MEMORANDUM

To:	**Andrew Lees Trust UK**
From:	**Stella Swanson, Ph.D.**
RE:	**Reports on Results of Water Quality Investigations after Overflow Incidents at the QMM Mine**
Date	**4th April 2022**

Over-Arching Comments

- The two reports do not provide sufficient information for a confident evaluation of effects of the two overflow incidents on water quality, fish, or human health
- The reports do not discuss possible connections between the analytical results and reported fish kills, nor do they provide sufficient information on the potential risk to human health from consumption of fish exposed to contaminants in the overflow water
- Plausible causes of fish kills related to the two incidents include the combination of low pH and elevated aluminum concentrations. This combination has been shown to cause damage to fish gills, resulting in asphyxiation.
- Other contributing factors to fish kills may include high levels of turbidity (a measure of suspended sediments) and low dissolved oxygen.
- Data required for interpretation of the potential for metal toxicity were not collected – notably water hardness and Total Dissolved Solids
- Data on concentrations of metals in fish were very limited and were not interpreted in relation to risk to human health
- Conclusions drawn in the reports are not based on sufficient evidence
- A comprehensive examination of the potential causes of the fish kills should follow guidance such as that provided by the US Environmental Protection Agency Causal Analysis/Diagnosis Decision Information System (CADDIS). Volume 2. Sources, Stressors and Responses. https://www.epa.gov/caddis
- Fish should be collected for analysis of a suite of radionuclides and metals as soon as possible, with large enough sample sizes to provide confidence that the results represent the range of concentrations present in fish collected from areas commonly used by fishers. It is very important to collect and analyse such data in the near future in order to either confirm the need for a closure of the fishery or confirm that the fish are safe to eat.

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Swanson Environmental Strategies

Summary Comments Regarding The Report on Radionuclides and Metals

The report does not provide sufficient information to draw confident conclusions regarding effects of the overflow incidents on fish or on human health resulting from release of radionuclides and metals. The discussion of results was either unclear or not supported by the evidence. Given ongoing mine-related discharges to the receiving environment, implementation of a rigorous monitoring program is highly recommended.

In particular, a much more comprehensive collection of data on concentrations in fish and shellfish is recommended, including analyses of radionuclides but also selected trace elements - notably mercury.

Radionuclides

- Analysis for only 3 radionuclides limits the ability to interpret total radiological exposure via drinking water. Other radionuclides which should have been analysed include radium-226, thorium-230, lead-210 and polonium-210.

- The detection limits for U-238 and Th-232 appear high, making it impossible to compare March 2022 results for U-238 and Th-232 with previous results.

- Since all detection limits reported for Th-232 in LCM 2022 are higher than the World Health organization guidance level, the statement that all values are within recommended thresholds is misleading. The WHO guidance level for U-238 of 10 Bq/kg does not appear to have been exceeded at any of the locations.

- The high detection limits and the analysis of only three radionuclides produce a dataset which does not support “ruling out” risk of radiation exposure.

Non-Radiological Parameters

- Statements regarding nitrates and phosphorus refer to discharge standards and drinking water standards but not receiving environment standards. Discharge standards apply at the “end of pipe” and are usually substantially higher than receiving environment standards. Clarity regarding the Malagasy standards would be helpful
- It would appear that nitrates are below international guidelines developed to protect aquatic life
- Phosphorus concentrations are high relative to international guidelines developed to protect against eutrophication of naturally nutrient-rich systems
- Sulphate does not appear to be a concern with respect to protection of aquatic life; however, the hardness of the water (measured as calcium carbonate) must be measured in order to confirm that hardness-based sulphate guidelines are being met.

- More than 11 trace elements should have been measured, if possible. If analysis using ICP-MS (Inductively Coupled Mass Spectrometry) is available, a full scan would generate results for additional trace elements of potential importance regarding the fish kills and human health
- Notable results are:

    - Substantially elevated aluminum concentrations which, at the acidic pH conditions in the area, are a plausible cause of fish kills (via damage to gills)
    - Some exceedances of zinc guidelines at WMC 603 on the QMM site and the Lake Front site
    - All mercury results exceed guidelines for protection of aquatic life. It is unclear whether the Malagasy standard applies to drinking water or aquatic life
    - Nickel concentrations may exceed updated guidelines for protection of aquatic life – again at WMC 603 and the Lake Front
    - Iron may exceed hardness-based guidelines
    - Lead should have been measured. Previous data showed that some lead concentrations in the Mandromondromotra River were close to or exceeded drinking water guidelines.

Concentrations in Fish

- There are very few data for only a small subset of contaminants
- It is not clear which standards for concentrations in fish are being referred to – for health of the fish or health of people eating the fish.
- Conclusions regarding concentrations in fish are not supported by sufficient evidence
- The few data for only 5 metals without additional explanation of whether the standards referred to are meant to protect fish or human health means that no definitive statements can be made.
- I agree that combined effects of a "cocktail" (or "multiple stressors") on fish cannot be ruled out and needs a more detailed study.

Detailed Comments Regarding The Report on Radionuclides and Metals

This memorandum provides the results of my review of water quality investigations conducted after two overflow incidents from the QMM site on February 17 and March 5, 2022. The location of these incidents is shown in Figure 1 (Figure provided by ALT UK). Figure 1 also shows the location of reported fish kills on March 12-13.

I have arranged my comments in response to specific statements in the Rapport and Interpretation D'Analyse Radiologique et Metaux des Eaux de QMM Fort Dauphin. (Labo Chimie Madagascar 2022).

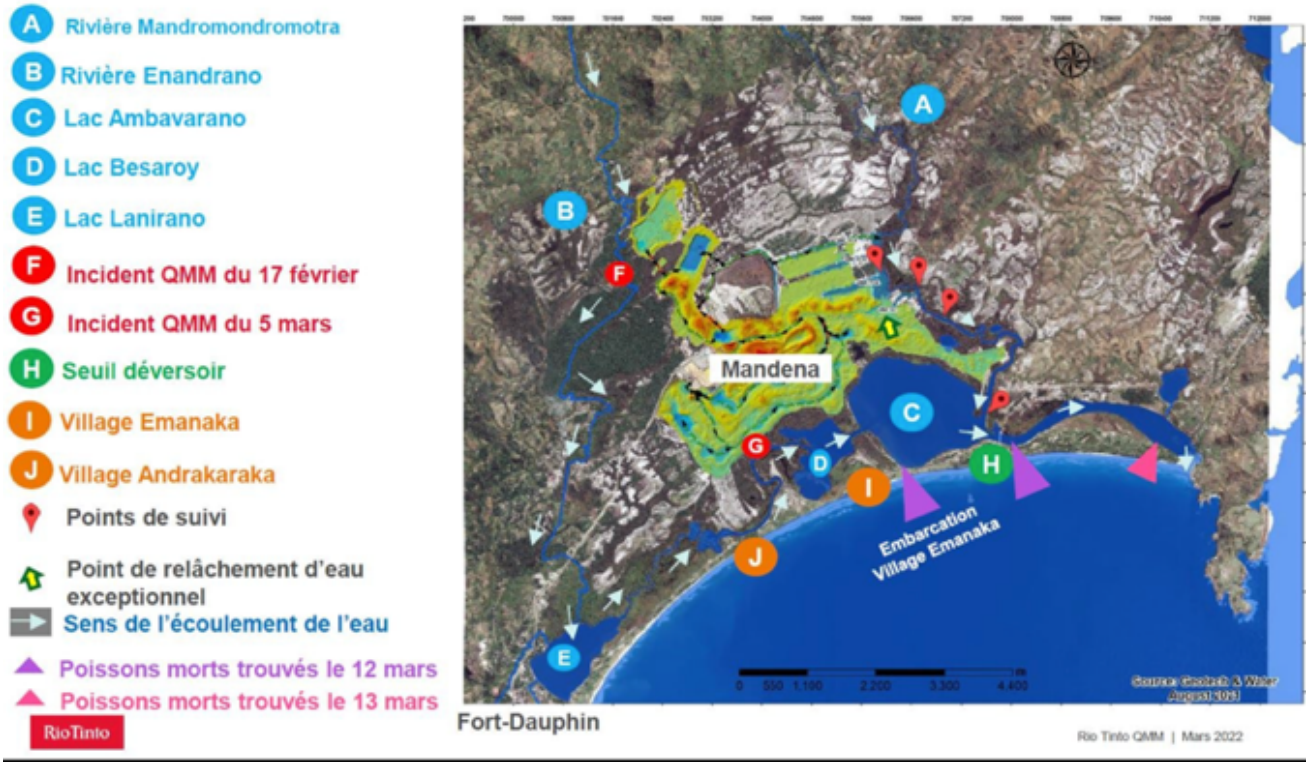

Figure 1. Location of the Two Overflow Incidents and Observed Fish Kills.

Translated from the Report: "For the case of our analysis, the radionuclides analyzed are all of natural origin and therefore constitute the local radiological background in terms of radioactivity. The values found for potassium-40, Uranium-238 and thorium-232 are within the recommended thresholds and the risk of radiation exposure is ruled out, whether for communities or for aquatic fauna."

Comments:

Analysis for only 3 radionuclides limits the ability to interpret total radiological exposure via drinking water. Other radionuclides which should have been analysed include radium-226, thorium-230, lead-210 and polonium-210.

The detection limits for U-238 and Th-232 appear high, making it impossible to compare March 2022 results for U-238 and Th-232 with previous results. Previous data for U-238 and Th-232 (Swanson 2019) showed measurable results well which are well below the detection limits reported in the LCM report 2022 report. For example, water from the Mandromondromotra River at QMM monitoring station S44 contained 0.270 Bg/kg U-238 (Swanson 2019 Table 4), but water taken from nearby monitoring stations S42 and S43 were below detection limits of 1.2-1.8 Bq/kg. Similarly, previous Th-232 data showed 0.006 Bq/kg Th-232 at S44 whereas the LCM report showed non-detect levels at stations S42 and S43 – with detection limits between 2.4 and 4.3 Bq/kg. The differences in detection limits makes it impossible to compare March 2022 results for U-238 and Th-232 with previous results.

The "recommended thresholds" for the three radionuclides measured in March 2022 (K-40, Th-232 and U-238) are not presented. I note that the World Health Organization (2011) guidance level for Th-232 is 1 Bq/kg. Since all detection limits reported for Th-232 in LCM 2022 are higher than this guidance level, the statement that all values are within recommended thresholds is misleading.

The high detection limits produce a dataset which does not support "ruling out" risk of radiation exposure.

Translated from the Report: All the values are in conformity with the thresholds recommended by the Malagasy standards. For nitrates, the levels comply with both the 50 mg/l concentrations of the drinking standard and 20 mg/l of the discharge standard. Besides, the phosphate contents are very low compared to the 10 mg/l content of the discharge standards. These two parameters are responsible for the eutrophication of surface waters at concentrations exceeding the standards. Their presence in the water is mainly linked to the agricultural activities of communities throughout the watershed.

Comments:
There is a usually a difference between discharge standards (set at the "end of pipe" or at the "last point of control" and receiving environment standards. What are the Malagasy receiving environment standards?

Receiving environment guidelines for nitrate are usually in the order of 10-15 mg/L for protection against acute toxicity (not meant for prevention of eutrophication). Phosphorus guidelines for receiving environments which are naturally nutrient-rich can be between 35 and 100 ug/L (0.035-0.1 mg/L) to prevent further eutrophication

Translated from the Report. Sulphate ions have lower levels compared to the regulatory threshold. They are mostly linked to anthropogenic activities in the watershed such as deforestation.

Comments:
What is the regulatory threshold? Sulphate guidelines usually vary with water hardness. Soft water sulphate guidelines are in the order of 130-220 mg/L. Hard water sulphate guidelines are in the order of 300 to 430 mg/L. Given the very low pH at most locations, hardness may be in the soft water category. All reported sulphate concentrations are below soft water-based guidelines.

There is no supporting argument for why sulphate might be linked to activities such as deforestation with no accompanying mention of mining. Mining is commonly associated with sulphate discharges because of the nature of mineralization of ores (which often contain sulphide minerals) and release of sulphate during ore processing.

Translated from the Report: A total of 11 elements were targeted for analysis in the surface waters of the study area. As their name suggests, metallic trace elements are found in the environment in trace amounts, i.e., in the order of micrograms per litre, and the abnormal content indicates a major source of pollution.

Comments:
Why these particular elements? If ICP MS was used a more comprehensive list of trace element results could be produced.

Translated from the Report. The rocks in the study area contain these ETMs. Water acts upon local geological formations and transports these TEs into the rivers. It should be noted that eroded mineral debris containing MTEs upstream reaches the coasts through the mechanical action of water and runoff.

Comments:
The issue is that mines release enhanced concentrations of trace elements via ore processing – both because ore crushing increases reactive surface areas and also because the whole point of ore processing is to extract minerals. I don't know why this is not mentioned and discussed regarding the possible incremental contribution of trace metals by the mine.

Translated from the Report. For our study, 10 elements out of 11 have normative values in relation to WHO regulations.

Aluminum in view of the WHO standard (drinkability) exceeds the threshold while for the Malagasy water discharge standard, only one case is in a situation of non-compliance. The abundance of aluminum in water is a function of temperature and pH.

Comments:
A table of applicable Malagasy standards or guidelines for the receiving environment should have been provided and if no guidelines exist, then applicable guidelines from elsewhere should have been used. Results that caught my attention included:

- Aluminum: Al guidelines vary with pH. At pH <6.5 guidelines are in the order of 5 ug/L. at pH >6.5 the guidelines increase greatly to 100 ug/L. Since pH is low in all samples – usually below 6.5, the lower guideline of 5 ug/L applies, making exceedances for Al even more prevalent.
- Zinc guidelines are usually in the order of 30 ug/L. Concentrations at WMC603 and LKF 01 exceed that.
- Mercury guidelines for protection of aquatic life are in the order of 0.02-0.03 ug/L. All results exceed that. Does the Malagasy standard apply to drinking water and not aquatic life?

- Nickel guidelines range from 25-150 ug/L depending on hardness. Recent studies have shown that these guidelines might be too high. Nickel may be of concern - again, at WMC 603 and LKF 01.
- Iron guidelines are dependent on hardness. At hardness less than 8 mg/L the iron guideline is in the order of 3 ug/L. At hardness greater than 8 mg/L the guideline is determined by an equation. E.g., at 50 mg/L hardness the guideline would be 33 ug/L. If the concentrations are ug/L in the table there may be exceedances depending on hardness of the water. NOTE: hardness of the water was not measured.

Lead should have been measured as well. Drinking water guidelines are in the order of 5 ug/L. Data I reviewed for Swanson (2019) showed that some lead concentrations in the Mandromondromotra River were close to or exceeding that guideline.

Translated from the Report: This graph clearly shows the acid character of the surface waters of the study area. Aluminum with an excess content represents an environmental impact on aquatic fauna. It causes damage to the nervous system in fish causing them to waste away. Aluminum is found in abundance in the soil in the process of pedogenesis and is transported to the water by the phenomenon of leaching. Nevertheless, the anthropic origin is also probable.

An important point deserves to be raised, because due to the higher density of TMs compared to water, they are found rather in the sedimentary phases of water, hence their low concentration in water.

Comments:

Density of metals is not what drives metal concentrations in water vs sediments. Sediment texture (particle size), amount of organic matter, the presence of manganese or iron hydroxides or acid volatile sulphides, and redox potential all affect partitioning between water and sediment. The mechanisms vary with metals. The metals of potential concern associated with QMM may include iron, lead, mercury and zinc and possibly nickel. The geochemical behaviour of each of these metals is distinctly different.

Important water quality drivers (depending on the metal) are pH, hardness, chloride concentrations, and total dissolved solids (TDS – a measure of total salinity related to cations such as calcium and magnesium and anions such as chloride, carbonate and sulphate). Hardness and TDS were not measured in the March 2022 samples.

Translated from the Report (referring to concentrations in fish). These concentrations are lower compared to the standards, however according to recent research, the "cocktail" phenomenon or combined effect of micropollutants even at minimal concentrations on fish is also likely but to be determined by a more detailed study.

Comments:
It is not clear which standards are being referred to. I would be surprised if there were Malagasy standards for fish tissue to protect the fish – such standards are rare even in developed countries. Standards for protection of human health are usually expressed in terms of Tolerable Daily Intake (TDIs) based on grams of fish consumed per week and will vary according to gender and age. There are rarely any human health TDIs for metals besides mercury.

The few data for only 5 metals without additional explanation of whether the standards referred to are meant to protect fish or human health means that no definitive statements can be made.

I agree that combined effects of a "cocktail" (or "multiple stressors") cannot be ruled out and needs a more detailed study.

Translated from the Report: Overall, the results showed compliance for all elements analyzed except the case of aluminum. Therefore, in general, we can advance that the chemical and radiological signature of the analyzed waters constitutes the local hydrochemical and radiological background characterized by the dominance of chemistry linked to geological and atmospheric conditions. Indeed, a hydrogeochemical study coupled with ecology will make it possible to determine the local distribution of this element and the compartments of proven sources. An analysis of the major cations will make it possible, together with the major anions, to determine the chemical facies of the waters in the study area.

Comments:
There is a complete lack of meaningful discussion of aluminum results – which are noticeably high relative to the low pH (<6.5) guideline of 5 ug/L. The combination of low pH and high aluminum (plus perhaps iron as a contributing factor) is a plausible cause of fish kills.

Translated from the Report: Moreover, apart from the aluminum effect, another track is also to be favored concerning the death of fish. Since the event takes place during the flood period and that during this period, algal activity is predominant, the toxins from the algae ingested by the fish would also be lethal for them.

Comments:
There is no supporting information for the statement about algal toxins. Have there been documented fish kills due to algal blooms? Have there been measurements of algal toxins in the water? And algal toxins are a human health concern.

Summary Comments Regarding The Report on Oils and Greases and Hydrocarbons

- The two incidents were on Enandrano River and upstream of Lac Besaroy. More sampling in the river and the lake should have been conducted in order to understand the contribution of the incidents to oils and greases and hydrocarbons to water quality as well as to fish tissue quality.
- Sites 42 and 43 on the Mandromondromotra River have higher hydrocarbon concentrations than any of the other sites. The report states that because Site WMC 602 on the QMM site has very low hydrocarbon concentrations, the mine is not a significant contributor of hydrocarbons to the river. There is no discussion of whether WMC 602 is a sufficient indicator of QMM-related hydrocarbon sources to the river.
- Although it is reasonable to assume that there are sources of hydrocarbons throughout the drainage basin that are not QMM-related, the discussion does not explain how concentrations were higher at sites adjacent to discharge points from the mine and then declined again.
- The report does not provide sufficient information regarding the role of transport of hydrocarbons to lakes via adsorption to suspended sediments in the rivers - followed by settling out in the lake basins.
- A comparison between high flow and low flow conditions as well as analysis of sediment concentrations would add to the understanding of the relative contribution from the mine as well as the importance of sediments in transport of hydrocarbons upstream to downstream.

Detailed Comments Regarding The Report on Oils and Greases and Hydrocarbons

I have arranged my comments in response to specific statements in the Rapport and Interpretation D'Analyse des Hydrocarbures des Huiles et Graisses des Eaux de QMM Fort Dauphin. (Labo Chimie Madagascar 2022).

Translated from the Report: The water samples come from various sources:
Mandromondromotra River which represents the place of discharge of mining effluents
ϖ Reference position
ϖ Receiving environment

The sampling points are mostly located west of the Mandromondromotra River. Administratively, the points belong to the respective municipalities of Fort-Dauphin, AmpasyNahampoana and Mandromondromotra

Figure 2. Sampling Points for Hydrocarbons and Oils and Greases.

Comment:
Figure 1 shows that the two incidents were on Enandrano River and upstream of Lac Besaroy so why were samples not focused on those areas, with more upstream-to-downstream samples in the river and more samples from Lac Besaroy?

Translated from the Report
Oils and fats
According to the results of the analyses, all the water points comply with the thresholds recommended by Malagasy legislation with a concentration of less than 0.001 mg/l. Mine waste water and Mandromondromotra water are free of oil and grease pollution with trace concentrations. Therefore, the risks associated with cancer, reduced air exchange and light penetration are avoided. As for oils and fats, the concentrations measured for total hydrocarbons are all compliant with Malagasy legislation. Nevertheless, there is a variation of the values according to the geographical location of the analyzed waters.

The possible origins of hydrocarbons in surface waters are of two kinds:
Natural: geological area containing oil reserves
• Anthropogenic: navigation on rivers, leaching by runoff water from different sources, atmospheric, etc.
In our case, it is rather anthropogenic origins. For the Mandromondromotra River, concentrations are higher upstream than downstream. The concentrations in the river just upstream of the discharge point are greater than the water released, which explains the origin of the hydrocarbons outside the mine site.

Comments:
The Table in the report shows that sites 42 and 43 have higher concentrations than the other sites. However, WMC 602 on the site has very low concentrations. Therefore, it appears that the logic is that WMC 602 should have higher concentrations if the mine was a significant source of hydrocarbons. This logic assumes that WMC 602 is an adequate indicator of QMM-related hydrocarbon sources to the river.

Translated from the Report. In reality, in surface waters, hydrocarbons tend to be found on the sediment side of rivers. The hydrocarbon concentration dynamics in Mandromondromotra shows a decrease in concentration from upstream to downstream in the water. In addition, the pollutants that exist in the river or other water bodies in the area come from the entire Mandromondromotra watershed and the main watercourse plays the role of receiver and conveyor. Therefore, the origins of any pollutants are the anthropogenic activities existing within the catchment area. In periods of flood, the dispersion of pollutants is greater than in periods of low water. The study area comprising the sampled waters is naturally located in the outlet of the said watershed and which is rather dominated by the flow regime. Indeed, the lower concentrations of hydrocarbons downstream are explained by their affinity with the sediments which retain them. Nevertheless, a probable increase during an accidental event can cause ecological impacts especially for aquatic fauna and the problem is that hydrocarbons are among the most persistent pollutants in the environment.

Comments
The above paragraph is difficult to follow. During flood events, one would expect hydrocarbons (which are hydrophobic and thus tend to adsorb to solids rather than dissolve in the water column) to be transported via suspended sediments downstream. Thus, there would be higher loadings the farther you go downstream – reflecting contributions from more and more of the catchment area.

The report does not say whether the water samples were filtered prior to analysis. If the water samples were filtered, then the role of total suspended solids cannot be known. Hydrocarbon loadings to Lac Ambavarano are of concern because suspended sediments are deposited on the lake bottom (including hydrocarbons adsorbed to those sediments).

Conclusion (Translated from the Report)
The contents of oils and greases and total hydrocarbons of all surface water around the water points of the mine comply with the standards of values imposed by national legislation. The discharge water leaving the mine complies with the specifications to which QMM is committed. Furthermore, it should also be noted that the anthropogenic sources of these parameters come from the activities that exist within the entire Mandromondromotra watershed and not just from a particular site if we were to stick to the hypothesis of a possible origin of the mine.
In addition, an analysis during the low water period is also necessary to assess the chemical dynamics of the surface waters of the area in comparison with the flood period. In the same perspective, it is also necessary to analyze river sediments to estimate their hydrocarbon content in order to confirm the fractionation of this parameter within the water column.

Comments;
Although it is reasonable to assume that there are sources of hydrocarbons throughout the drainage basin, the discussion does not explain how concentrations were higher at sites adjacent to discharge points from the mine and then declined again.

Samples should have been collected in the Enandrano River and more samples in the Lac Besaroy area.

I agree that a comparison between high flow and low flow conditions as well as sediment concentrations would add to the understanding of the relative contribution from the mine as well as the importance of sediments in transport of hydrocarbons upstream to downstream.

The Need for More Complete Data Collection and Evaluation

Further data collection should take advantage of guidance provided by the US EPA in its Causal Analysis/Diagnosis Decision Information System (CADDIS). Volume 2. Sources, Stressors and Responses. https://www.epa.gov/caddis.

The focus should be on screening for plausible causes of the fish kills and then collecting data to confirm or reject hypotheses about plausible causes. The two reports provide no rationale for the analytes chosen, nor did they provide a comprehensive evaluation of causes of fish kills. Instead, they appeared to focus on finding evidence that the overflow incidents were not significant sources of contaminants.