AN INTERGRATED MODEL FOR WASTE STABILISATION POND PRACTITIONERS

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ABSTRACT

The challenge facing practitioners working with wastewater stabilization ponds is often deriving actionable insights from incomplete information. Sampling and measurements of key operating indicators may be limited and sporadic. This paper describes an integrated model that can be used for scenario simulation and to help practitioners derive actionable insights from the data they have.

This paper describes an integrated model framework for practitioners to test "what if" type scenarios. The model is implemented in the SUMO™ simulation software which uses an open-source framework for viewing and editing biological, physico-chemical and transport model equations. The model has been developed specifically for algal based oxidation ponds that we have in New Zealand and has been calibrated and validated against real data from one of Watercare's oxidation pond systems.

KEYWORDS

Oxidation Ponds, Simulation Modelling, Treatment Mechanisms and Pathways

PRESENTER PROFILE

Kevan Brian is Watercares Innovation and Technology manager. He has experience in developing simulation models and applying these to real world situations

INTRODUCTION

Because of their extensive nature, waste stabilization ponds (WSPs) are often viewed as "simpler" than activated sludge treatment plants. But the variety of processes to consider when assessing their treatment is greater. To illustrate, the pathway for ammonia removal in activated sludge is nitrification only. Ammonia removal in WSPs, however, can be nitrification, algal assimilation, or atmospheric stripping.

Engineers who work with mechanical plants have a powerful tool in the activated sludge models (ASM) which simulation software providers have integrated with biofilm, aeration and water chemistry models. While the literature of models developed for WSPs is significant, it has not benefited from the same degree of integration. As a result, the engineering tools available for WSPs are less powerful than they are for activated sludge.

Practitioners working with WSPs often face the challenge of deriving actionable insights from incomplete information and understanding of the fundamental mechanisms that may be active in WSP's. Is ammonia removal governed by nitrification, algal assimilation or stripping? How much does each mechanism contribute to performance? Practitioners merit a tool that is equal to the complexity of their task and that allows them to better understand mechanisms within WSP's that may lead to new or innovative ways to optimise of improve performance. This paper describes an integrated model framework for practitioners to test "what if" type scenarios. The model is implemented in the SUMO™ simulation software which uses an open-source framework for viewing and editing biological, physico-chemical and transport model equations.

METHOD

The purpose of an integrated model is to tie together multiple sub-models in an overall framework held together by a materials balance. For WSP's, key sub-models include water balance to relate inflow, outflow and evaporation to total liquid volume, sedimentation and its impacts on accumulated volume of sediments, water chemistry, pH and its impacts on atmospheric stripping, temperature and light extinction models, water column biological activity models including algal photosynthesis, heterotrophic BOD removal and nitrification, sediment layer biological activity, digestion of solids and methane generation.

The integrated model discussed in this paper is implemented in the SUMO™ simulation software package. The advantage of using SUMO™ is that it uses an open-source model base that is coded in Excel spreadsheets. This means that anyone can view, and even change, the details of the individual sub-models. It is therefore a powerful tool for both researchers and practitioners. The utility of this model will be illustrated by applying it to a pond system in North West Auckland, New Zeeland where they face challenges in achieve adequate ammonia removal year-over-year. An aerial view of this pond system is presented in Figure 1.

Figure 1: Aerial View of Helensville Pond System

Currently practitioners who want to model an WSP in any of the commercially available simulation models such as BioWIn, SUMO or WEST need to use a combination of activated sludge, clarification, and anaerobic digestion models to try and simulate liquid phase reactions such as nitrification, sediment accumulation and degradation. Inputs such as aeration are typically done via surface aeration models, fine bubble or coarse bubble diffusion models that are specifically designed for mechanical aeration. These do not adequately describe oxygen transfer mechanism with a WSP.

Some of the above mechanisms are applicable to an WSP. However many of the key assumptions behind ASM type models may not be applicable to what is happening in a sometimes poorly mixed system such as a WSP. The key algal related mechanisms that are active in a WSP are discussed below along with the approach to modelling these.

ALGAE

Currently wastewater process simulation software packages do not have a model for the growth of algae. Hence one of the predominant organisms in a WSP is not modelled and this leads to some very significant inaccuracies in model predictions and seasonal behaviour of WSP systems.

As shown in figure 2 algae are one of the key mechanisms in a WSP

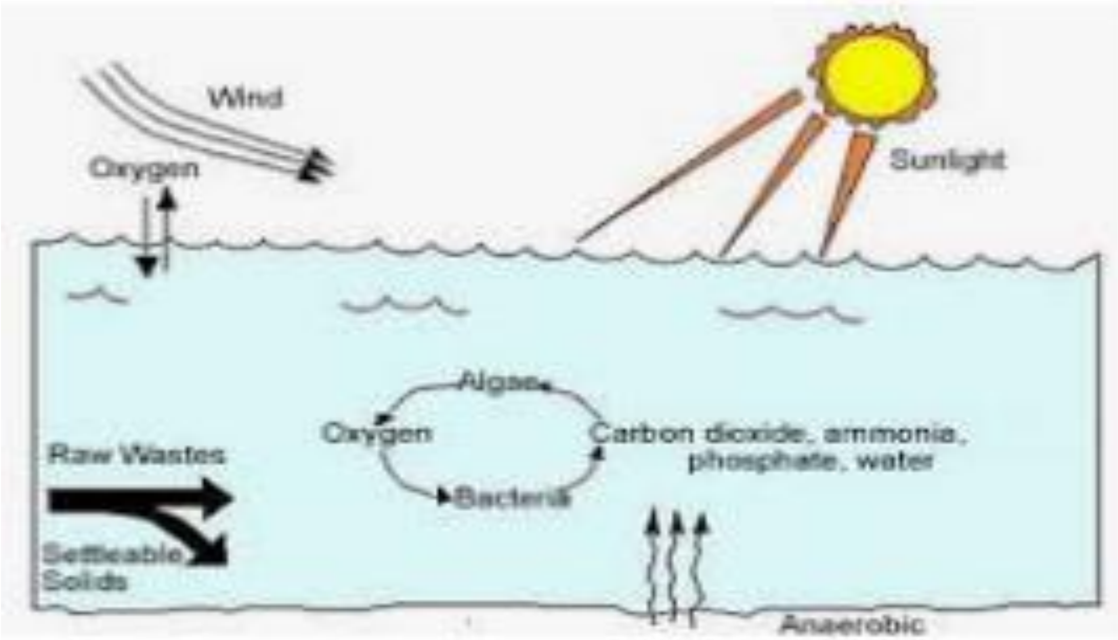

Figure 2: WSP mechanisms

Algal species in a WSP use sunlight, dissolved CO2 and nutrients for growth and produce oxygen as a by-product of photosynthetic activity – this has several implications in trying to model what a WSP does and the main mechanisms that are involved.

GROWTH

The growth of algae in a WSP is not directly related to the load of BOD or COD coming into the WSP as is the case with activated sludge. Algae use dissolved CO_2 in the water column as a carbon source for growth and get their energy from photosynthesis. This process adds carbon to the lagoon system that has nothing to do with the incoming wastewater.

In the proposed model a mechanism has been added for algal growth based upon light intensity and kinetic equations that are of a similar structure to those describing the activated sludge process. This allows prediction of algal suspended and includes a variable in the model that accounts for algal growth and provides a source of COD/BOD that eventually settles to the base of the pond and decays (benthic feedback).

POND PH

In the summer in New Zealand the pH of pond systems if often significantly higher (more basic) than neutral and can at times be as high as 9-10. Elevated pH is usually the result of algal activity. As the algae grow, they remove dissolved CO_2 from the water column, and this raises the water pH. In general, the more algal activity there is in the pond the higher the pH will go until this limit's growth.

The proposed model includes a modified approach where pH is calculated from water chemistry, biological reactions and now includes the growth of algae and the removal of dissolved CO_2. The model also includes the inhibitory effects of high (and low) pH on the growth of nitrifying bacteria, algae and heterotrophs

POND NUTRIENTS

Algae use both nitrogen and phosphorus as a macro nutrient for growth, hence their growth removes these nutrients from the water. Capturing this is essential for describing how nitrogen and phosphorus are cycled within a lagoon system. This allows the designer or operator a means of determining how significant algae assimilation might be when in the removal of ammonia from the wastewater.

Assimilation of nitrogen and phosphorus into algal cells is modelled in the same way as for heterotrophic growth and considerers nutrients "lost" in the pond effluent due to assimilation. The model also has a mechanism for the decay and lysis of nutrients from all types of microorganisms in the models. This means that the effects of assimilation, lysis and decay and transfer of nutrients from the sediment layer to the water column can be quantified.

DISSOLVED OXYGEN

As discussed above algae produce oxygen as a by-product of photosynthesis. This oxygen can then be used by other organisms in the WSP, including nitrifiers. One of the unique characteristics of a WSP is that algae are effectively transferring pure oxygen to the water column rather than oxygen mixed with air.

Henry's law (see equation 1) states that the higher the partial pressure of oxygen, the more it will dissolve into the water.

$C=kP$ (1)

Where:

C = concentration of dissolved Oxygen gas

k= Henrys constant

P = partial Pressure of Oxygen

This means that with high rates of algal activity dissolved oxygen levels in the WSP can be more accurately predicted using Henrys law of partial pressures and will often be significantly higher than table saturation values. These mechanisms are also incorporated into the proposed model.

AMMONIA STRIPPING

One of the important mechanisms to consider in the performance of a WSP in terms of nitrification and nitrogen removal is stripping to the atmosphere. Due to high levels of algal activity, pond pH can increase to between 8-10 during the sunniest part of the day. At this pH, some of the ammonia in the water column will be present as free ammonia and will strip form the surface of the WSP. The amount of stripping is related to the pond pH, surface turbulence and mixing.

RESULTS

The primary driver for modifying SUMO to include a dedicated WSP model is to give designer, operators and planners a tool to understand what mechanisms are likely occurring in the WSP and to what extent. This understanding should help with optimisation, understanding performance issues and planning for future upgrades.

An example of the model output is shown in figure 3. Here the mechanisms for the consumption and inputs of dissolved oxygen in a two-pond system are presented. From this the practitioners can gain a good understanding of what mechanisms are occurring in each pond and how they may interact in different scenarios.

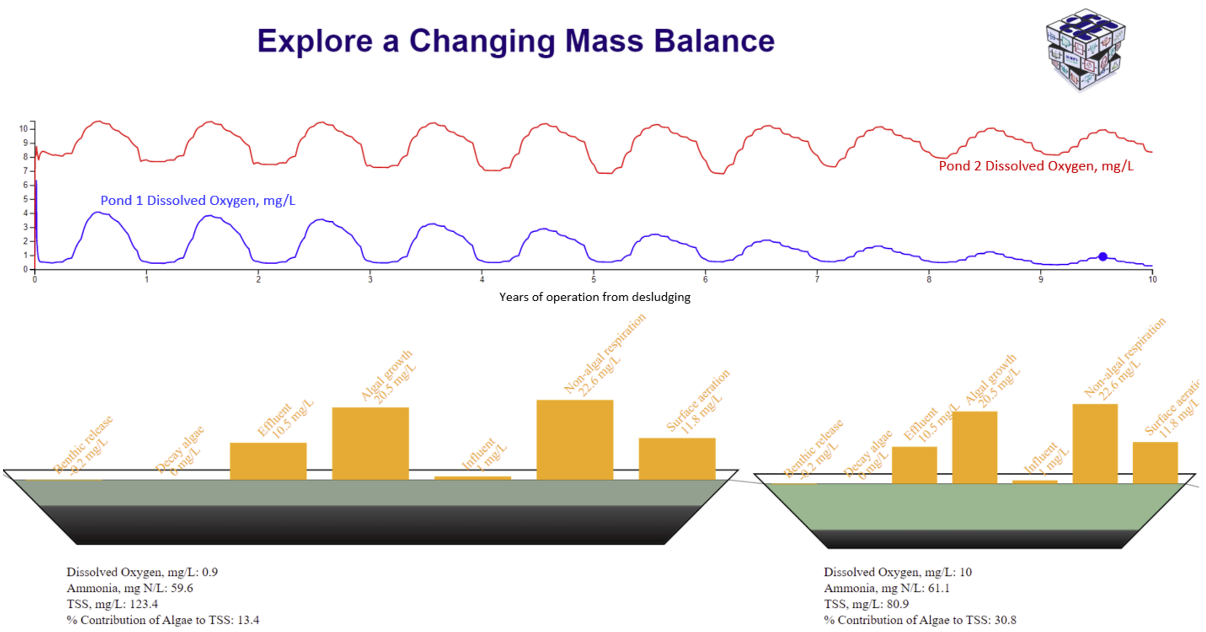

Figure 3: Example Model Output

Figure 4 presents a simulated pond effluent ammonia from a real lagoon system versus that predicted by the model.

Simulated results show a good match to the measured data based on a varying proportion of ammonia balance directed through nitrification, as presented in Figure 4b. By tracking the relative contribution of nitrification, algal photosynthesis, stripping and benthic feedback scenarios will be investigated for the stability of long-term ammonia removal given the influence of sediment accumulation on the order of 100 mm per year.

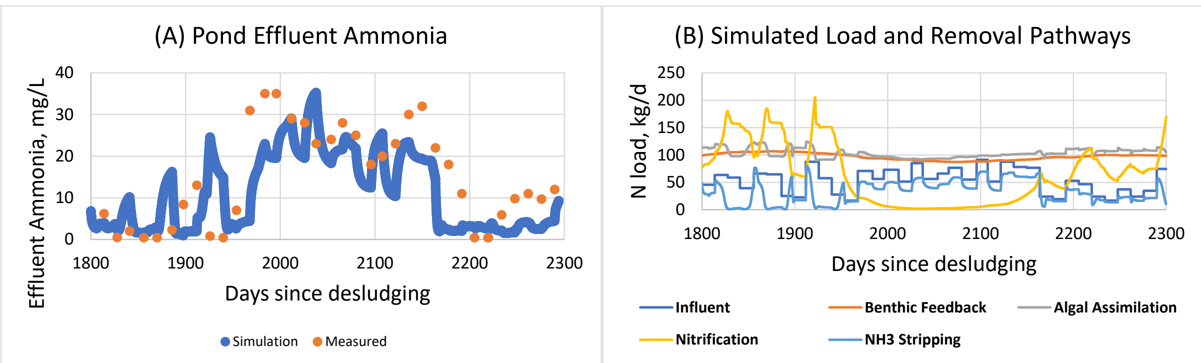

Figure 4: Comparison of measured and simulated effluent ammonia (left) as well as simulated ammonia removal pathways (right)

While these parameters are difficult to calibrate, inclusion of these mechanisms in the model will help practitioners with understand what the most important mechanism are the model

CALIBRATION

It is noted that some of the parameters in a WSP model may be difficult to calibrate or might require a lot of detailed data. At this stage the purpose of the model is to identify the main mechanisms and interactions in the WSP such that calibration effort can be directed at the most important mechanisms, while those that are less significant can be modelled without detailed calibration.

FUTURE WORK

The next stages of development are to use the model and to compare predictions over a wide range of WSP systems and improve its accuracy. In addition, a calibration and "how to" guide is being developed to help with quick and easy setup of the models. For those modelers who would like to add more detail the model will be able to accept variable season, daily and yearly data including that which affects the growth and behavior of algae.

CONCLUSIONS

Comparison of simulation results to the field data from the ponds under study allowed evaluation of the impact of relative contributors to the nitrogen mass balance including influent load, benthic load, nitrification, algal assimilation and ammonia stripping. Even in the absence of complete knowledge about which of these processes is governing, or the accuracy of model calibration, the integrated model framework nevertheless provides a powerful tool for evaluating "what if" scenarios that lead to actionable insights to inform future planning and optimization.