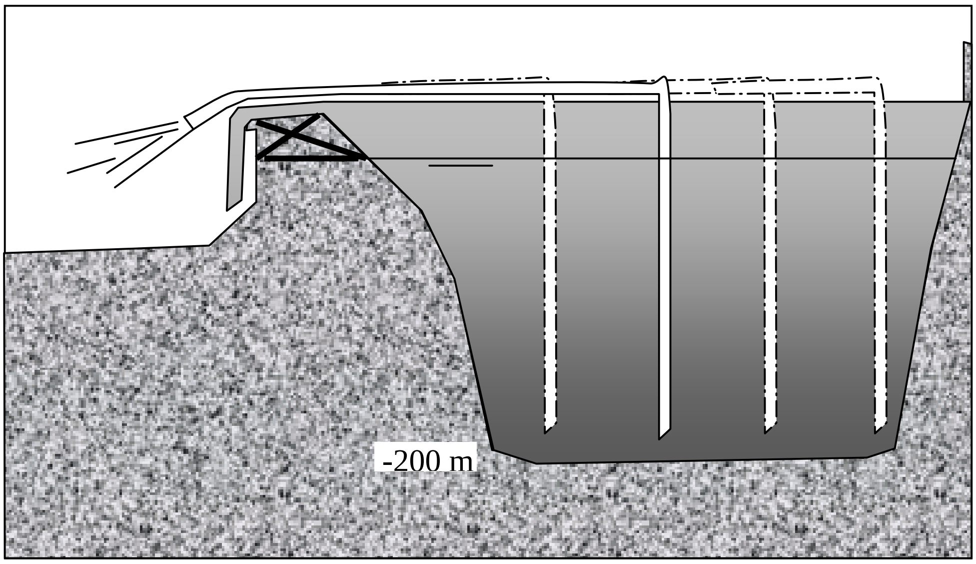
Lake Nyos Mitigation Project

The proposed Lake Nyos Mitigation Project would consist of the following steps:

- Rehabilitation of the road from Bamenda to the lake, to enable contractors to mobilize equipment and materials;
- Production or purchase of materials (pipes, valves, floats, etc.) for the release of the water;
- Transport of the equipment and the materials to lake Nyos;
- Installation of the whole system for operation;
- Operation of the system for 3 to 6 months;
- Reduction of the crest height of the spillway with 20 meters by use of dynamite;
- Preparation of two pipes for permanent degassing;
- Demobilization.

The implementation period for the project requires at least two dry seasons; one to improve the road to the area, and another for discharging the water (and gas) from the lake. As soon as the water level has been lowered, the affected people could be allowed to move back into the valley.

The rehabilitation of the road to Nyos is actually a separate part of the project, to be taken up first. At best it shall be carried out in the coming dry season. It can also be tendered separately from the rest of the project, if that would speed up matters. This project has already been defined in view of other objectives previously and would be a worthwhile undertaking in any case.



The design of the discharge system is yet based on a discharge of 50 m^3/s, assuming that this is close to the maximum discharge over the spillway in the wet season in the present condition. This will ensure that the river in the valley can handle the discharge without any further measures. With 50 m^3/s, the lake water level will reduce slowly. Assuming a lake surface area of 1.5 km^2, it will reduce the level at a rate of 2.88 meters per day. As this will probably be too fast in view of the gas stability within the lake; a lower rate of e.g. 0.25 meters per day will be applied. In this case, it will take 80 days (3 months) to drop the lake water level by 20 meters.

Only after a decision to accept and implement the project, further design details of this project are required. Aspects that will need to be further elaborated and designed are:

- The speed of reducing the water level in the lake, in view of the stability of the dissolved gas. In this respect the natural water level variations during the wet and dry season are relevant references;
- The pipes: pipe layout, number of pipes, pipe size, location of pipes, and location of alternative discharge points;
- The target crest level of the spillway: for now the target level is suggested at 1071[2] meters above sea level. This will reduce the load on the dam by 75%, while the stronger part of the dam is maintained and the weaker (narrower) part is removed. Maybe draining less water will suffice;
- Control aspects: monitoring system, trial runs, possible preventive degassing with the system;

[2] The present level (1091 meters above sea level) minus 20 meters

- Suggested verifications and elaborations of the proposed solution: checking the volume of carbon dioxide gas[3] that will be exhausting from the pipes with the discharge of water;
- The horizontal discharge of the gas-water mixture over the surface of the lake should also be verified.

Timeframe and costs

It is estimated that the full implementation will take two years. The total costs are roughly estimated at 15 million USD.

The guarantee a coordinated and effective implementation, an efficient management and a clear organizational structure are required. In the box below, a suggestion is provided on how the entities and associated responsibilities can be organised.

[3] If this is like 90% against 10% water, a discharge of 50 cubic meters of water per second implies a gas discharge of 450 cubic meters of gas per second

Organisational level	**Responsibilities**
1. Board of directors Participation of involved ministries, involved donors and a representative of the affected population. Meeting bi-monthly	Ensuring funds, safeguard progress and securing the programme objectives, both for the dam safety and the return programme.
2. Steering committee Managers and government employees Meeting monthly	Ensuring the proper management of the dam safety project and the return programme.
3. Coordination committee Representatives of various involved local and regional authorities, human interest groups. Meeting bi-weekly	Safeguarding the interests of various groups.
4. Expert body Participation of authority in various disciplines like engineering, contracting, risk analysis, humanitarian affairs, financing, etc. Meeting monthly.	Ensuring technical integrity of the dam safety project, safeguarding against disasters from gas bursts or dam breaches, securing other project risks.
5. Committee for humanitarian affairs Participation of specialists in human affairs, human aid and cultural aspects. Meeting monthly	Ensuring the humanitarian integrity of the return programme
6. Project office for the dam safety Project managers, specialists for engineering, accounting, contracting, environmental aspects, etc.	Ensuring the proper implementation of the dam safety project, acting as the employer for contractors
7. Programme office for the return programme Humanitarian program managers, specialists in administration, legal affairs, humanitarian and cultural aspects, etc.	Ensuring the proper implementation of the return programme, acting as the operative body and bureau for contact with those involved and affected by the programme.
8. Contractors, consultants, advisors, specialist's, etc. that are contracted for the implementation of the project.	

References

Lake Nyos Natural dam, northwest Cameroon: another catastrophe in the making. I.K.Njilah, M.Tchindjang and M.K.Ndikontar, 2002.

Monitoring the safety level of the lake during te degassing process, Michel Halbwachs, Chambery July 1999. (available on the internet)

Mag/Razel Contractors, providing insight in the estimated costs for the suggested technical solution.

Joint Report of the Mission to the Natural dam, HSF/IRGM, HYOS, 2001.

Survol de l'etat des lieux du Lac Nyos, Ministry of Territorial Administration and Decentralization, September 2005.

Acknowledgements

The experts and the Joint UNEP/OCHA Environment Unit would further like express their deep appreciation to:

The Government of Cameroon (in particular the Ministry of Territorial Administration and Decentralization)
UNICEF and UNDP, Cameroon
The Government of the Netherlands (Ministry of Transport, Public Works and Water Management, Ministry of Foreign Affairs)
Doctor Isaac Njilah of the University of Yaounde, Cameroon;
Doctor Jean Pierre Nana, Director DPC, Cameroon
Mr. Janvier Mvogo, Mission leader Lake Nyos Assessment trip, and
Ms. Sophie de Caen, UN Resident Representative, Cameroon.

Annex 1 Mission logbook

Wednesday 21 Sep.05 Travel from the Netherlands

Thursday 22 Sep.05 Yaounde, Cameroon

Meeting with Dr. Jean Pierre Nana, Director of Civil Protection, Ministry of Territorial Administration and Decentralization

Friday 23 Sep.05 Yaounde, Cameroon

Meeting with Ms. Sophie de Caen, United Nations Resident Representative
Meeting with Alphonse Ngbwa, Secretary General MINAT; Dr. Jean Pierre Nana, MINATD; Faustin Tsimi, Red Cross; Ms. Stephanie Etoundi, CEP/DPC; Limieau Abada Assono, MINATD/Celcam; Dr. Isaac Njilah, University Yaounde; Janvied Mvogo, SAI/DOC; Dominique Kuitsove, DPC/MINATD; Jean Luc Angounou Emane, Point Focal Central/ONR/MINATD/DPC; Dr. Gregory Tanyileke, SP/NMPD; Ms. Joshuane Tene, FICR; Daniel Sayi, Chef de Mission FICR;
Meeting with Dr. Isaac Njilah.
Meeting at Ministry of Territorial Administration and Decentralization.
Meeting with Dr. Gregory Tanyileke, researcher.Discussed technical details

Saturday 24 Sep.05 Travel to Lake Nyos

Team members include Mr. Janvier Mvogo, Dr. Isaac Njilah and the driver Mr. Njikam. Yaounde-Bamenda 360 km good tar road in 4:40 hours, Bamenda-Nkambe 66 km tar road in 1 hour; 130 km dirt road with some tar patches in 4 hours. Total 08:40 hours drive, plus some 2 hours for lunch and stops.

Sunday 25 Sep.05 Visit to lake Nyos

Nkambe-German bridge 40 km mud road in 1:30 hours,
German bridge-Lake Nyos 30 km dry narrow field track in 2:30 hours.
Meeting with Mr. Che Usmanou, one of the four survivors of the 1986 disaster.
Lake Nyos-Nkambe 70 km on dry roads in 3:30 hours,
Meeting with the Chief of Kimbi, the mayor of Funfunka and Mr. Kenah Ngong Gideon, the Elite of Nyos all the way from Douala, invited by Senior Divisional of Menchum.
Total 7:30 hours drive, plus some 3 hours visiting Lake Nyos.

Monday 26 Sep.05 Return to Yaounde, Cameroon

Meeting with local reporters in Bamenda.

Tuesday 27 Sep.05 Yaounde, Cameroon

Meeting with Mr. Tansa Musa, Reuter correspondent.
Meeting with Ms. Kimbi Mary from BUKILSDA (Buaba-Kimki Lake Nyos Survivors Cultural and Development Association).
Meeting with Mr. Shey Jones Yembe from NAG contractors to discuss feasibility of inserting pipes in the lake and cost estimate.
Briefing with Ms. Sophie de Caen.
Meeting with Dr. Gregory Tanyileke to discuss findings.
Meeting with Dr. Joseph Victor Hell, Director at Ministry of Research and Innovation.
Briefing with Dr. Jean Pierre Nana and Dr. Isaac Njilah.

Wednesday 28 Sep.05 Yaounde, Cameroon

Presentation and meeting with several donors (World Bank, IMF, UNDP) and Embassies (Japan, French, UK).
Meeting with Mr. Laurent Bedu of the French Embassy
Meeting with Dr. Isaac Njilah.
Meeting with Mr. Guy Blin, geologist working for French Embassy
Meeting with Ms. Sophie de Caen, UN Resident Representative
Debriefing with Ministry of Territorial Administration and Decentralization and UNDP
Meeting with Mr. Norbert Braakhuis, Ambassador of the Netherlands

Thursday 29 Sep.05 Yaounde/Return to the Netherlands

Meeting with Ms. Mariam Coulibaly Ndiaye, UNICEF, Ms. Fatma Samoura, UNWWP; Mr. Jacques Franquin, UNHCR; Ms. Sophie de Caen, UNDP Resident Representative; Dr. Isaac Njilah
Meeting with Dr. Jean Pierrre Nana and Dr. Isaac Njilah.
Meeting with Mr. Shey Jones Yembe from NAG Contractors and a representative of RAZEL Contractors.

Friday 30 Sep.05 Arrival in the Netherlands

Annex 2 Carbon dioxide gas in Lake Nyos

This annex provides background information on the gas burst phenomenon and should enable specialists in the field to verify the assumptions on which the proposed solutions in this report are based.

Based on research, a number of possible causes (and combination thereof) for the sudden gas eruption in 1986 have been identified. They include extensive rainfall, a possible landslide or rock fall into the lake, seismic activity or natural oversaturation of the carbon dioxide.

Heavy rains

Reportedly, there was a week of continuous rainfall foregoing the gas burst. Theoretically, this rain could have been colder than the lake water and thus be denser and sink to the bottom of the lake, forcing the water upward and causing a gas burst. This course of events is not very likely, as heavy rainfall is not that unique in the area, thus, this would have happened before. Because this is the first time for a gas burst at Lake Nyos was reported, heavy rainfall is not considered a likely cause.

Landslide

A landslide could have happened, causing a gas burst, but there were no indications of this were detected when the first teams arrived at the site.

Rock fall

Reportedly, a fresh rock wall was visible directly after the gas burst. This could be the indication of a rock fall, which displaced a substantial volume of water from the bottom of the lake, forcing it to rise and thus inducing a gas burst.

Seismic activity

A small tremor could have caused a gas burst in nearly oversaturated water in the bottom of the lake. There is no recording of such seismic activity at the time of the gas burst, so this cause is not likely.

Natural oversaturation

As there is a constant influx of carbon dioxide gas into the bottom of the lake, the water could at some time reach oversaturation. Oversaturation would definitely lead to a gas burst. However, the question remains why such a gas burst has not happened again since 1986.

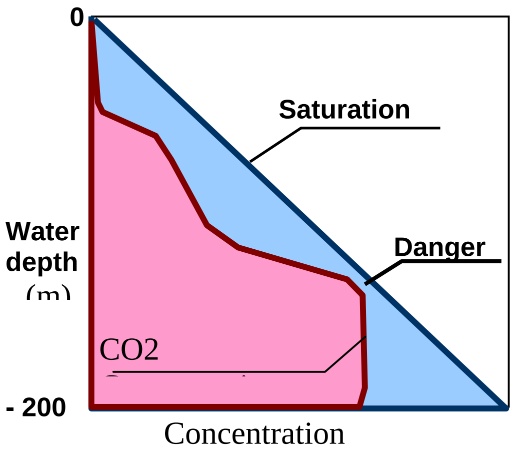
From all these causes, the rock fall is the most likely one. A tremor, and/or the heavy rain induced an unstable overhanging rock to break off. In this scenario, there are two important elements to consider. Firstly, the ongoing degassing will not prevent a new rock fall, and puts into question how much security in respect to a future gas eruption is achieved by the project. Secondly, after the incident in 1986, an estimated 600,000 tons of carbon dioxide remain dissolved in the lake. The rock fall did apparently not disturb the lake enough to release the entire amount of dissolved carbon dioxide. This leads to the assumption that the layers of different density and gas content are, to a certain extent, resilient to sudden impacts.

Degassing project

The current degassing project constitutes of a big pipe placed vertically into the lake. The water in the pipe has been initiated to flow vertically and has been kept flowing up since. As the water pressure drops, while the water flows up, the gas evaporates in the pipe causing the density to drop dramatically. Thus, the water is pushed upward by hydrostatic pressure and leaves the pipe at the top with high speed, causing a fountain up to some 50 meters high.

This project is effective and generates a lot of information from its monitoring and study program. The current degassing project is estimated to release some 20,000 tons per year, while 5,000 tons per year are emitted into the lake by the volcano mantle. To degas the entire lake, approximately 600,000 tons of carbon dioxide will have to be removed. It is estimated that this will take 30 years[4]

The lake is situated within an old volcanic crater. This volcano releases carbon dioxide into the water at the bottom of the lake. The gas dissolves in the water, increasing the water density. The solubility of gas in water depends on the water pressure. This physical phenomenon is known as Henry's law. The figure on the right shows that water can contain more gas at greater depth. In other words, the saturation increases with the depth. The figure also



[4] 600,000 tons of carbon dioxide / (20,000-5,000)= 30

schematically shows the actual concentration of carbon dioxide in the lake. Where this concentration becomes higher than the saturation level, the gas can no longer be dissolved and small gas bubbles will appear. The gas bubbles in the water will reduce the water density. When this happens at the bottom of the lake, the relevant water volume will become lighter than the volumes above it. The water volume with the gas bubbles will rise (float) to the surface. Upon reaching the surface, the gas will be released into the air and a disaster similar to the one in 1986 can occur.

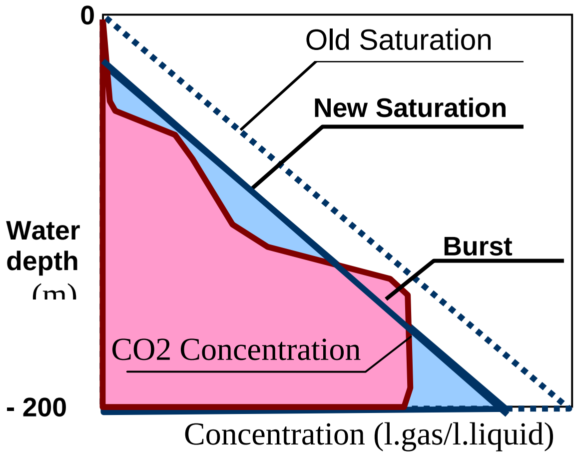
Transmission of the gas through the lake

The gas is emitted from the volcano into the deeper layers of the lake. There it transmits upward through the water layers. It has done so for centuries, without any reports about gas bursts (until 1986). Thus the gas finds a way of upward transport. Presumably there are two phenomena involved in this. One is the natural mixing of the water in the lake, causing an exchange of gas between the layers. The other phenomenon is the near over saturation of a deeper layer, causing gas to travel upward. Thereby the gas travels upward through the various layers to the surface of the lake. It must have done so for ages. (The same phenomenon can be seen in a glass of soda water. Small gas bubbles formed at the bottom disappear before they reach the top of the glass. Apparently the gas dissolves in less saturated layers)

This latter phenomenon also provides some stability to the lake. It is still surprising that during the gas burst of 1986, the lake did not turn over completely. When the gas burst occurred, there must have been a tremendous movement in the lake, and still only a fraction of the gas (still a enormous cloud when it reached the surface) escaped from the lake, as some 600,000 tons (325 million cubic meters at 1 atmosphere pressure) remained dissolved.

Reducing the water pressure at a fast pace

Lowering the water pressure reduces the solubility. When there is more gas in the water than can be dissolved (the solubility), the water gets over saturated. When that happens in a short period of time, the gas comes free, creating small gas bubbles. The gas bubbles decrease the density, so the relevant water-gas volume will rise. The same happens when you open up a bottle of (carbonised) soda water. This is how a fast reduction of the water level can cause a gas burst.



However, if water is removed from the bottom of the lake, something different will happen. As is shown in the third figure below, this will just take out some water with a high percentage of gas content being dissolved in it. A problem will only occur if this is done too fast, as the water level goes down, while the high density water layers have no time to adjust. Experience from the degassing project will be most useful to estimate the speed of the self-equalizing effect of these water layers.