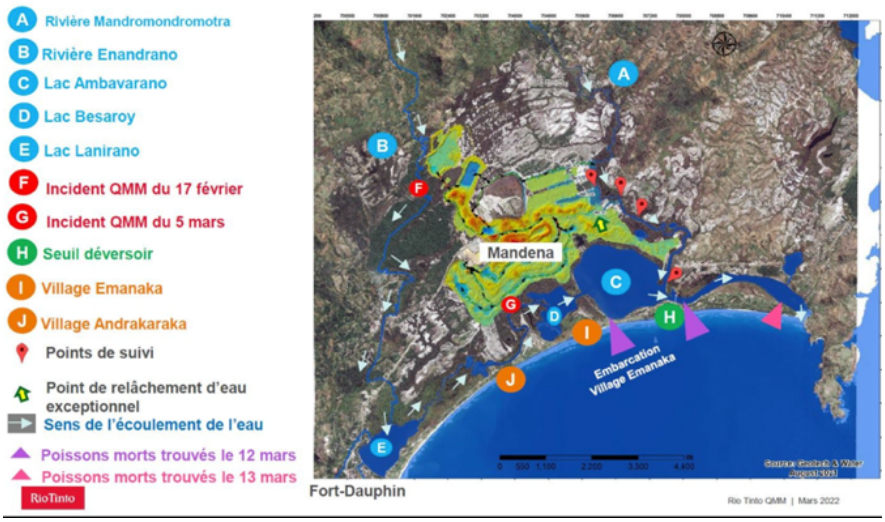
MEMORANDUM

To: **Andrew Lees Trust UK**
From: **Stella Swanson, Ph.D.**
Date: **April 20, 2022**
RE: **Cause of Fish Kills After QMM Water Releases**

Recent Water Releases from the QMM Mine and Fish Kills

After cyclones and heavy rains, mine process water held in impoundments on the QMM site was released under "exceptional permission" from the Malagasy water regulator, ANDEA. Release was permitted over a period of seven weeks.



Dead fish were found in Lake Ambavarano and close to the QMM weir days after the release of the mine process water. As there is no detailed report on the release available, a QMM diagram that was shared online is used to understand the release point, and location of the dead fish. See Diagram 1, left.

The release point is indicated by arrow ('point de relâchement de l'eau exceptionnel' in diagram key)

It is not possible to confirm if the designated QMM release point/s are used for this exceptional release, or if water has been released directly from the mining pond to the Mandromondromotra river under the "exceptional" permission. According to QMM its: *"release stations are natural pre-existing swamps modified with low lying berms to slow water flow. In some documents, those releases are called release point or discharge point. ...They are the only location where QMM has the permit to release process water." (QMM, August 2021)*

2383 Highway 3 South, Fernie, BC V0B 1M1 Phone: 250-423-6741 ~ 403-830-2948 (mobile) stellastrat@gmail.com

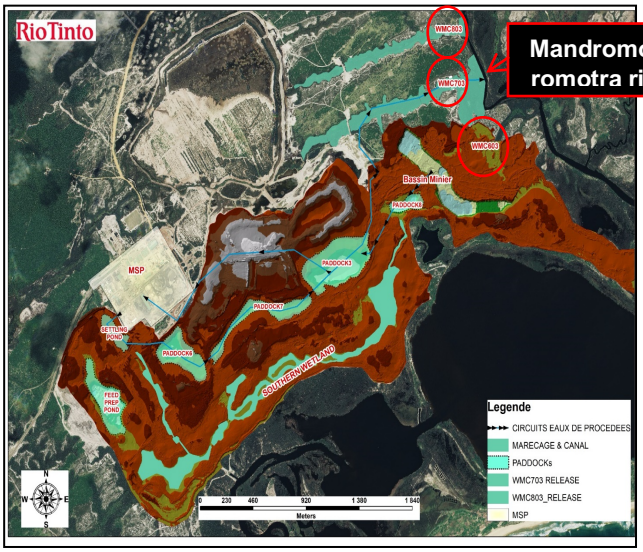


Diagram 2 QMM Designated Release Points

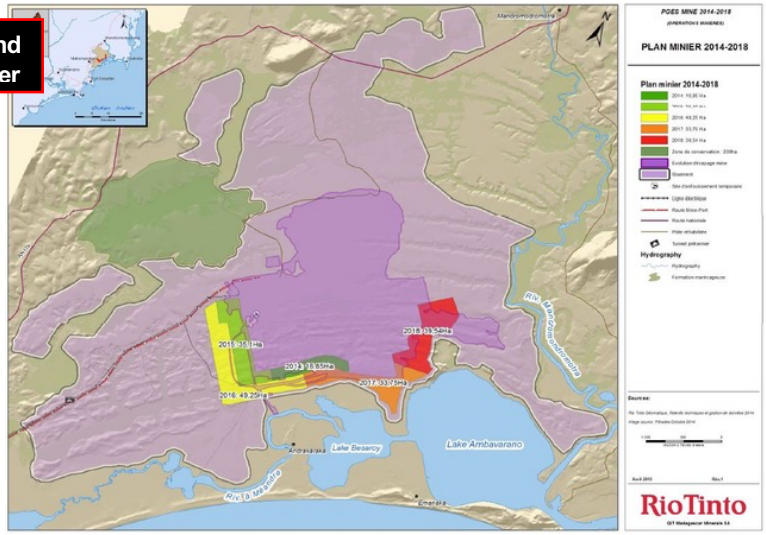


Diagram 3: QMM Mine Site

Could the QMM Water Releases Have Caused the Fish Kills?

Causes of unexpected death of fish over a short period of time include: abrupt changes in water temperature; acid mine drainage; ammonia (from fertilizer runoff or industrial discharges); low dissolved oxygen (which in turn can be caused by the decay of aquatic plants and algae or sewage); flushes of pesticides from fields during rainfall events; metals; oil spills; spills or unplanned releases from mine sites or industrial sites; highly turbid (cloudy) water; and, disturbance of contaminated sediments.

Fish kills are not a regular occurrence in the Anosy region. Fish kills within a few days after the release of mine process water indicate that the mine water may have been the cause. The first step in investigating whether mine water caused fish kills is to examine the mine process water characteristics that could kill fish.

Acidic Water

The characteristics of mine process water are described in a report by CNRE (2019) after releases from the QMM site due to heavy rains in November and December, 2018. The acidity of the mine process water is an obvious issue. The mine process water held in mining basins (paddocks) on the QMM site is very acidic (pH of 3-4) (CNRE 2019). Water collected from wetlands described as “in the process of becoming natural” east of the Meandre River upstream of Lac Besaroy is even more acidic (pH 2-3) (CNRE 2019). The pH of QMM mine process water is similar to vinegar and is in the range of pH where adult fish die (see the diagram below).

2383 Highway 3 South, Fernie, BC V0B 1M1 Phone: 250-423-6741 ~ 403-830-2948 (mobile) stellastrat@gmail.com

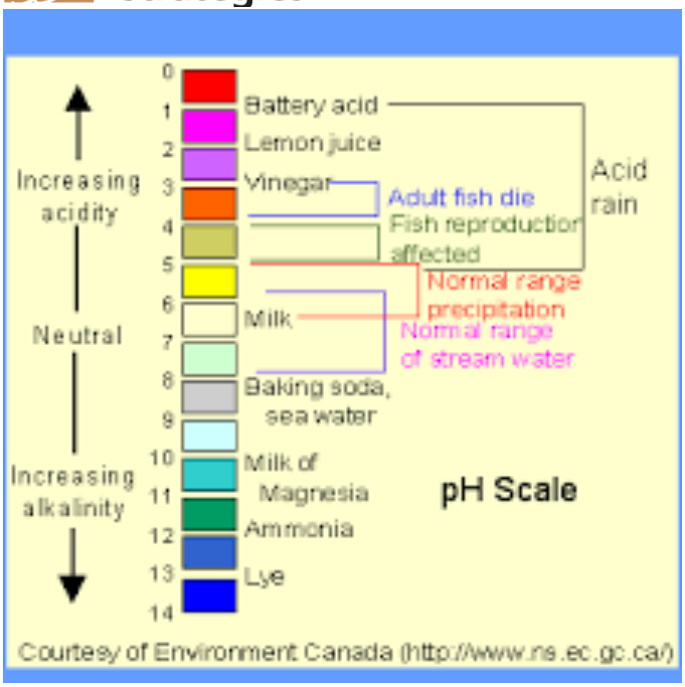


Diagram 4: The pH Scale and Examples of Acid and Alkaline Liquids

Low Dissolved Oxygen

Other characteristics of QMM mine process water that may have played a role in causing fish kills are low dissolved oxygen concentrations and cloudy water (turbid water) containing fine particles. Dissolved oxygen in mining basins ranged from 4.45 to 6.33 milligrams per litre and from 3.00-5.95 in wetlands along the south and southeast margins of the QMM site (CNRE 2019). These dissolved oxygen concentrations are low and may be lower than what is needed by fish for normal respiration and activity, especially at the water temperatures common in the region.

Turbid (Cloudy) Water

The turbidity (cloudiness) of the water in mining basins reported by CNRE (2019) ranged from 4.02 to 590 NTU (Turbidity Units). The Madagascar standard is 25 NTUs for the receiving environment. Turbidity can act directly on fish, killing them or reducing their growth rate or resistance to disease.

Metals

Metals can also cause fish kills, if they are present in high amounts. The CNRE (2019) report included information on copper and zinc concentrations in mining basins and wetlands adjacent to the south and south east of the QMM site, but not other metals. Copper and zinc concentrations were very low. Metal concentrations were measured in samples taken on March 6, 11 and 14 by Labo Chimie Madagascar (LCM, 2022).

2383 Highway 3 South, Fernie, BC V0B 1M1 Phone: 250-423-6741 ~ 403-830-2948 (mobile) stellastrat@gmail.com

Aluminium concentrations were high in mining basin water as well as wetland water, with the highest concentrations found in water from the Lac Besaroy lakefront. Aluminium concentrations were high enough to be a potential cause of fish kills, particularly in combination with acidic pH.

Iron had elevated concentrations that may have contributed to fish kills (LCM 2022a). Iron concentrations were well above the Madagascar standard of 1000 micrograms per litre in one mining basin sample as well as at the Lac Besaroy lakefront. The combination of iron and aluminum under acidic conditions could have added up to greater effect than any one of these three factors alone.

Hydrocarbons

The samples taken in March 2022 were also analysed for hydrocarbons (LCM 2022 b). Results were for "total hydrocarbons" only; therefore, interpretation of the results with respect to potential causes of fish kills is not possible. This is because toxicity of the various types of hydrocarbons varies greatly. The hydrocarbons most commonly associated with sudden fish kills are compounds which are "lighter" (they float on the water) and evaporate quickly such as those found in gasoline. The chemicals of particular concern are benzene, toluene, ethyl-benzene and xylene. Spills containing these compounds have caused large fish kills in both freshwater and marine environments.

The total hydrocarbon concentrations were higher at sites in the Mandromondromotra River downstream of mine discharges than any of the other sites, including a sample taken from a sampling station called WMC 602 on the QMM site. This result was interpreted by Labo Chimie Madagascar (LCM) as indicating that the mine is not a significant contributor of hydrocarbons to the river. Additional samples from other locations on the QMM site are needed to support this interpretation.

Radiation

Radionuclides in amounts measured by LCM (2022) in water near the QMM mine were very low, and in most cases, below the laboratory limits of detection. Radionuclide levels would have to be 1000s of times higher to cause sudden fish kills.

Other Suggested Causes of Fish Kills

The CNRE (2019) report stated that the wetlands adjacent to the QMM site are naturally acidic and that aquatic fauna in the wetlands have adapted to these conditions. The report did not discuss the difference between a sudden release of high volumes of acidic water and natural releases from wetlands.

2383 Highway 3 South, Fernie, BC V0B 1M1 Phone: 250-423-6741 ~ 403-830-2948 (mobile) stellastrat@gmail.com

The CNRE (2019) report also presents an argument that "fairly high" concentrations of phenols and quinones (chemicals produced by the decay of aquatic plants) may explain the absence of life in the wetlands (they do not acknowledge the contradiction between adaptation to water chemistry conditions in the wetlands and "absence of life"). The "high" phenol concentrations in natural wetland waters were only marginally above that measured in lagoon waters (0.9 milligrams per litre versus 0.2-0.3 milligrams per litre). Furthermore, these concentrations were not compared to toxicity thresholds for phenols from the scientific literature.

It is argued in the CNRE report that aquatic plants and animals have adapted to the low pH and chemistry of the mining basins and regenerating wetlands on the QMM site. On the other hand, it is argued that the fish swept from the overflow basins to the wetlands during the heavy rains in 2018 were killed by high phenolic concentrations in the wetlands. The concentrations are not much higher in the wetlands than in lagoons. If anything, concentrations during heavy rains would be lower. Therefore, fish kills caused by phenolic concentrations produced by natural decay that are not much different in the wetlands than they are in the lakes is not particularly plausible.

Most Probable Connection Between QMM Water Releases and Fish Kills

The combination of acidic water and elevated aluminium in the water released from the QMM site is the most probable connection between the water releases and the fish kills observed after those releases.

Acidic water in combination with metals is a well-documented cause of fish kills. Scientific studies over the past 30+ years have shown that acid drainage from mines, in combination with metals such as aluminium and iron can kill fish.

The aluminium concentrations reported by LCM (2022) ranged from 432.35 to 5604.77 micrograms/litre. All of these concentrations substantially exceed water quality guidelines for the protection of aquatic life established in countries such as Canada, the USA, and Australia.

The LCM (2022) report did not include pH measurements. The report cited data from 2015 showing pH ranging from about 5.5 to 6.8 but locations for these samples were not provided. LCM stated that the 2015 data "clearly shows the acid character of the surface waters of the study area". The report went on to state that excess aluminium is associated with environmental impact on aquatic fauna.".

Mine process water released for seven weeks at relatively high volumes could flow through the wetlands through "preferred pathways" quite rapidly. This water would enter the natural environment as a plume of cloudy, acidic water with substantially elevated aluminium and enough iron in it to add to the toxic effects on fish gills. The density of this plume may be sufficient to maintain it as a distinct zone of water extending out into the receiving environment.

2383 Highway 3 South, Fernie, BC V0B 1M1 Phone: 250-423-6741 ~ 403-830-2948 (mobile) stellastrat@gmail.com

It is quite possible that a plume of acidic water with elevated aluminium could persist long enough to kill fish. The dead fish could then be carried by wind and water currents to other locations farther away from the discharge locations. Thus, dead fish collected farther along the shoreline from locations of QMM releases did not necessarily die at those locations.

Concentrations of the other metals measured in QMM release water (especially iron) may contribute to toxic effects on fish; however, the measured concentrations are not in the range associated with causing sudden fish kills.

Radionuclide concentrations are 1000s of times too low to cause sudden fish kills.

Hydrocarbons associated with spills of gasoline or diesel can cause sudden fish kills. The LCM data do not include measurement of the specific hydrocarbons known to cause fish kills. Therefore, **hydrocarbon toxicity cannot be ruled out; however, total hydrocarbon concentrations indicate that this is unlikely.**

Conclusions

The most probable cause of observed fish kills which can be connected to release of QMM mine water is acidic water containing substantially elevated aluminium concentrations.

The available data indicate that it is unlikely that hydrocarbons caused the fish kills, but more data are required in order to rule out compounds found in gasoline and diesel fuel.

Radiation is an extremely unlikely cause of the fish kills.

Additional Information: Aluminium Effects on Fish

Aluminium Effects on Fish

Aluminium affects fish in two main ways: (1) disruption of respiration and (2) disturbance of salt balance within the fish. Damage to respiration, maintenance of salt balance or a combination of the two can cause death.

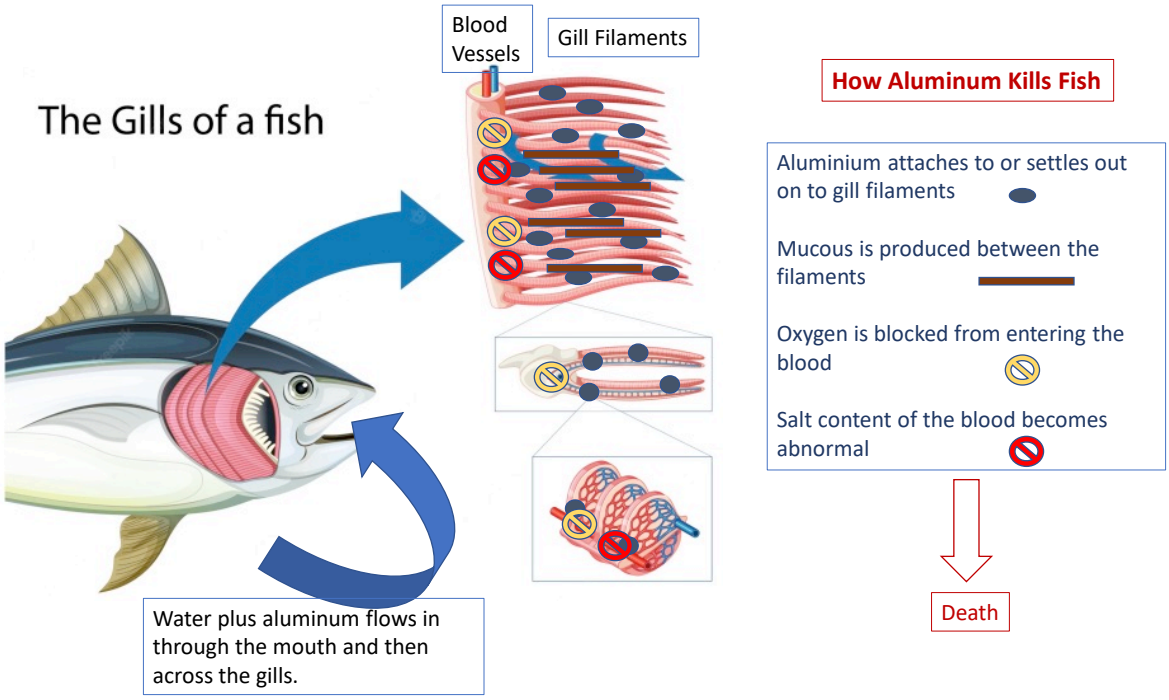
Gills are the primary surface where aluminium binds to fish.

Aluminium can precipitate on to the gill surface, clogging the spaces between the gill layers with mucous, and preventing sufficient oxygen from entering the bloodstream of the fish. This causes hypoxia, resulting in death.

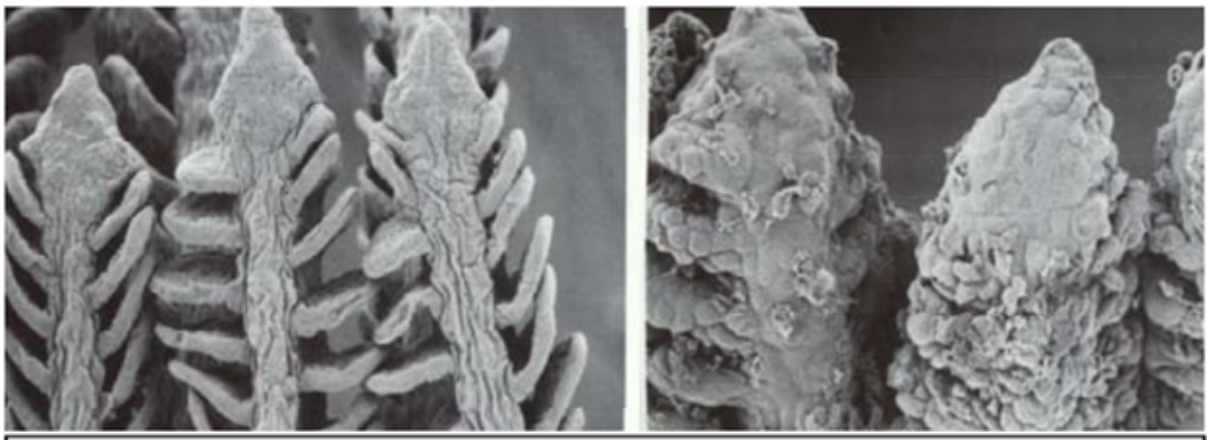
2383 Highway 3 South, Fernie, BC V0B 1M1 Phone: 250-423-6741 ~ 403-830-2948 (mobile) stellastrat@gmail.com

At more acidic pH levels, aluminium which binds directly to the gill surface can result in a decrease in blood sodium and chloride levels, with subsequent effects on the function of vital organs such as the heart.

This is shown in Diagram 5 below: Gills of a Fish /How Aluminium Kills Fish



Photograph 1: Fish Gills Affected by Aluminium



"In addition to absorbing oxygen and removing carbon dioxide, gills also regulate the exchange of ions. On the left, normal Atlantic salmon gill filaments. On the right, gill filaments damaged by aluminum." "Water Chemistry & Atlantic Salmon Physiology" North East Fishery Science Center.

2383 Highway 3 South, Fernie, BC V0B 1M1 Phone: 250-423-6741 ~ 403-830-2948 (mobile) stellastrat@gmail.com

Modifiers of Aluminium Toxicity

Increasing pH, dissolved organic carbon (DOC), and water hardness (measured as calcium carbonate) have a protective effect against aluminium toxicity for fish. Therefore, it is important to collect data on these three parameters at the same places and times as water samples are taken for analysis of aluminium. Unfortunately, this was not done after the QMM releases in March.

Estimates of pH, DOC and hardness were derived using data from the CNRE (2019) report which was produced after releases of QMM mine water in 2019. The CNRE report included pH and "organic matter data", but not hardness. Calcium data were used as an approximate indicator of hardness.

Water Quality Guidelines for the Protection of Fish from Aluminium

Recent water quality guidelines for aluminium are derived using an equation which accounts for the effect of pH, DOC and hardness on the form of aluminium (whether it is dissolved or precipitated). The Canadian equation was used to derive approximate aluminium guidelines for Lac Besaroy and the Mandromondromotra River. ***The approximate guidelines ranged from 44 to 150 micrograms per litre, largely driven by the acidic pH in QMM release water and in river and lake water.***

Measured concentrations of aluminium were about 4 to 56 times higher than the approximate guidelines. The highest concentration (5604.77 micrograms/litre) was measured at the Lac Besaroy lakefront. The approximate aluminium guideline at this location is 100 micrograms/litre. Concentrations in the Mandromondromotra River adjacent to discharges from the QMM site ranged from 508.47 to 1019 micrograms/litre. The approximate aluminium guideline in the river adjacent to QMM discharges is 150 micrograms/litre.

Aluminium Effects in People

Aluminium affects people differently than fish. Fish are more sensitive to aluminium.

Everyone is exposed to aluminium from food, air, water and soil. Only very small amounts of aluminium that you breathe in or ingest with water or food will enter your bloodstream. Exposure to aluminium is usually not harmful but workers who breathe large amounts of aluminium dusts can have lung problems or decreased performance in some tests that measure functions of the nervous system (ATSDR 2022).

2383 Highway 3 South, Fernie, BC V0B 1M1 Phone: 250-423-6741 ~ 403-830-2948 (mobile) stellastrat@gmail.com

References

ATSDR 2022. Aluminum – ToxFAQs. Agency for Toxic Substances and Disease Registry. CAS#7429-90-5.
https://wwwn.cdc.gov/TSP/ToxFAQs/ToxFAQsDetails.aspx?faqid=190&toxid=34

CNRE 2019. Mission d'Expertise sur l'Incidence des Eaux de Debordements de QMM dans le Systeme Lagunaire Lanirano-Evatraha a Fort-Dauphin. Centre National de Recheres dur L;Environmment. March, 2019.

LCM 2022a. Rapport et Interpretation d'Analyse des Hydrocarbones et Huiles et Graises des Eaux de QMM Fort Dauphin. Labo Chimie Madagascar.

LCM 2022b. Rapport d'Interpretation Analyse Radiologique et Metaux des Eaux de QMM Fort Dauphin 2022. Labo Chimie Madagascar.

2383 Highway 3 South, Fernie, BC V0B 1M1 Phone: 250-423-6741 ~ 403-830-2948 (mobile) stellastrat@gmail.com