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Centre for Ecology and Hydrology
Lancaster Environment Centre,
Library Avenue, Bailrigg
Lancaster
LA1 4AP

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Analysis of the Potential Impacts of a Sodium Nitrate Dosing Strategy in TR&S Ponds at Sellafield on Algal Growth

Prepared by:

R. Groben

CEH Project: NEC03569 Task 12
Project Leader CEH: Rene Groben
Report to: Natalie Robinson, Sellafield Ltd.

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1. Introduction and contract remit

It has been proposed that the Thorp Receipt and Storage (TR&S) pond is subject to sodium nitrate dosing at 10 ppm (10 mg L^{-1}) as an anti-corrosive measure for the long-term storage of AGR fuel. As nitrate is a microbial nutrient, there is speculation that the introduction of sodium nitrate may cause a microbial bloom.

Previous work has suggested that due to the low levels of light (in most pond areas) and other microbial nutrients, such as phosphate and carbon, the existing microbial population would not have enough nutrients to initiate a bloom.

The potential impact of sodium nitrate dosing on microbial growth will need to be determined prior to the implementation of the dosing strategy.

Scope of Work

- *Characterisation of existing microbial growth conditions*
  A review of the pond operational parameters to support the characterisation of the existing nutrient levels in the pond. If possible, any deductions regarding the potential impact of increasing the nitrate levels should be presented. If not possible, the consultant should advise what additional analyses would be required.

- *Experimental strategy to determine the limiting nutrient*
  Of the range of experimental techniques available, the consultant should advise which of those will be the most suitable to identify the limiting nutrient in TR&S storage pond. The consultant should also advise the confidence in the results generated by the experimental strategy.

- *Long term monitoring arrangements*
  To provide forewarning of impending microbial blooms, a regime to monitor the pond water parameters will be required. The consultant should advise what parameters should be measured and if feasible, what the trigger limits are for preventative action. If possible, the consultant should advise what monitoring techniques are available.

[Text taken from the "Scope for Consultancy Arrangements to Support Sodium Nitrate Dosing Strategy in TR&S (TD/16459)".]

2. Summary

- The conditions in the TR&S ponds are generally unfavourable for algal growth with low nutrient and light levels, which is limiting current algal growth to biofilms on pond walls near strong light sources.

- Previous experiments and measurements indicate that phosphate is the limiting nutrient for algal growth in the ponds.

- Based on these data it is not likely that the proposed nitrate dosing will lead to a strong algal growth as long as phosphate levels stay low.

- Uncertainties exist due to the unknown species composition of the biofilms and their exact nutrient requirements. Also, benthic algae might accumulate nutrients which can lead to increased growth in the long-term.

- The current routine measurements of the ponds are sufficient for a simple monitoring scheme, although a higher sensitivity of the phosphate measurements is necessary.

- To obtain a better understanding of the pond biology and potential risks of changing conditions, e.g. rises in nutrient levels and thresholds for evasive actions against algal blooms, it would be necessary to identify the algal species present and determine their growth requirements.

- Phytoplankton models, like PROTECH, could be used as a management tool to estimate the effects of changes in nutrient levels or other environmental parameters onto algal growth in the TR&S and other ponds at Sellafield. These models are though only capable of estimating phytoplankton growth and not directly growth of benthic algae.

3. Characterisation of existing microbial growth conditions

As correctly stated in the consultancy agreement, algae require various nutrients, mainly carbon, phosphate, nitrate, in addition to light for their growth.

The TR&S is fed by water [redacted] which contains very low levels of nutrients. The mean amount measured [redacted] during a survey in 2005 was only 3.9 µg L^{-1} for total phosphorus, and around 0.5 µg L for phosphate-P, the lowest phosphorus concentration measured among 20 lakes and tarns of the English Lakes District. The annual mean for nitrate-nitrogen was 318 µg L^{-1} which is slightly above the average of those 20 lakes (Maberly et al. 2006). Dissolved Organic Carbon (DOC) is neither routinely measured in the monitoring programme of CEH nor has it been determined during the survey in 2005 but a comparison among Cumbrian lakes and rivers in 1988 showed a mean DOC concentration [redacted] of 0.9 mg L^{-1}. Mean DOC concentration in the analysed lakes were in the range of 0.7 – 2.6 mg L^{-1} but DOC measurements between 0.1 and 6.2 mg L^{-1} were recorded ([redacted] 0.1 – 2.8 mg L^{-1} DOC) (Tipping et al. 1988). Based on these values, [redacted] is considered oligotrophic or even ultra-oligotrophic and the most unproductive lake in the Cumbrian Lake District (Maberly et al. 2006).

The low levels of nutrients in the water were confirmed by measurements taken by Thorp personnel at the TR&S ponds in 2010, where amounts of PO_4-P and NO_3-N were mostly below the limit of detection (100 µg L^{-1}) or in rare cases slightly above (NO_3-N). The sensitivity of the detection method is though not sufficient for the low levels of phosphate that are to be expected normally [redacted] / TR&S ponds. DOC was not measured.

Even under the existing low nutrient levels, algal growth does occur and was visible on the walls of the TR&S ponds close to bright light sources (safety lights). Light intensities were not measured but the fact that intensive algal growth only seems to occur in close proximity to the safety lights in the pond walls indicates that the ambient light in the halls does not suffice for detectable algal growth.

The observed algae grow benthically in patches (biofilms) on the walls of the pond. It was not possible to examine the algae closer due to health & safety restrictions and therefore a taxonomic identification was not possible in this project. No phytoplankton growth could be observed in the water body during a visit to the facilities on 6th December 2010 but Thorp personnel reported that a very faint turbidity of the surface water can occur sometimes which is possibly caused by phytoplankton or bacteria. This has not caused though any problems so far.

The observations and measurements confirm the generally unfavourable conditions for algal growth in the TR&S ponds. Nutrient levels in the ponds are very low, especially for phosphate, which seems to be the limiting factor for algal growth [redacted]. Based on these data and previous experiments (Maberly & Hall, 1992; see chapter 4) it is not to be expected that an increase in nitrogen would trigger a strong increase in algal growth as long as phosphate levels remain low.

4. Experimental strategy to determine the limiting nutrient

A report by Maberly & Hall (1992) analysed the effect of sodium nitrate additions to water taken from a cooling tower at the Sellafield facilities on algal and bacterial growth. The algae in these experiments were taken from scrapings of biofilms from the cooling tower and were identified as mainly belonging to the genus *Chlorosarcinopsis* (Chlorophyta). During the experiments, no growth in biomass was observed after addition of either 75 or 300 mg L^{-1} of sodium nitrate to the water. The conclusion was that growth of algae and bacteria was limited by the availability of nutrients other than nitrogen, most likely phosphorus (Maberly & Hall, 1992).

The measured nutrient levels and the results of the experiments by Maberly & Hall (1992) give an indication about the potential impact of sodium nitrate dosing on algal growth in the TR&S pond. The proposed dosing of 10 ppm (10 mg L^{-1}) sodium nitrate is much lower than the amounts added during the experiments of Maberly & Hall (1992) which did not trigger algal growth. Therefore the risk of an increased algal growth through nitrate dosing is low as long as phosphate levels in the water do not rise.

The experiments of Maberly & Hall (1992) showed that nitrate dosing of the pond water would most likely not lead to increased algal growth, but they did not determine the phosphate level at which such growth would occur. Additional laboratory experiments would have to be conducted in which different amounts of phosphate would be added to the pond water and algal growth measured. These experiments would help to determine thresholds for phosphate levels in the TR&S ponds at which mitigating actions would have to be implemented, e.g. increasing the water flow to purge the phosphate from the ponds. This would also be effective at reducing any phytoplanktonic algae but would not remove benthic algae.

While it seems unlikely that the proposed sodium nitrate dosing causes additional mass growth of algae there are nevertheless uncertainties:

Different algal species vary in their nutrient requirements. Without an identification of the species present in the pond now and possibly some following growth experiments, it is not absolutely certain how they will react to the sodium nitrate dosing. The algae currently growing in the TR&S pond might be different from the species found in 1992 and have different growth requirements.

The long-term effect of additional nitrate on the algae in the biofilms is unclear. Algae growing in a biofilm on the pond walls would receive a constant supply of nutrients through water flow and mixing that they might be able to accumulate. Additional nitrate might then cause slightly higher algal growth when the otherwise limiting nutrient, i.e. phosphorus, has been accumulated, although it is unlikely that this would cause a bloom-like mass growth.

5. Long term monitoring arrangements

A long term monitoring scheme for the Sellafield ponds that has the aim to forewarn about algal mass growth should ideally take both pelagic (phytoplankton in the water column) and benthic algae (growth on pond walls, mainly near light sources) into account. The physical and chemical parameters that need to be measured and monitored for this are those parameters that have already been mentioned as important for algal growth, mainly nitrate, phosphate, temperature and light. All these, with the exception of light intensities, are already routinely monitored at the TR&S pond. The detection limit for nutrients of the currently used Dionex 5 analyser is not good enough at 0.1 mg L^{-1} to detect changes in the very low levels of phosphate present in the pond but it is understood that a new analyser with a higher sensitivity will be replacing the Dionex 5 soon. The current frequency of measurements for nutrients (three times a week) and temperature (daily) is more than sufficient and could even be reduced for the purpose of monitoring nutrient levels. A higher sensitivity of the measurements is more important than a high frequency of sampling. Light intensity has not been measured so far but given that the TS&R pond is indoors and intensities are not expected to change drastically over time, this parameter does not need to be monitored regularly. If the application of models to forecast algal growth would be implemented (see below) then a few single measurements of light intensities would be required near places of current algal growth.

With the current monitoring arrangements it is possible to get a forewarning for a potential increase of algal growth, although it is not possible based on the current data about the pond biology to set clear-cut thresholds for the different environmental factors that might cause algal blooms. Further information about the algal species present in the pond and their nutrient requirements would be necessary to set limits at which to start counteractive measures to prevent increased algal growth.

Possible strategies for long-term monitoring of the TR&S ponds could be:

a) Retaining the current measurements without further analyses of algal communities: Even without additional information it would be possible to get at least a rough monitoring system in place. Under current conditions, algae growth does occur but at a non-critical level and it is not expected that additional nitrogen would change this. However, if phosphate levels would drastically rise then it should be reacted upon, e.g. through an increase in water purge rate, depending of the source of the phosphate. While this is of course the easiest and cheapest approach, it would be based on trial and error in managing algal growth with possible negative consequences.

b) Experimental analysis of algal communities in the TR&S ponds and their nutrient requirements: This approach would require starting a new project in which samples would be taken from the ponds and analysed. These analyses would firstly identify the occurring algae microscopically and then determine their growth rates under different environmental conditions if these data are not already available from the literature for these species. This information would help determine the conditions at which actions would need to be taken to prevent increased growth of these algae.

c) Modelling phytoplankton dynamics: Computer models could be used to understand the dynamics of algal growth in the TR&S ponds. A potential model for this is PROTECH (**P**hytoplankton **R**esp**O**nses **T**o **E**nvironmental **Ch**anges). PROTECH is a processed-based model that simulates changes in biomass of various phytoplankton species under different environmental conditions (nutrients, light, temperature, predation). It has not only been successfully used in the past to answer scientific questions but also for environmental organisations and companies to manage water quality in lakes and reservoirs. (For a more detailed description of PROTECH and its applications see Elliott et al. 2010). The application of PROTECH or any other model would require the characterization of present algal communities through sampling and microscopic identification at the start, followed by further (e.g. monthly) sampling over possibly a year to validate the output of the model and refine it. The advantage of using a modelling approach over the pure identification of currently occurring algal species (strategy b) would be a better understanding of the interaction of environmental conditions in the TR&S ponds and therefore allow better management of the ponds. PROTECH could also be applied to other storage ponds in Sellafield where phytoplankton growth is a problem.

It should be noted though that PROTECH can only be used to model phytoplankton growth and cannot be used to estimate the influence of changes in nutrient levels for benthic algae growing on the walls of the ponds. Plans exist to expand PROTECH with a module for modelling benthic algae in addition to phytoplankton but the implementation of this is possibly 4-5 years in the future. To our knowledge there is currently no model available, or under development, that can be used to estimate the growth of benthic algae.

6. References

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