



Adding Effluent Pond Methane Reduction technology into Overseer

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Executive Summary

This report provides a detailed account of the integration of the EcoPond™ system for reducing methane emissions from dairy effluent ponds. Methane produced from effluent management systems can contribute up to 6% of total farm greenhouse gas (GHG) emissions. The EcoPond™ system, developed by Ravensdown Ltd at Lincoln University, uses chemical treatment of effluent to inhibit methanogen activity and reduce methane emissions by an average of 96%. This treatment includes both the original polyferric sulphate (PFS)-based formulation (Generation 1) and a newer formulation incorporating a 50:50 mixture of PFS and sulphuric acid (Generation 2).

The goal of the report is to evaluate the scientific robustness of the beta functionality in OverseerFM for modelling EcoPond™ treatment of effluent. The modelling design, assumptions, and evaluation work are described herein and have been externally peer-reviewed by subject-matter experts.

Model Specification for Treatment of Stored Effluent

The original EcoPond™ Generation 1 mitigation technology formed the basis of the initial specification work and peer-review process associated with incorporation into the national Agriculture Inventory Model (AIM), confirming that the technology was mature and supported by sufficient publications, field data and documentation to be used at national scale. Subsequently, additional testing and measurements supported further refinement of the technology, leading to the Generation 2 formulation, which was incorporated into the April 2026 AIM release.

This document defines the specifications required for the implementation of both the Generation 1 and Generation 2 EcoPond™ systems within the Overseer model. The work was led by Jean-Paul Tavernet (Overseer Ltd, lead modeller) and David Wheeler (AgResearch), in consultation with key experts (Hong Di, Keith Cameron and Peter Carey of Lincoln University). It accounts for nutrient flows and the impacts of chemical treatment on methane and phosphorus losses and aligns with available literature and expert feedback.

Evaluation and Impact Analysis

Several scenarios were modelled to assess the impact of chemical treatment across different effluent management systems. These scenarios showed a 96% reduction in methane emissions from effluent ponds, which is consistent with observed reductions reported in the literature (typically ranging from ~90% to 99%). Phosphorus loss was reduced by up to 31% in farms with significant effluent volumes, while embodied emissions associated with treatment showed minimal CO₂ impact (1-3% increase). The evaluation indicates the system's potential for significant environmental benefits in terms of GHG emissions and nutrient loss reductions.

Next Steps

The report recommends transitioning from beta functionality to full implementation in OverseerFM, formalising the model update for both Generation 1 and Generation 2 EcoPond™ systems and communicating the findings through technical release notes. This will align OverseerFM with AIM updates and provide farmers with formal access to this technology within OverseerFM.

1 Introduction

1.1 Background

The Overseer science model (henceforth referred to as Overseer) provides insights into the flow of nutrients across a user-described farming system. For dairy farms, a key part of this nutrient flow is associated with effluent and is determined by numerous factors, including the effluent management system. Effluent is defined here as the liquid waste created when milking sheds and animal yards are cleaned with water, noting that sludge is defined as the residual, semi-solid material that is produced from effluent ponds as a by-product during treatment or storage of effluent.

Within the OverseerFM user base, the percentage of year-end analyses that include dairy cows, and thus where effluent management is a factor, is approximately 70% for the 2019-2023 period. Most of the effluent generated on farm is a result of animals entering structures, e.g., milking sheds, or feed pads for dairy cattle. Dairy faecal matter naturally contains a range of microorganisms, one of which is a class known as methanogens (Laubach J. et al., 2015). These bacteria break down the organic material in effluent, primarily volatile organic compounds usually dissolved in liquid under anaerobic conditions, producing methane (Pratt C. et al., 2012). When effluent is collected and stored, the methanogens in the effluent will proliferate, generating methane that contributes to on-farm greenhouse gas (GHG) emissions. On average, this methane production accounts for up to 10% of the total annual methane production for a typical dairy farm using a holding pond effluent management approach. This contributes up to ~6% of the farm's total GHG emissions after accounting for non-methane sources, as methane remains the dominant source of farm GHG emissions (Revill et al., 2024).

This work is driven by two complementary goals: first, to improve model alignment between AIM and Overseer (Revill et al., 2024), and second, to incorporate mitigation measures that have been thoroughly tested and scientifically reviewed for inclusion into Overseer. Initial work involved an internal review which was followed by an update of effluent management modelling in Overseer (See [6.5.5 model release notes](#)). This work resulted in minor bug fixes and updating how the impact of different effluent management strategies impact GHG emissions. The next piece of work identified in this workstream was the inclusion of methane reduction technology for effluent ponds, with the first technology of this kind being recommended (MPI, 2023) and approved for inclusion into the April 2026 release of the Agricultural Inventory Methodology (AIM).

This technology included in AIM, known as EcoPond™, was developed by Lincoln University, Ravensdown Ltd and MPI (Cameron & Di, 2021). EcoPond™ is a system whereby a solution primarily composed of polyferric sulphate (PFS) is mixed into effluent storage systems. The controlled introduction of PFS creates conditions where the biological activity of methanogens is significantly impeded. This results in a significant reduction in methane emissions from effluent ponds. A simple schematic of how EcoPond™ fits into a farm system is shown in Figure 1. Here, the PFS injection point is between the effluent collection point and the effluent pond.

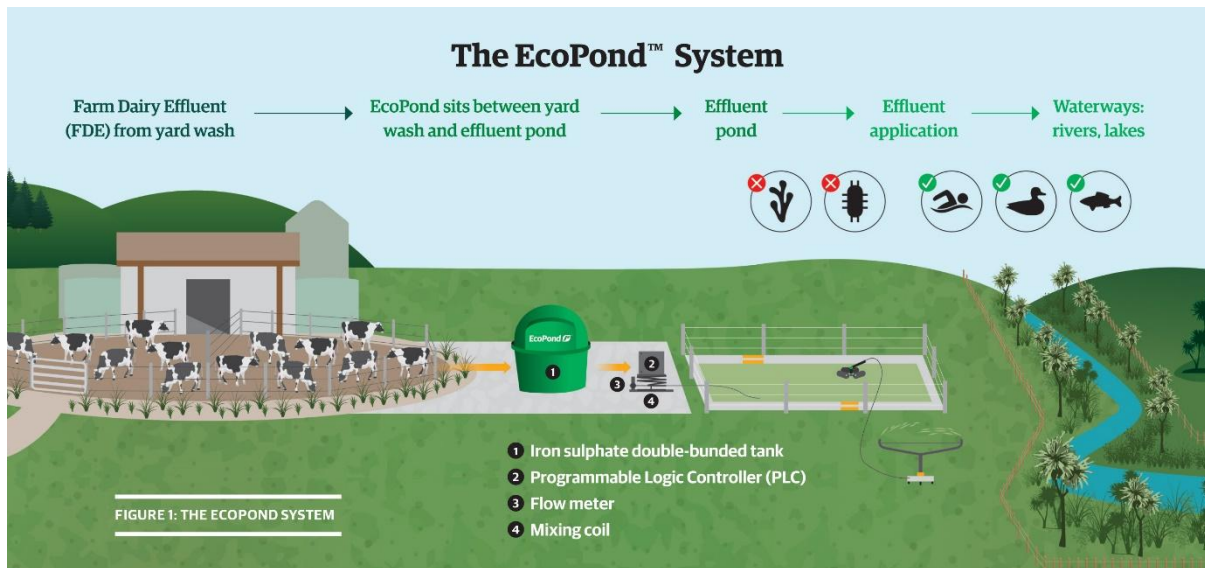


Figure 1: The EcoPond™ Generation 1 system. PFS is injected into the effluent flow between the source of the farm dairy effluent and the effluent pond. Key components include an iron sulphate double-banded tank (1), a programmable logic controller (PLC) (2), a flow meter (3), and a mixing coil (4). The treated effluent is then stored in the effluent pond before being applied to land. Taken from Lee (2023)

The use of PFS on farms was originally focused on clarifying effluent to facilitate water recycling (ClearTech). As research and development into ClearTech was progressing, a reduction in methane emissions from the stored effluent was repeatedly observed, leading to the development of PFS use specifically aimed at reducing methane emissions resulting from effluent storage. This led to the approach of adding PFS to effluent ponds, which has been found to have multiple modes of action that collectively lead to the observed reduction in methane production. These mechanisms include (Cameron & Di, 2021):

- Increased activity of “iron increasing redox potential” & “sulphate reducing bacteria” that inhibit the growth of methanogens.
- Maintenance of redox conditions above the threshold necessary for methanogenesis, thereby preventing the proliferation of methanogens.
- Methanogen inhibition through the presence of sulphide (produced from PFS).

EcoPond™ has been specifically designed for and experimentally tested on dairy cow farms using “holding pond” effluent management systems. As such, this effectiveness in reducing methane emissions and P losses has only been established for these farming systems and has not yet been implemented and evaluated on alternative effluent management systems such as those using separated solids, bunker systems under wintering pads/animal shelters, or for treating effluent from other animals (e.g., milking goats or sheep).

A graph showing OverseerFM user-reported percentage use of effluent management systems for the 2019-2023 period is presented in Figure 2. Here, the effluent management systems that would be impacted by using PFS treatment (Holding ponds and 2-ponds+discharge) represent 68.8% of dairy farmers during the period 2019-2023.

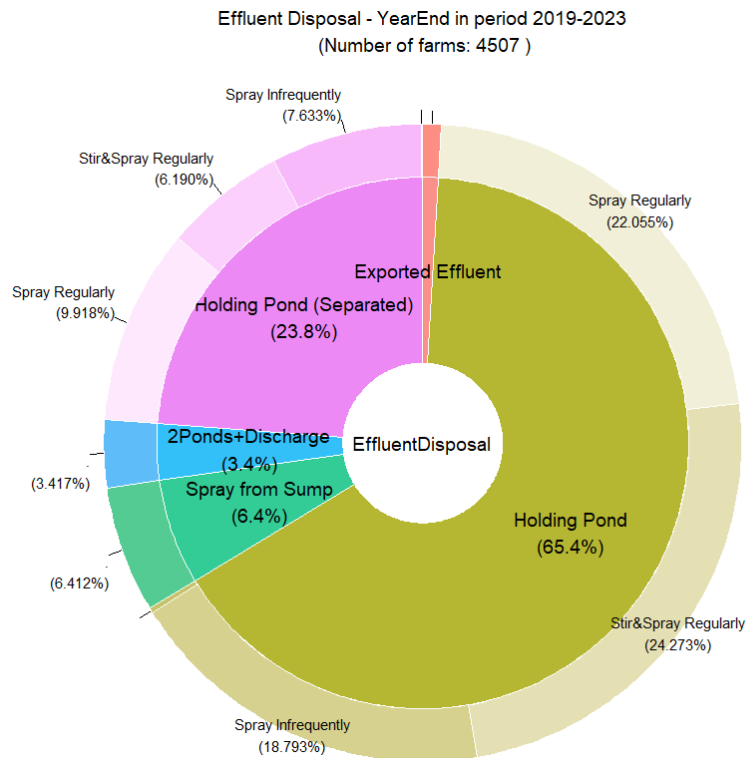


Figure 2: Percentage use of effluent management systems for the 2019-2023 period is based on user-reported data from Overseer. All farms with a defined effluent management system are included. Each farm is represented once, and if multiple analyses were conducted during the 2019-2023 period, only the latest analysis is considered. Definition of all effluent management systems is in Wheeler 2018b.

As such, including the representation of this technology into Overseer and thus OverseerFM presents the inclusion of an emerging technology, keeping in step with recent updates with AIM. In addition, this work will extend the modelling captured in AIM, as AIM does not consider nutrient flows beyond GHG (i.e., phosphorus, sulphur, and acidity) and does not model at the farm level. Therefore, inclusion of this technology into OverseerFM would also represent the first piece of work to assess the science and ability to model the impact of treating effluent with PFS at the farm scale on the entire nutrient budget. Lastly, this work will deliver the ability for farmers to comprehensively understand the full impact that using PFS to treat effluent has on their farm's nutrient budget and losses.

1.2 Purpose

This report aims to provide a detailed account of the implementation of the beta functionality to model PFS treatment of dairy effluent into OverseerFM, enabling an evaluation of its scientific robustness. Section 2 details the modelling specification design and captures the rationale of any assumptions and design choices made and how these relate to the literature and feedback from experts. Section 3 describes the validation and impact testing work done on the specification, after it was implemented into code. This is followed by the next steps (section 4), where a recommendation on it going past a beta release is provided.

2 Model specification for treatment of stored effluent

2.1 Scope

The following specification for modelling the impacts of treating stored effluent with PFS assumes the use of an EcoPond™ Generation 1 system along with good management practices (GMP) for pond management and effluent application. This is because EcoPond™

is the only version of this PFS use that has peer-reviewed science behind it and is market ready in Aotearoa New Zealand. Please refer to Appendix B for the extension of this modelling approach to include the Generation 2 version of EcoPond™, which is also included in the April 2026 update of the national AIM model.

As previously stated, literature on EcoPond™ currently only describes the design and experimental testing on dairy cow farms using “holding pond” effluent systems. Therefore, the applicability and considerations of this model change only apply to these systems when used on a dairy farm.

2.2 Specification development

This spec development was led by Jean-Paul Tavernet (Overseer Ltd, lead modeller) and David Wheeler (AgResearch) using reported information in the referenced articles, reports, and the Overseer code, whilst in consultation with key experts (Hong Di, Keith Cameron, and Peter Carey of Lincoln University).

To model how the use of PFS impacts the Overseer nutrient budget, the additional nutrients imported into the farm system first needs to be calculated, followed by the impacts of these nutrients and how the nutrients will flow through the farm, finishing with where and how nutrient losses are impacted. The following sub-sections describe these components in sequence and set out the relevant science, as well as the assumptions required to represent these processes in the model.

2.3 Nutrients brought onto the farm

2.3.1 Nutrients from PFS

To achieve the modelled reduction in methane emissions, a sufficient amount of PFS needs to be added relative to the volume of effluent being treated. As such, the required amount of PFS needing to be added to effluent varies with effluent volume. The default annual S input is derived from the assumption that 2000 kg of S as PFS is needed for a system with 445 mature milking cows (Keith Cameron, Lincoln University, pers. comm.). PFS used for EcoPond™ contains 12% S (Cameron & Di, 2019) although it is noted that the S content of PFS can vary with the source. Furthermore, it is assumed that both the volume of effluent and the required amount of PFS change linearly with the number of cows (Keith Cameron, Lincoln University, pers. comm.).

The amount of S brought (kg S/year) on to the farm can be estimated as:

$$\text{Equation 1} \quad \text{AmountPFS}_s = \frac{2000}{445} \times \text{NumberMilkers}$$

Where *NumberMilkers* is the peak number of milking cows.

This base estimation of PFS only considers the time that animals spend in the farm dairy. When additional structures such as feed pads, standoff pads, or wintering pads are incorporated into the farm dairy effluent system, the extended time that animals spend on these structures leads to increased effluent processing. As a result, the default amount of base estimation of PFS must be adjusted by a factor that accounts for all additional effluent introduced into the farm dairy effluent system. This adjustment is made using the following ratio:

$$\text{Equation 2} \quad \text{AmountPFS}_s = \frac{2000}{445} \times \text{NumberMilkers} \times \text{FactorEffluentAdjustment}$$

Where:

- *NumberMilkers* is the peak number of milking cows.
- *FactorEffluentAdjustment* is the multiplicative factor that accounts for the additional effluent, and is calculated as follows:

Equation 3
$$FactorEffluentAdjustment = (FDE + FromFeedPad.Liquids + FromWinteringPad.Liquids + FromStandOff.Liquids)/FDE$$

Where:

- *FDE* is the N amount of effluent from the farm dairy.
- *FromFeedPad.Liquids* is the N amount of liquid effluent from feed pad treated in the FDE management system.
- *FromWinteringPas.Liquids* is the N amount of liquid effluent from wintering pad treated in the FDE management system.
- *FromStandOff.Liquids* is the N amount of liquid effluent from standoff pad treated in the FDE management system.

Note that effluent amounts are estimated after N loss by volatilisation has occurred. Also, it is assumed that any feed or bedding contamination in the effluent does not impact on the effectiveness of PFS or alter the required PFS-to-effluent ratio. It is important to note that modelling the impact of PFS treatment on specific effluent systems associated with the wintering pad (e.g., bunker systems) is currently not possible due to the absence of data for these types of effluent systems.

Additional effluents produced by other types of animals present in the different structures are not considered in the calculation of the required PFS quantity, and effluents from dairy cows must remain dominant, in the order of 90% of the total revised stock unit (RSU), to maintain the accuracy of the estimate and the impact.

2.3.2 Nutrients from PFS impurities

Of the most prevalent impurities present in PFS, identified from Table 1 from Cameron and Di (2019), only Mg and Na are present in high enough concentrations to be considered for their nutrient impacts. These are estimated in (kg Mg/year) and (kg Na/year), respectively, as:

Equation 4
$$AmountPFS_{Mg} = 44 \times \frac{AmountPFS_s}{2000}$$

Equation 5
$$AmountPFS_{Na} = 82 \times \frac{AmountPFS_s}{2000}$$

where 44 kg Mg and 82 kg Na are the amounts added when 2000kg S as PFS is added.

2.4 Impact on nutrient distribution during storage

Adding PFS to effluent directly impacts its nutrient composition via introducing nutrients (see previous section). Given the flocculating properties of PFS and that treated effluent goes into storage ponds, the impact of PFS on nutrient distribution between the effluent and sludge needs to be considered.

In Overseer, the distribution of each nutrient between the solid (sludge at the bottom of the pond) and liquid (effluent) phases of stored effluent is mathematically represented in a corresponding separation ratio. This ratio is important because the solid and liquid phases of effluent are often managed differently, meaning this ratio determines the proportion of nutrients that enter different areas of the farm. The liquid fraction is typically applied to selected blocks via spraying (effluent blocks), while the solid fraction (sludge) is less periodically applied across various areas of the farm when the pond is emptied for cleaning or desludging. A change in separation ratios can have a real impact on a farm's management strategy for effluent. For example, variation in separation ratios for N can influence the amount of N added to effluent blocks, and hence the effluent block sizes to achieve target N application rates and the potential N leaching losses from those blocks. Similarly, variation in nutrient separation ratios for other nutrients can affect things such as maintenance fertiliser nutrient requirements.

Normally, these separation ratios depend on the liquid management practices employed. In general, the shorter the duration that effluent is allowed to settle – thereby minimizing the settling of solids into sludge – or when sludge is actively broken up and is mixed into the effluent (stirred), the higher the nutrient content in the liquid effluent. Conversely, extended settling periods result in lower nutrient concentrations in the liquid effluent. This is modelled using the options frequent spraying (less than 2 weeks settling time) with and without stirring or infrequent spraying. The impact these strategies have on separation ratios is shown in Table 1, which reflects what is currently in Overseer.

Table 1: *Proportion of nutrient in the sludge used by the Overseer model.*

Nutrient	Liquid management		
	Spray regularly	Stir and spray regularly	Spray infrequently
N	0.1	0.01	0.3
P	0.3	0.03	0.7
K	0.033	0.0033	0.1
S	0.165	0.0165	0.5
Ca	0.31	0.031	0.95
Mg	0.28	0.028	0.85
Na	0.12	0.012	0.35
H	0.23	0.023	0.56

For EcoPond™, it is assumed that the amount of nutrient leaving the storage pond is the same as for untreated effluent under the same management conditions (Keith Cameron, Lincoln University, pers. comm.). Consequently, nutrient separation is assumed to be governed by the pond storage system rather than PFS treatment, and the nutrient separation ratios shown in Table 1 are applied unchanged to PFS-treated effluent under the same management.

It is noted, however, that while this assumption is justifiable in principle, there is currently no measured data that directly supports it. In addition, the impact of variables such as partial stirring, deferred irrigation, and point of effluent extraction have not been considered due to a lack of data and are assumed to have minimal impact on nutrient distribution.

As with specific nutrient distributions, the effect of PFS treatment on volatile carbon compounds also needs to be considered. These compounds are the primary substrates of methanogens, which convert them into methane. When effluent solid sludge begins to separate out, generally the large particulate matter goes into the sludge, and the volatile carbon compounds remain in the effluent. Unpublished results from Keith Cameron and Di Hong (Lincoln University, pers. comm.) indicate that methane production and the magnitude of methane reduction was the same for settled effluent as for fresh effluent, which is consistent with the assumption that the volatile carbon compounds remain in the effluent. As such, the use of PFS is also considered to not meaningfully impact the concentration of volatile carbon compounds in the liquid phase of stored effluent.

Overseer currently estimates N volatilisation rates for different processes throughout the effluent management system, including 35% when sludge is applied to land. As there is currently no data to suggest that N volatilisation differs after treatment, the volatilisation rate is assumed to remain consistent with values established for untreated systems.

2.5 Impact on Acidity

PFS is a chemical that is classified as a strong acid. Therefore, on-farm management of PFS must strictly adhere to best management practices (BMPs) to mitigate potentially undesired

environmental impacts, and it is assumed that these BMPs are in place and followed during application.

The practical implications of adding a strong acid to an effluent storage system will manifest when the different portions of the effluent leave the storage pond. For the management systems accounted for here, liquid is applied to a block, with solids applied to a block or removed from the farm. Of these scenarios, consideration is needed when applying the effluent or sludge to a block.

According to the results of Chen et al. (2019) and Che et al. (2023), no significant differences in soil pH were observed when spraying PFS treated effluent vs non-treated effluent. Similarly, applying PFS treated effluent or clarified water to blocks showed little change in soil pH when compared to applying untreated dairy farm effluent. These findings suggest that the application of PFS treated effluent has no significant effects on soil pH compared to applying untreated effluent in available studies; assumed unchanged in the model due to lack of direct experimental evidence.

That said, the acidity model within Overseer, based on de Klein et al. (1997) and described within the acidity section of the “Block Nutrient Budgets” technical manual, includes an estimate of acidity generated by different processes such as leaching, volatilisation, and denitrification when different forms of N are supplied (ammonium or nitrate). Here, Overseer assumes that the N composition of effluent is 17.8% ammonium-N for the liquid phase and 5% ammonium-N in the sludge phase, with nitrate-N proportions set at 0.7% for both phases and the remaining N assumed to be in organic form.

Preliminary work was done for understanding PFS use in ClearTech to see if the proportion of ammonium and nitrate in PFS treated effluents varied compared to non-treated effluent. Cameron and Di (2019) reported ammonium-N accounted for 13% of the total N in farm dairy effluent (FDE), treated effluent, and about 50% of total N in clarified water (CW) under controlled tank conditions. While ammonium concentrations can differ in pond systems due to processes such as settling, volatilisation, and immobilisation, these results indicate that ammonium concentrations do not vary significantly between treated and untreated effluent (solid phase). It should be noted, however, that when used in a ClearTech context, PFS will lead to a meaningful change in ammonium levels in CW. This impact is not directly applicable when using PFS in a EcoPond™ system.

As with the nutrient separation ratios, direct measurements on how PFS treatment impacts ammonium levels have not been done. The assumption that the PFS treated effluent has the same nitrate and ammonium composition as untreated effluent will be updated as experimental data becomes available.

2.6 Impact on GHG

The primary impact of adding PFS to the effluent pond is a reduction of methane emissions, with no expected direct or indirect effects on nitrous oxide or direct carbon dioxide emissions, except for the embodied emissions associated with PFS use. This section captures the portion of the specification that aligns with the AIM model (section Methane).

2.6.1 Methane

As previously discussed, PFS treatment of effluent ponds reduces methane emissions through multiple modes of action that collectively lead to an average reduction in methane production from effluent storage ponds of 96% (range 90-100%, SE 3.3; Cameron & Di, 2021).

In its implementation, AIM uses an average rate of effectiveness for PFS in reducing methane emissions from farm dairy effluent of 96% (MPI, 2023). This reduction assumes the default amount of PFS is applied, as reported by Cameron and Di (2019, 2021). Following the lead

from this work, the specification for Overseer also assumes a 96% reduction in methane emissions, translating to a reduction factor of 0.04 applied to methane emissions from anaerobic ponds.

Methane emissions from holding pond system were based on the IPCC methodology. Thus, methane emissions (kg methane/year) from holding ponds are estimated as:

$$\text{Equation 6} \quad CH_{4HP} = \text{Dung2Pond} \times (1 - \text{ASH}) \times B_0 \times 0.67 \times \text{MCF} \times F_{PSF}$$

Where:

- CH_{4HP} is in kg methane/year
- Dung2Pond is the effluent dung added to holding pond system (kg dung/year), which is calculated from farm effluent management practices (e.g. proportion of excreta collected via feed pads, stand-off pads, or milking parlour).
- ASH is the ash content of manure calculated as a fraction of the dry matter feed intake, 0.08 (IPCC, 2006, table 10.2 default value).
- B_0 is the maximum CH_4 -producing capacity of manure variable by species and diet, $0.24 \text{ m}^3\text{CH}_4/\text{kg VS}$ (IPCC, 2006, table 10A-4; Oceania default value, verified by Pratt et al. (2012)).
- 0.67 is the conversion factor for converting CH_4 from cubic metres to kilograms (IPCC, 2006).
- MCF is the CH_4 conversion factor, 0.76 (IPCC, 2006, table 10.17, default for uncovered anaerobic lagoon, average annual temperature 15 degrees Celsius, verified by Pratt et al. (2012)).
- F_{PSF} is the CH_4 reduction factor, set to 0.04 (96%)

The methane calculation is based on the existing baseline emissions routines already coded in Overseer, which account for the chosen effluent management system (e.g. two-pond systems, holding ponds with or without solids separation). The result is then multiplied by the PFS reduction factor. Farm-specific factors, such as temperature fluctuations of the effluent pond and initial effluent pH are not incorporated into the methane emission or efficacy of PFS in reducing methane emissions, which are assumed to have a negligible impact within the current model framework.

2.6.2 Embodied emissions.

While the use of PFS is assumed to have no direct or indirect impact on carbon dioxide emissions, using PFS on farm means the embodied emissions of PFS needs to be accounted for. Embodied emissions represent the GHGs emitted during manufacture, transport, and use of a product on the farm, which is reported in CO_2 equivalence. Overseer also estimates the embodied energy consumption of manufacture, transport, and use of a product on the farm, which is reported in megajoules (MJ).

The LCA analysis, based on data from the Lincoln University dairy farm, estimated an embodied emission of 2372 kg CO_2e per year (**Figure 3**, Peter Carey, personal communication). With a standard input of 2000 kg S as PFS for 445 cows (section 2.3.1), and assuming S input scales linearly with herd size, the total S input for the 555-cow herd used in the LCA is calculated as $2000 \times 555 / 445 = 2494$ kg S as PFS. This corresponds to 0.95 kg CO_2e per kg S as PFS, or, given a PFS S content of 12% (section 2.3.1), an emission factor of 0.114 kg CO_2e per kg of PFS. This is equivalent to ~ 4.3 kg CO_2e per cow per year.

Note that the estimated embodied emissions represent a small fraction of the total pond emissions, estimated at 1.3% (**Figure 3**), while effluent emissions themselves account for around 7% of the total farm emissions. This estimate is considered sufficient but may be updated in the near future to ensure compliance and accuracy.

The embodied energy emissions factor was estimated using the fertilisers and lime data already in the model, excluding urea, calcium ammonium nitrate (CAN), elemental S, and MgO. This gave a ratio of 7.78 MJ/kg CO₂e, or 0.88 MJ/kg for PFS. The additional GHG emissions due to the use of PFS on farm are calculated as a product of the aforementioned ratios and the amount of PFS in kilograms brought onto the farm.

LCA model output

Model inputs	Input values	Units	Input description	References
Pond size	1,000,000	L	Size of effluent pond	Carboncare 2024. Global CO2 Calculator for Transport and Logistics. Switzerland. Retrieved 4/3/2024. www.carboncare.org
Distance to farm	100	km	Travel distance to deliver PFS/SA	
Treatment frequency	1	monthly	How often pond is treated	
Herd size	555	cows	Number of milking cows	Hasanbeigi A 2022. Steel Climate Impact - An International Benchmarking of Energy and CO2 Intensities. Global Efficiency Intelligence. 30 p. Intelligence GE. Florida, USA. https://www.globalefficiencyintel.com/steel-climate-impact-international-benchmarking-energy-co2-intensities 1/12/2023
Truck class	5,000-7,500	kg	Average gross vehicle mass (GVM)	
Trailer present	No		Add trailer payload (if applicable)	
Truck recycled	Yes		Offset of truck replacement CO ₂ e costs	Liu C, He Y, Li F, Wang H 2013. Preparation of poly ferric sulfate and the application in micro-polluted raw water treatment. Journal of the Chinese Advanced Materials Society 1 (3): 210-218.
Origin of PFS	China		Country of origin to calculate transport cost	Lyu Z, Pons D, Zhang Y 2023. Emissions and Total Cost of Ownership for Diesel and Battery Electric Freight Pickup and Delivery Trucks in New Zealand: Implications for Transition. Sustainability 15 (10): 7902.
Origin of sulphur	Canada		Country of origin to calculate transport cost	Marwa M, Soumaya A, Hajjaji N, Jeday MR 2017. An environmental life cycle assessment of an industrial system case of industrial sulfuric acid. International Journal of Energy, Environment and Economics 25 (4): 255-268.
Start of milking season	1/08/2023	date	Date at which pond treatment begins	New Zealand Transport Agency-Waka Kotahi 2024. General heavy motor vehicle definitions and specifications. NZTA. Retrieved 4/3/2024. https://www.nzta.govt.nz/roadcode/heavy-vehicle-road-code/licence-and-study-guide/information-for-heavy-vehicle-drivers/definitions-and-specifications-for-heavy-motor-vehicles/general-heavy-motor-vehicle-definitions-and-specifications/
End of milking season	31/05/2024	date	Date at which pond treatment ceases	Song X, Du S, Deng C, Shen P, Xie M, Zhao C, Chen C, Liu X 2023. Carbon emissions in China's steel industry from a life cycle perspective: Carbon footprint insights. Journal of Environmental Sciences.
Whole months over season	10	months	Period over which pond receives treatment	Yang L, Hao C, Chai Y 2018. Life Cycle Assessment of Commercial Delivery Trucks: Diesel, Plug-In Electric, and Battery-Swap Electric. Sustainability 10 (12): 4547.
Manufacture & shipping of PFS	1593	kg CO ₂ e		Zouboulis AI, Moussas PA, Vasilakou F 2008. Polyferric sulphate: Preparation, characterisation and application in coagulation experiments. Journal of Hazardous Materials 155 (3): 459-468.
Manufacture & shipping of SA	204	kg CO ₂ e		
Transport of PFS & SA to farm	576	kg CO ₂ e		
Total manufacture & transport emissions	2372			
AIM CO ₂ e annual pond emissions	188,567			
Percentage of annual pond emissions	1.3%			

LCA shows manufacture and transport CO₂e emissions cf. annual pond emissions = 1.3%

Figure 3: Life Cycle Assessment (LCA) results for the PFS product.

As such, the embodied emissions and embodied energy consumption from PFS use are calculated as follows:

$$\text{Equation 7} \quad \text{EmbodiedCO2PFS} = \text{totalPFSAppliedInKg} \times 0.114$$

$$\text{Equation 8} \quad \text{EmbodiedEnergyPFS} = \text{totalPFSAppliedInKg} \times 0.88$$

Where the amount of PFS in kilograms brought onto the farm is estimated as:

$$\text{Equation 9} \quad \text{totalPFSAppliedInKg} = \frac{\text{AmountPFS}_s}{0.12}$$

And AmountPFS_s is as calculated in Equation 2

2.7 Impact on the nutrient budget

The chemical structure of PFS is polymerised iron sulphate, which is composed of iron, sulphur, oxygen, and hydrogen. In addition, some trace magnesium oxide is present, which is an impurity from the manufacturing process. While the impact of this chemical has already been discussed, the impact of its individual components still needs to be accounted for.

The addition of S, Mg and Na impacts the nutrient budget through being introduced as a nutrient input to the farm, which has already been considered (see Nutrients brought onto the farm). The flow of these extra nutrients in the effluent is modelled using existing methodology.

The last remaining component, iron, is not directly modelled in Overseer. However, certain forms of iron have a strong affinity for creating complexes with phosphorus (Wilfert P., 2015). Thus, the impact of PFS-iron on phosphorus leaching was examined and needs to be accounted for within Overseer.

2.7.1 P loss in runoff and leaching

According to Che et al. (2022), spraying PFS-treated effluent onto a block results in a significant reduction in total P losses when compared to spraying untreated effluent. As described in the [Block Nutrient Budget TMC](#), Overseer calculates P loss (Prunoff) from overland flow and leaching as a sum of three components:

$$\text{Equation 10} \quad \text{Prunoff} = \text{SoilPloss} + \text{FertPloss} + \text{EffPloss}$$

Where:

- SoilPloss is the background P loss (kg P/ha/year)
- FertPloss is the incidental fertiliser P loss (kg P/ha/year)
- EffPloss is the incidental effluent P loss (kg P/ha/year)

The background P loss (SoilPloss), combining dissolved and particulate P losses via overland flow as a function of soil test values (e.g. Olsen P), soil properties (e.g. anion storage capacity, structural integrity), hydrology, slope/topography, and deer presence. The similarity in dissolved reactive phosphorus (DRP) and total dissolved phosphorus (TDP) levels between control and PFS-treated effluent application conditions reported by Che et al. (2022) suggests that soil P dynamics remain unchanged with use of PFS. As such, it is assumed that PFS treatment has no effect on the SoilPloss component of P loss. Similarly, FertPloss relates to fertiliser use, and thus also reasonably assumed to not be affected by the introduction of PFS via effluent.

EffPloss represents incidental P loss from effluent application, which varies as the risk of runoff or leaching varies at time of effluent application. The observed drop in P losses by Che et al. (2022) is proposed to occur due to the iron in PFS, which binds to the P in the effluent to make insoluble complexes (a mixture of FePO_4 and $\text{Fe}_3(\text{PO}_4)_2$). Due to the insolubility of these complexes, the potential for runoff or leaching during effluent land application is significantly reduced. The reductions cited – 60% for freshly treated effluent (liquid effluent sprayed regularly) and 45% for stored treated effluent (liquid effluent sprayed infrequently) – apply exclusively to farm dairy effluent. These reductions were observed under specific soil and management conditions (artificially drained, stony soils).

Given the limited empirical evidence and the specific context of the Che et al. (2022) study, the reductions in P loss are applied only where supporting data exist. This approach reduces the risk of overstating the effectiveness of PFS in contexts not studied. Specifically:

- Stony soils or artificially drained paddocks (weighted by artificially drained area):
 - Effluent application depth < 12 mm:
 - 0% reduction, regardless of management.
 - Effluent application depth \geq 12 mm (including 12–24 mm and > 24 mm):
 - If actively managed (e.g., deferred irrigation, low-risk timing, or moisture-aware scheduling):
 - 0% reduction.
 - If unmanaged:
 - 60% reduction (for regularly sprayed effluent) or,
 - 45% reduction (for infrequently sprayed effluent).

- All other soils (non-stony or non-artificially drained paddocks):
 - 0% reduction, regardless of depth or management.

As Overseer does not differentiate between forms of P in the liquid phase (i.e., dissolved vs. particulate) when estimating incidental P loss, the total P reduction observed by Che et al. (2022) is applied uniformly to the EffPloss term.

The reduction factor is applied only if effluent depth ≥ 12 mm, unmanaged, and on stony or artificially drained soils, as shown in the equation below:

Equation 11 $EffPloss_f = EffPloss_i \times FP_{PFS}$

Where:

- $EffPloss_f$ is the incidental P loss from effluent application after applying the PFS reduction factor.
- $EffPloss_i$ is the initial incidental P loss during effluent land application
- FP_{PFS} is the reduction factor,
 - set to 0.4 (60% reduction) for regularly sprayed effluent,
 - set to 0.55 (45% reduction) for infrequently sprayed effluent,
 - but only under the soil and management conditions described above.

The variation in P reduction observed between regularly vs infrequently sprayed effluent is thought to occur due to the slow decomposition of the Fe-P complexes and consumption of the iron, although the mechanism remains uncertain.

As for treated sludge being applied to land, there is no experimental data examining the effect of PFS treatment on P loss during this process. In addition, it is unclear what the formation and degradation rates of PFS and Fe-P complexes might be over time, meaning a reasonable estimate cannot be derived from first principles. Consequently, a conservative approach has been taken, and no reduction in P loss for PFS treated sludge use is included in this specification but will be reviewed for potential update when sufficient experimental peer-reviewed data becomes available.

2.7.2 Direct P loss to water

In Overseer, direct loss to water refers to the nutrients that are lost directly into waterways, either through drainage systems, direct discharge from 2-pond system or when animals directly deposit excreta into the water.

Direct P loss can occur through mole drains when liquid effluent is sprayed on land that has mole drainage. These mole drains provide a pathway for effluent to enter waterways. To account for this, a constant value of 0.3125 kg P/ha is multiplied by the effectiveness of the drainage system.

For liquid effluent from PFS-treated FDE, the same reduction approach is applied as in the previous section: a 60% reduction for freshly treated effluent (sprayed regularly) and a 45% reduction for stored treated effluent (sprayed infrequently).

The design of Overseer uses the direct P loss value to estimate the direct loss of other nutrients to water. To ensure that reductions in P loss do not affect the estimated losses of other nutrients, a mechanism has been implemented to maintain constant ratios between P and other nutrients. This approach ensures that while P reductions from PFS treatment are applied, the loss of other nutrients remains unchanged.

As with runoff and leaching, no reduction is applied to sludge, solids, or other types of imported effluents, due to the lack of experimental data and uncertainty about the formation and degradation rates of PFS and Fe-P complexes.

3 Implementation and Evaluation

3.1 Implementation into code

After clearly defining the specification for modelling the impacts of treating stored effluent with PFS, the next step was to translate that specification into the existing Overseer model codebase. Changes to this codebase follow a structured process designed to ensure accuracy, consistency, and seamless integration with the established software architecture.

This process begins with a comprehensive walkthrough of the specification by the scientists, the Overseer modelling team, and the software development team to ensure the implementation team fully understands the intent behind the changes. The specification is then broken down into clear, actionable tasks that align with the model's architecture and existing implementation processes. Implementation follows an iterative approach, with each change undergoing cycles of coding, peer review, and testing until the scientific translation is accurately reflected. Throughout this process, strict adherence to code quality standards and best practices is maintained, ensuring compatibility with existing modules.

3.2 Evaluation

Following implementation, this evaluation is intended to illustrate the behaviour of the model under representative scenarios and to confirm that the implementation reproduces expected responses (e.g. methane reduction and nutrient effects). A more comprehensive validation, including analysis across soil types and drainage conditions (e.g. mole drainage), is provided in Appendix A. The analysis focused on assessing changes in key indicators, including methane emissions and the overall nutrient budget, to determine whether the implemented PFS treatment achieves the intended outcomes. The objective was to quantify the effect of PFS treatment on effluent under various scenarios, providing insights into its impact on both emissions and nutrient management. In addition, this work indirectly provides insight into the effectiveness and broader implications of this technology.

The baseline farm used in this evaluation is the dairy farm model defined in Revill et al. (2024), which represents an average mature dairy farm. The total flat area of 125 hectares of allophanic soil with ryegrass (rare pugging) was divided into two distinct blocks: a grazing block with effluent application (25% of the total area) and a grazing block without effluent application (75% of the total area), to represent a typical dairy cattle test farm. The key characteristics of the animals are outlined in **Table 2**.

Table 2: Summary of key animal characteristics.

Breed	Friesian
Replacement rate	20%
Number of mature animals	350
Milk production	4452 L/yr/head
Calving date	13 August
Drying off date	13 June
Average weight	466 kg
Gestation length	269 days
Mean birth weight	41.9 kg

The evaluation of PFS on-farm implementation was designed to explore extreme scenarios across a range of possible conditions, rather than conducting a comprehensive sensitivity analysis across all dairy farms modelled in Overseer. By focusing on boundary cases, we aim to capture the most significant environmental and operational impacts of PFS treatment in effluent management, without attempting to model every variation in farm practices or environmental conditions. This approach allows assessment of the upper and lower bounds

of potential outcomes, providing insight into the broader applicability of PFS without the need for exhaustive scenario modelling across the entire population of farms.

3.2.1 Holding pond with a ‘stir and spray regularly’ liquid management

In this first scenario, the test farm is equipped with a holding pond where liquid effluent is stirred and sprayed on the effluent block regularly (sludge not spread in the reporting year).

The results, presented in **Table 3**, demonstrate the desired 96% reduction in methane emissions from effluent storage, and 6% overall. In addition, a 19% reduction in P losses on the effluent block was observed after spreading the treated effluent, translating to a 2% overall reduction at the farm scale. As no fertiliser was applied to the land in this scenario, P loss was the sum of only two of the factors, as outlined in Equation 10 (SoilPloss + EffPloss). In this case, P loss was primarily driven by background soil phosphorus loss (SoilPloss), with the 60% reduction in EffPloss resulting in a 19% reduction in total phosphorus loss, provided the conditions for P loss reduction (soil type, drainage, management, and application depth) are met.

The use of PFS on-farm results in a slight increase in CO₂ emissions (+1%), primarily due to the additional embodied emissions associated with the production and application of the PFS product.

Table 3: Emissions and variation with classic FDE and PFS-treated FDE (Holding Pond with liquid sprayed).

National farm with holding pond and liquid stirred and sprayed regularly							
Farm level	FDE	PFS	Variation				
N loss (kg N/ha/yr)	18	18	0%				
P loss (kg P/ha/yr)	0.83	0.81	-2%				
GHG emission (t CO ₂ e/ha)	10.6	10	-6%				
CH ₄ emissions (kg CO ₂ e/ha/yr)	7701	7093	-8%				
CH ₄ enteric (kg CO ₂ e/ha/yr)	6993	6993	0%				
CH ₄ dung (kg CO ₂ e/ha/yr)	71	71	0%				
CH ₄ effluent (kg CO ₂ e/ha/yr)	636	28	-96%				
N ₂ O emissions (kg CO ₂ e/ha/yr)	1540	1540	0%				
CO ₂ emissions (kg CO ₂ e/ha/yr)	1357	1369	1%				
Effluent block (30.5 ha)	FDE	PFS	Variation	Non-Effluent block (94.5 ha)	FDE	PFS	Variation
N loss (kg N/ha/yr)	19	19	0%	N loss (kg N/ha/yr)	17	17	0%
P loss (kg P/ha/yr)	0.53	0.43	-19%	P loss (kg P/ha/yr)	0.4	0.4	0%
Maintenance P (kg/ha)	6	6	-	Maintenance P (kg/ha)	18	18	0%
Maintenance K (kg/ha)	0	0	-	Maintenance K (kg/ha)	0	0	-
Maintenance S (kg/ha)	0	0	-	Maintenance S (kg/ha)	4	4	0%
Maintenance Ca (kg/ha)	18	18	-	Maintenance Ca (kg/ha)	36	36	0%
Maintenance Mg (kg/ha)	0	0	-	Maintenance Mg (kg/ha)	0	0	-
Maintenance Na (kg/ha)	0	0	-	Maintenance Na (kg/ha)	0	0	-
Maintenance Lime (kg/ha)	50	50	-	Maintenance Lime (kg/ha)	150	150	0%

3.2.2 Holding pond with a ‘stir and spray regularly’ liquid management, wintering pad, and sludge management

In this scenario, the farm is equipped with a holding pond where liquid effluent is stirred and sprayed regularly. The farm also utilises wintering practices, where animals are housed in a covered wintering pad throughout July and August. The effluent generated from the wintering pad is managed as part of the overall farm dairy effluent system (sludge not spread in the

reporting year). The farm also features a feed pad, where animals spend 2 hours per day during the milking season.

The PFS treatment of the stored effluent led to the expected 96% reduction in methane emissions from effluent (**Table 4**). Due to the significant volume of stored effluent in this system, a correspondingly significant reduction in total GHG emissions was observed (23%). Whilst large, this change in GHG results coincides with technical and scientific expectations, with this farm scenario representing a farm system with a significant volume of stored effluent and thus methane producing capacity.

Table 4: Emissions and variation with classic FDE and PFS-treated FDE (holding pond + structures).

National farm with holding pond and structure							
Farm level	FDE	PFS	Variation				
N loss (kg N/ha/yr)	17.4	17.4	0%				
P loss (kg P/ha/yr)	0.904	0.832	-8%				
GHG emission (t CO ₂ e/ha)	13.15	10.19	-23%				
CH ₄ emissions (kg CO ₂ e/ha/yr)	10271	7282	-29%				
CH ₄ enteric (kg CO ₂ e/ha/yr)	7097	7097	0%				
CH ₄ dung (kg CO ₂ e/ha/yr)	58	58	0%				
CH ₄ effluent (kg CO ₂ e/ha/yr)	3116	127	-96%				
N ₂ O emissions (kg CO ₂ e/ha/yr)	1524	1524	0%				
CO ₂ emissions (kg CO ₂ e/ha/yr)	1354	1388	3%				
Effluent block (30.5 ha)	FDE	PFS	Variation	Non-Effluent block (94.5 ha)	FDE	PFS	Variation
N loss (kg N/ha/yr)	25.6	25.6	0%	N loss (kg N/ha/yr)	13.04	13.04	0%
P loss (kg P/ha/yr)	0.85	0.59	-31%	P loss (kg P/ha/yr)	0.39	0.39	0%
Maintenance P (kg/ha)	0	0	-	Maintenance P (kg/ha)	29	29	0%
Maintenance K (kg/ha)	0	0	-	Maintenance K (kg/ha)	22	22	0%
Maintenance S (kg/ha)	0	0	-	Maintenance S (kg/ha)	12	12	0%
Maintenance Ca (kg/ha)	0	0	-	Maintenance Ca (kg/ha)	42	42	0%
Maintenance Mg (kg/ha)	0	0	-	Maintenance Mg (kg/ha)	0	0	-
Maintenance Na (kg/ha)	0	0	-	Maintenance Na (kg/ha)	0	0	-
Maintenance Lime (kg/ha)	0	0	-	Maintenance Lime (kg/ha)	120	120	0%

The increase in the volume of effluent sprayed on land is reflected at the block level where the application occurs, resulting in a 31% reduction in P loss. The increase in effluent volume is attributed to the structures installed on the farm, which allow more effluent to be captured and treated. Consequently, the volume of sprayed effluent rises, leading EffPloss to contribute to a larger proportion of total P loss on the treated blocks. The higher volume of effluent applied, the higher the potential impact that PFS treatment has on reducing the P loss from EffPloss, leading to a more pronounced reduction in overall P losses.

The consequence of increased PFS use is the increase in CO₂ emissions (+3%) due to the embodied PFS emissions, which is far outweighed by the benefits in this case.

3.2.3 Holding pond with a 'spray infrequently' liquid management

In this scenario, the test farm is equipped with a holding pond where liquid effluent is sprayed on the effluent block infrequently and outside the drainage season (sludge not spread in the reporting year).

The results, presented in **Table 5**, demonstrate the desired 96% reduction in methane emissions from effluent storage, and 6% overall. The use of PFS on-farm results in a slight increase in CO₂ emissions (+1%), primarily due to the additional embodied emissions associated with the production and application of the PFS product. In this case, there is no

impact on P loss since the effluent is sprayed outside the drainage season, meaning there is no P loss during spraying.

Table 5: Emissions and variation with classic FDE and PFS-treated FDE (holding pond + infrequently sprays).

AIM farm with HP and spray infrequently							
Farm level	FDE	PFS	Variation				
N loss (kg N/ha/yr)	17.97	17.97	0%				
P loss (kg P/ha/yr)	0.8	0.8	0%				
GHG emission (t CO2e/ha)	10.6	10	-6%				
CH4 emissions (kg CO2e/ha/yr)	7701	7093	-8%				
CH4 enteric (kg CO2e/ha/yr)	6993	6993	0%				
CH4 dung (kg CO2e/ha/yr)	71	71	0%				
CH4 effluent (kg CO2e/ha/yr)	636	28	-96%				
N2O emissions (kg CO2e/ha/yr)	1548	1548	0%				
CO2 emissions (kg CO2e/ha/yr)	1357	1369	1%				
Effluent block (30.5 ha)	FDE	PFS	Variation	Non-Effluent block (94.5 ha)	FDE	PFS	Variation
N loss (kg N/ha/yr)	17.18	17.18	0%	N loss (kg N/ha/yr)	16.56	16.56	0%
P loss (kg P/ha/yr)	0.39	0.39	0%	P loss (kg P/ha/yr)	0.39	0.39	0%
Maintenance P (kg/ha)	14	14	-	Maintenance P (kg/ha)	18	18	0%
Maintenance K (kg/ha)	0	0	-	Maintenance K (kg/ha)	0	0	-
Maintenance S (kg/ha)	1	0	-	Maintenance S (kg/ha)	4	4	0%
Maintenance Ca (kg/ha)	34	34	-	Maintenance Ca (kg/ha)	35	35	0%
Maintenance Mg (kg/ha)	0	0	-	Maintenance Mg (kg/ha)	0	0	-
Maintenance Na (kg/ha)	0	0	-	Maintenance Na (kg/ha)	0	0	-
Maintenance Lime (kg/ha)	110	110	-	Maintenance Lime (kg/ha)	150	150	0%

3.2.4 Holding pond with a 'spray infrequently' liquid management with structure

In this scenario, the test farm is equipped with a holding pond where liquid effluent is sprayed on the effluent block infrequently and outside the drainage season (sludge not spread in the reporting year). The farm also utilises wintering practices, where animals are housed in a covered wintering pad throughout during July and August. The effluent generated from the wintering pad is managed as part of the overall farm dairy effluent system. The farm also features a feed pad, where animals spend 2 hours per day during the milking season.

Table 6: Emissions and variation with classic FDE and PFS-treated FDE (holding pond + infrequently sprays + structures).

AIM farm with HP and spay infrequently, with structures							
Farm level	FDE	PFS	Variation				
N loss (kg N/ha/yr)	15.45	15.45	0%				
P loss (kg P/ha/yr)	0.77	0.76	-1%				
GHG emission (t CO ₂ e/ha)	13.1	10.2	-22%				
CH ₄ emissions (kg CO ₂ e/ha/yr)	10184	7272	-29%				
CH ₄ enteric (kg CO ₂ e/ha/yr)	7089	7089	0%				
CH ₄ dung (kg CO ₂ e/ha/yr)	59	59	0%				
CH ₄ effluent (kg CO ₂ e/ha/yr)	3037	124	-96%				
N ₂ O emissions (kg CO ₂ e/ha/yr)	1529	1529	0%				
CO ₂ emissions (kg CO ₂ e/ha/yr)	1356	1392	3%				
Effluent block (30.5 ha)	FDE	PFS	Variation	Non-Effluent block (94.5 ha)	FDE	PFS	Variation
N loss (kg N/ha/yr)	17.44	17.44	0%	N loss (kg N/ha/yr)	13.12	13.12	0%
P loss (kg P/ha/yr)	0.43	0.43	0%	P loss (kg P/ha/yr)	0.39	0.39	0%
Maintenance P (kg/ha)	14	14	-	Maintenance P (kg/ha)	31	31	0%
Maintenance K (kg/ha)	0	0	-	Maintenance K (kg/ha)	21	21	-
Maintenance S (kg/ha)	0	0	-	Maintenance S (kg/ha)	14	14	0%
Maintenance Ca (kg/ha)	40	40	-	Maintenance Ca (kg/ha)	40	40	0%
Maintenance Mg (kg/ha)	0	0	-	Maintenance Mg (kg/ha)	0	0	-
Maintenance Na (kg/ha)	0	0	-	Maintenance Na (kg/ha)	0	0	-
Maintenance Lime (kg/ha)	20	20	-	Maintenance Lime (kg/ha)	140	140	0%

The increased volume of effluent, resulting from on-farm structures, leads to a significant reduction (-22%) in total GHG emissions, despite a slight increase (+3%) in CO₂ emissions due to the increase of the amount of PFS used on the farm. Additionally, there is no impact on P loss, as the effluent is applied outside the drainage season, minimising P loss during land application.

These results confirm that the implementation behaves consistently with the specification under a range of representative farm systems. A more detailed assessment of performance across soil types and drainage conditions is presented in Appendix A.

4 Conclusion

This report details the development and testing of specifications to incorporate PFS treatment of dairy effluent, aimed at reviewing the implementation of EcoPond™ in a beta version of Overseer. Through description of the specification and the corresponding assumptions, their scientific robustness is captured and detailed.

Using the specified 96% methane reduction factor for EcoPond™ technology, Overseer estimates a 6–8% reduction in total GHG emissions at the whole-farm level for typical test farms. For the test farm with significant infrastructure, such as wintering pads and feed pads, where effluent volumes are higher, this reduction in total GHG emissions reached up to 23%.

Additionally, the application of treated effluent to land can reduce P loss from the effluent block. When effluent volumes are low, reductions in P loss are modest, around 2%. However, on farms with substantial effluent production and certain conditions, such as those utilising multiple structures, frequent effluent application, and sprayed during winter months, P loss

reductions can reach up to 31%. These results are in alignment with experimental findings and demonstrate an impact of EcoPond™ technology that is not fully captured within AIM.

Given the specification development, code implementation, and subsequent evaluation all align with the relevant literature, the April 2024 AIM model update, and the consulted scientific experts, the recommended next step for this work is to move the effluent pond methane reduction technology model release beyond a beta and formally release into OverseerFM.

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6 Appendix A: Extended validation of PFS treatment under varying soil types and drainage conditions

This appendix presents an extended evaluation of the effects of polyferric sulphate (PFS) treatment of dairy effluent on phosphorus (P) losses under a range of soil and drainage conditions. The analysis builds on the core evaluation presented in Section 3 by examining how modelled responses vary across soil orders with contrasting phosphorus retention capacities and under both natural and artificially drained (mole-drained) systems.

The objective is to quantify the magnitude and distribution of P loss reductions at both the effluent block and whole-farm scales, and to identify the conditions under which PFS treatment is most effective. To achieve this, simulations were conducted across representative soil types and effluent management configurations, allowing comparison of P loss responses between systems with and without mole drainage.

6.1 Method

The work uses an average mature dairy farm model from Revill et al. (2024), with scenarios designed to isolate the effect of PFS under controlled conditions. Four representative soil orders were selected (Allophanic, Pumice, Pallic, and Gley) covering a wide range of P retention capacities and drainage behaviours. Each soil was modelled under two drainage configurations:

- No mole drainage, naturally drained conditions.
- 100% mole drainage, intensive artificial drainage.

Two farm configurations were evaluated:

- Farm without structures, except a holding pond with stirred liquid effluent regularly sprayed on the effluent block (12–24 mm application depth).
- Farm with structures, same effluent management as above, plus a covered wintering pad and a feed pad, resulting in larger volumes of stored effluent.

6.2 Baseline farm

The baseline farm used in this evaluation is the dairy farm model defined in Revill et al. (2024), which represents an average mature dairy farm. The total flat area of 125 hectares with ryegrass (rare pugging) was divided into two distinct blocks: a grazing block with effluent application (25% of the total area) and a grazing block without effluent application (75% of the total area), to represent a typical dairy cattle test farm. The key characteristics of the animals are outlined in **Table 2**.

The evaluation of PFS on-farm implementation was designed to explore scenarios across a range of possible conditions, rather than conducting a comprehensive sensitivity analysis across all dairy farms modelled in Overseer. By focusing on specific cases, we aim to capture the most significant environmental and operational impacts of PFS treatment in effluent management, without attempting to model every variation in farm practices or environmental conditions.

6.3 Soil conditions

Four soil orders were selected to represent a range of phosphorus (P) retention capacities and drainage behaviours common in New Zealand dairy farming systems. These soils differ in their texture, and drainage class, which influence P sorption onto the soil matrix and the movement of water and nutrients through the profile.

The simulations modelled each soil order under two drainage configurations:

- No mole drainage – representing naturally drained conditions.
- 100% mole-drained area, representing intensive artificial drainage water removal.

The soil characteristics are summarised in the following table:

Table 7: Summary of key soil characteristics.

Soil Order	Soil Group	Bulk Density (kg/m ³)	Clay (%)	Sand (%)	Surface Saturation (0–10 cm, %)	Surface Field Capacity (0–10 cm, %)	Surface Wilting Point (0–10 cm, %)	Profile Saturation (%)	Profile Field Capacity (%)	Profile Wilting Point (%)	ASC (%)	Drainage Class
Allophanic	Volcanic	764	23	39	54.9	40.3	13.4	57.5	40.2	22	83	Moderately
Pumice	Pumice	866	19	65	48.6	32.3	10.3	54.2	29	8.7	49	Well
Pallic	Recent	1,236	23	24	43.6	35.6	14.1	40	28.5	14.2	21	Imperfect
Gley	Sedimentary	859	33	19	55.1	44.1	18.9	50.8	39.7	18.8	49	Poor

6.4 Farm without structures

In this first scenario, the test farm is equipped with a holding pond where liquid effluent is stirred and sprayed on the effluent block regularly at an application depth of 12-24 mm (sludge not spread in the reporting year).

6.4.1 Without mole drainage

The results, presented in Table 8, demonstrate the desired 96% reduction in methane emissions from effluent storage, and 6% overall GHG reduction for all soil types.

In addition, reductions in P losses from the effluent block were observed following application of treated effluent. In this scenario, no fertiliser was applied, so total P loss was comprised only of two components: (1) a baseline/background soil P loss, and (2) a P loss associated with the sprayed effluent. As soil P retention decreases, the baseline loss becomes larger, meaning the contribution from the effluent component is proportionally smaller. Consequently, the relative reduction achieved with PFS declines in low-P-retention soils.

Effluent block reductions ranged from –9% in Pallic soils to –23% in Allophanic soils. The larger proportional reduction in Allophanic soils reflects their high ASC, which keeps baseline/background losses low and makes effluent the dominant source, so treating it produces a greater percentage drop. The smaller proportional reductions in low-ASC soils occur because effluent’s share of total P loss decreases.

Table 8: Emissions and variation with classic farm dairy effluent (FDE) and PFS-treated FDE (Holding Pond with liquid sprayed).

Average farm with holding pond and liquid stirred and sprayed (12-24 mm) regularly												
	Allophanic			Pumice			Pallic			Gley		
	No mole drainage			No mole drainage			No mole drainage			No mole drainage		
	FDE	PFS	Variation	FDE	PFS	Variation	FDE	PFS	Variation	FDE	PFS	Variation
Farm level												
N loss (kg N/ha/yr)	23	23	0%	22.6	22.6	0%	25.9	25.9	0%	19.6	19.6	0%
P loss (kg P/ha/yr)	0.5	0.5	0%	0.74	0.73	-1%	0.98	0.96	-2%	0.82	0.82	0%
GHG emission (t CO ₂ e/ha/yr)	10690	10065	-6%	10688	10063	-6%	10700	10075	-6%	10678	10053	-6%
CH ₄ emissions (kg CO ₂ e/ha/yr)	7811	7175	-8%	7811	7175	-8%	7811	7175	-8%	7811	7175	-8%
CH ₄ enteric (kg CO ₂ e/ha/yr)	7072	7072	0%	7072	7072	0%	7072	7072	0%	7072	7072	0%
CH ₄ dung (kg CO ₂ e/ha/yr)	74	74	0%	74	74	0%	74	74	0%	74	74	0%
CH ₄ effluent (kg CO ₂ e/ha/yr)	665	29	-96%	665	29	-96%	665	29	-96%	665	29	-96%
N ₂ O emissions (kg CO ₂ e/ha/yr)	1498	1498	0%	1496	1498	0%	1508	1508	0%	1486	1486	0%
CO ₂ emissions (kg CO ₂ e/ha/yr)	1381	1392	1%	1381	1392	1%	1381	1392	1%	1381	1392	1%
Effluent block (31.2 ha)												
N loss (kg N/ha/yr)	23.7	23.7	0%	23.4	23.4	0%	27.5	27.5	0%	20.4	20.4	0%
P loss (kg P/ha/yr)	0.13	0.1	-23%	0.42	0.35	-17%	0.67	0.61	-9%	0.51	0.45	-12%
Non-effluent block (93.8 ha)												
N loss (kg N/ha/yr)	20.9	20.9	0%	20.5	20.5	0%	23.5	23.5	0%	17.4	17.4	0%
P loss (kg P/ha/yr)	0.09	0.09	0%	0.34	0.34	0%	0.57	0.57	0%	0.42	0.42	0%

At the whole-farm scale, the effect of PFS was minimal (0–2%) because lanes and races, which are not influenced by the treatment of effluent, remain the main source of P loss. In this farm system type, around 50 kg P/year is lost from lanes and races leading to the milking shed. These surfaces are modelled as hard, compacted areas with little or no infiltration, making them highly susceptible to generating P-rich runoff during rainfall events (e.g., Monaghan et al., 2009; Wilcock et al., 2013). As a result, P losses from lanes and races can dominate the farm’s overall P budget, meaning that mitigation applied only to the effluent block has limited impact on total farm losses. This also explains why Allophanic soils showed no reduction (–0%) at farm scale.

In summary, PFS reduced effluent-block P losses by up to 23% in high-ASC soils, but whole-farm reductions were negligible because lanes and races dominate the P budget in this system.

6.4.2 With mole drainage

The results, presented in Table 9, demonstrate the desired 96% reduction in methane emissions from effluent storage, and 6% overall GHG reduction for all soil types.

In these simulations, use of PFS in the holding pond applies an effluent P loss reduction factor of 60%. With mole drainage, the observed reductions in the effluent block were around 30% for Allophanic and Pumice soils, and slightly higher (34–35%) for Pallic and Gley soils. This indicates that, under mole-drained conditions, approximately half of the total P loss from the effluent block originates from the effluent itself, with the remainder arising from background soil P loss.

The higher proportional reductions in low-ASC soils occur because mole drainage increases the transport of effluent-bound P, raising its share of total losses. This bypasses the soil’s retention capacity, making effluent treatment more impactful. At the farm scale, PFS reductions rose to 6–10% compared to 0–2% without mole drainage, reflecting the greater contribution of effluent-derived P in mole-drained systems.

Table 9: Emissions and variation with classic FDE and PFS-treated FDE (Holding Pond with liquid sprayed) with mole drainage.

Average farm with holding pond and liquid stirred and sprayed (12-24 mm) regularly												
	Allophanic			Pumice			Pallic			Gley		
	With mole drainage			With mole drainage			With mole drainage			With mole drainage		
	PDE	PFS	Variation	PDE	PFS	Variation	PDE	PFS	Variation	PDE	PFS	Variation
Farm level												
N loss (kg N/ha/yr)	23.5	23.5	0%	23.6	23.6	0%	27.3	27.3	0%	21	21	0%
P loss (kg P/ha/yr)	0.82	0.77	-6%	1.12	1.03	-8%	1.26	1.14	-10%	1.17	1.05	-10%
GHG emission (t CO ₂ e/ha/yr)	10691	10066	-6%	10692	10067	-6%	10704	10079	-6%	10683	10058	-6%
CH ₄ emissions (kg CO ₂ e/ha/yr)	7811	7175	-8%	7811	7175	-8%	7811	7175	-8%	7811	7175	-8%
CH ₄ enteric (kg CO ₂ e/ha/yr)	7072	7072	0%	7072	7072	0%	7072	7072	0%	7072	7072	0%
CH ₄ dung (kg CO ₂ e/ha/yr)	74	74	0%	74	74	0%	74	74	0%	74	74	0%
CH ₄ effluent (kg CO ₂ e/ha/yr)	665	29	-96%	665	29	-96%	665	29	-96%	665	29	-96%
N ₂ O emissions (kg CO ₂ e/ha/yr)	1499	1499	0%	1500	1500	0%	1512	1512	0%	1491	1491	0%
CO ₂ emissions (kg CO ₂ e/ha/yr)	1381	1392	1%	1381	1392	1%	1381	1392	1%	1381	1392	1%
Effluent block (31.2 ha)												
N loss (kg N/ha/yr)	25.5	25.5	0%	27.6	27.6	0%	32.8	32.8	0%	25.8	25.8	0%
P loss (kg P/ha/yr)	0.64	0.45	-30%	1.19	0.83	-30%	1.51	0.99	-34%	1.38	0.9	-35%
Non-effluent block (93.8 ha)												
N loss (kg N/ha/yr)	21	21	0%	20.5	20.5	0%	23.6	23.6	0%	17.6	17.6	0%
P loss (kg P/ha/yr)	0.33	0.33	0%	0.59	0.59	0%	0.67	0.67	0%	0.59	0.59	0%

In summary, mole drainage increased the share of effluent-derived P losses, allowing PFS to achieve farm-scale reductions of up to 10%, with the greatest gains in low-ASC soils.

6.5 Farm with structures

In this scenario, the farm is equipped with a holding pond where liquid effluent is stirred and sprayed regularly at an application depth of 12-24 mm. The farm also utilises wintering practices, where animals are housed in a covered wintering pad throughout July and August. The effluent generated from the wintering pad is managed as part of the overall farm dairy effluent system (sludge not spread in the reporting year). The farm also features a feed pad, where animals spend 2 hours per day during the milking season.

6.5.1 Without mole drainage

The results, presented in Table 10, show that the PFS treatment of stored effluent resulted in a 96% reduction in methane emissions from the effluent component. Given the substantial volume of effluent stored in this system, this translated into a notable 28% reduction in total GHG emissions.

The most pronounced P reductions occurred in the effluent block, where decreases ranged from -31% (Pumice) to -45% (Allophanic). The highest value for Allophanic soils is due to the low level of background P losses, reflecting their inherently high P retention, which makes effluent the main source of loss. In the other soil types, roughly half of the P loss originates from effluent, so the proportional reduction is closer to 30%.

At the farm scale, the use of PFS reduced P losses by 6-17%, with the largest proportional reductions observed in Pumice soils (-17%), followed by Gley (-10%) and Pallic (-9%) soils. Allophanic soils showed the smallest reduction (-6%), because farm-scale totals are dominated by P loss from lanes and races, which are unaffected by PFS.

Table 10: Emissions and variation with classic FDE and PFS-treated FDE (Holding Pond with liquid sprayed), farm with structures.

Average farm with holding pond and liquid stirred and sprayed (12-24 mm) regularly, and structures												
	Allophanic			Pumice			Pallic			Gley		
	No mole drainage			No mole drainage			No mole drainage			No mole drainage		
	FDE	PFS	Variation	FDE	PFS	Variation	FDE	PFS	Variation	FDE	PFS	Variation
Farm level												
N loss (kg N/ha/yr)	24	24	0%	24	24	0%	27.8	27.8	0%	21.5	21.5	0%
P loss (kg P/ha/yr)	0.49	0.46	-6%	0.77	0.64	-17%	1.08	0.98	-9%	0.91	0.82	-10%
GHG emission (t CO ₂ e/ha/yr)	14173	10249	-28%	14173	10249	-28%	14185	10261	-28%	14164	10240	-28%
CH ₄ emissions (kg CO ₂ e/ha/yr)	11346	7385	-35%	11346	7385	-35%	11346	7385	-35%	11346	7385	-35%
CH ₄ enteric (kg CO ₂ e/ha/yr)	7160	7160	0%	7160	7160	0%	7160	7160	0%	7160	7160	0%
CH ₄ dung (kg CO ₂ e/ha/yr)	58	58	0%	58	58	0%	58	58	0%	58	58	0%
CH ₄ effluent (kg CO ₂ e/ha/yr)	4128	167	-96%	4128	167	-96%	4128	167	-96%	4128	167	-96%
N ₂ O emissions (kg CO ₂ e/ha/yr)	1424	1424	0%	1424	1424	0%	1436	1436	0%	1415	1415	0%
CO ₂ emissions (kg CO ₂ e/ha/yr)	1403	1440	3%	1403	1440	3%	1403	1440	3%	1403	1440	3%
Effluent block (31.2 ha)												
N loss (kg N/ha/yr)	34.8	34.8	0%	35.7	35.7	0%	44.4	44.4	0%	33.1	33.1	0%
P loss (kg P/ha/yr)	0.29	0.16	-45%	0.74	0.51	-31%	1.31	0.87	-34%	1.09	0.67	-39%
Non-effluent block (93.8 ha)												
N loss (kg N/ha/yr)	18.7	18.7	0%	18.4	18.4	0%	20.5	20.5	0%	15.8	15.8	0%
P loss (kg P/ha/yr)	0.09	0.09	0%	0.34	0.34	0%	0.57	0.57	0%	0.42	0.42	0%

In summary, large effluent volumes amplified the absolute P reduction in the effluent block, but whole-farm reductions remained limited to a maximum of 17%.

6.5.2 With mole drainage

The results, presented in Table 11, show that the PFS treatment of stored effluent resulted in a 96% reduction in methane emissions from the effluent component. Given the substantial volume of effluent stored in this system, this translated into a notable 28% reduction in total GHG emissions.

At the farm scale, PFS reduced total P losses by 25–36%, with the largest proportional reductions occurring in low-ASC soils: Pallic (–35%) and Gley (–36%), followed by Pumice (–31%) and Allophanic (–25%). These reductions are substantially greater than those seen in the no-mole-drainage scenario, reflecting the increased transport of effluent-derived P through artificial drainage pathways that bypass the soil’s natural P sorption capacity.

The effluent block experienced very large P loss reductions, ranging from –51% (Allophanic) to –54% (Pallic, Gley). These consistently high reductions occur because in mole-drained systems, a greater part of total P loss originates from effluent, which is directly mitigated by PFS. Low-ASC soils benefit most because both baseline and effluent-related P losses are high, and drainage accelerates transport.

Overall, these results demonstrate that in farms with both large effluent volumes and mole drainage, PFS delivers its largest absolute and proportional reductions in farm-scale P losses, particularly in low-retention soils where drainage pathways accelerate nutrient transport. Total farm GHG emissions were reduced by ~28%. This is driven almost entirely by the 96% reduction in methane emissions from effluent storage (CH₄ effluent), while enteric and dung methane emissions remain unchanged, and CO₂ emissions increase slightly (+3%), likely due to the PFS embodied emissions.

Table 11: Emissions and variation with classic FDE and PFS-treated FDE (Holding Pond with liquid sprayed), farm with structures and mole drainage.

Average farm with holding pond and liquid stirred and sprayed (12-24 mm) regularly, and structures												
	Allophanic			Pumice			Pallic			Gley		
	With mole drainage			With mole drainage			With mole drainage			With mole drainage		
	PDE	PFS	Variation	PDE	PFS	Variation	PDE	PFS	Variation	PDE	PFS	Variation
Farm level												
N loss (kg N/ha/yr)	26.1	26.1	0%	28.6	28.6	0%	33.7	33.7	0%	27.3	27.3	0%
P loss (kg P/ha/yr)	1.17	0.88	-25%	1.94	1.33	-31%	2.39	1.56	-35%	2.25	1.45	-36%
GHG emission (t CO2e/ha/yr)	14180	10256	-28%	14189	10265	-28%	14206	10282	-28%	14184	10260	-28%
CH4 emissions (kg CO2e/ha/yr)	11346	7385	-35%	11346	7385	-35%	11346	7385	-35%	11346	7385	-35%
CH4 enteric (kg CO2e/ha/yr)	7160	7160	0%	7160	7160	0%	7160	7160	0%	7160	7160	0%
CH4 dung (kg CO2e/ha/yr)	58	58	0%	58	58	0%	58	58	0%	58	58	0%
CH4 effluent (kg CO2e/ha/yr)	4128	167	-96%	4128	167	-96%	4128	167	-96%	4128	167	-96%
N2O emissions (kg CO2e/ha/yr)	1431	1431	0%	1440	1440	0%	1457	1457	0%	1435	1435	0%
CO2 emissions (kg CO2e/ha/yr)	1403	1440	3%	1403	1440	3%	1403	1440	3%	1403	1440	3%
Effluent block (31.2 ha)												
N loss (kg N/ha/yr)	43	43	0%	54	54	0%	68.3	68.3	0%	56.1	56.1	0%
P loss (kg P/ha/yr)	2.24	1.09	-51%	4.68	2.21	-53%	6.22	2.88	-54%	5.9	2.72	-54%
Non-effluent block (93.8 ha)												
N loss (kg N/ha/yr)	18.8	18.8	0%	18.4	18.4	0%	20.5	20.5	0%	15.9	15.9	0%
P loss (kg P/ha/yr)	0.33	0.33	0%	0.59	0.59	0%	0.67	0.67	0%	0.59	0.59	0%

In summary, the combination of large effluent volumes and mole drainage are associated with the largest farm-scale reductions (25–36%) because they are most affected by effluent-driven P losses, particularly in low-ASC soils where baseline losses are highest.

6.6 Conclusions

Simulations confirm that mole-drained systems, particularly those on low-ASC soils such as Pallic and Gley, experience the largest proportional and absolute reductions in P losses when PFS is applied to effluent. Across all scenarios, the non-effluent block showed no change in P loss, underscoring that benefits are localised to effluent-treated areas. At the effluent block scale, P loss reductions exceeded 50% for all soils with mole drainage, compared with 9–45% without mole drainage. At the farm scale, mole drainage is associated with an increased proportional P loss reduction from 0–17% for no mole drainage to 6–36% with mole drainage.

Nitrogen losses were unchanged in all modelled scenarios, confirming that PFS acts solely on P losses and methane emissions from effluent storage. The treatment consistently achieved a 96% reduction in methane emissions from effluent as modelled, leading to a 6–28% reduction in total farm GHG emissions, with the highest GHG benefit in systems with large volumes of stored effluent.

These results highlight that targeting mole-drained, low-ASC systems can yield the greatest return on investment for PFS in terms of P-loss reduction.

The comparative summary table where the farm-scale P loss reduction (%) from PFS is presented in Table 12.

Table 12: Comparative summary table where the farm-scale P loss reduction (%) from PFS.

Scenario	Allophanic	Pumice	Pallic	Gley
Small effluent volume – No mole	0%	-1%	-2%	0%
Small effluent volume – Mole	-6%	-8%	-10%	-10%
Large effluent volume – No mole	-6%	-17%	-9%	-10%
Large effluent volume – Mole	-25%	-31%	-35%	-36%

6.7 References

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7 Appendix B: Evolution of EcoPond™ Technology (Generation 1 to Generation 2)

This report is based on the specification and scientific evidence available for EcoPond™ Generation 1 (Gen 1), which, at the time of writing, represents the only version of the technology that has been sufficiently peer-reviewed and incorporated into the Agricultural Inventory Model (AIM) and, consequently, into OverseerFM.

Since the completion of this work, an updated formulation and application approach, referred to as EcoPond™ Generation 2 (Gen 2), has been developed. The purpose of this appendix is to document the key differences between Gen 1 and Gen 2, and to clarify implications for modelling within OverseerFM.

7.1 Overview of EcoPond™ Generation 2

EcoPond™ Gen 2 represents an evolution of the original methane mitigation technology, maintaining the same fundamental mode of action (suppression of methanogens via redox manipulation), while introducing two primary changes:

- Revised chemical formulation
 - Gen 1: 100% polyferric sulphate (PFS)
 - Gen 2: 50:50 mixture of PFS and sulphuric acid (H₂SO₄)
- Modified treatment approach (“shock dosing”)
 - Gen 1: continuous dosing of incoming effluent
 - Gen 2: periodic “shock dosing” of the pond (typically every 6–8 weeks), targeting the entire effluent mass and sludge

This shift removes the need for on-farm dosing infrastructure and reduces capital and operational requirements.

7.2 Performance Consistency

Available evidence indicates that methane reduction performance remains broadly equivalent between Gen 1 and Gen 2, with both achieving an average 96% reduction in methane emissions from effluent ponds under appropriate conditions.

The mechanisms responsible for methane reduction remain consistent, including:

- Increased redox potential inhibiting methanogens
- Competition from sulphate- and iron-reducing bacteria
- Sulphide toxicity effects
- Anaerobic methane oxidation processes

7.3 Implications for OverseerFM Parameterisation

While the overall model structure does not require modification, key parameter values differ between Gen 1 and Gen 2, primarily due to the change in formulation.

- Sulphur application rate
 - Gen 1: 2000 kg S per 445 cows
 - Gen 2: 2300 kg S per 440 cows
- Sulphur concentration in product
 - Gen 1: 12% S
 - Gen 2: 21.5% S
- Nutrient impurities (Mg, Na)
 - Gen 1: Mg: 2.2% of the amount of S; Na: 4.1% of the amount of S
 - Gen 2: Mg: 1.1% of the amount of S; Na: 2.05% of the amount of S
- Embodied emissions
 - Gen 1: ~0.114 kg CO₂e per kg product
 - Gen 2: ~0.176 kg CO₂e per kg product
- Methane reduction factor
 - Unchanged between generations (96%)
- Phosphorus loss reduction factors
 - Unchanged between generations

These changes affect input parameterisation only, including default sulphur loading, associated nutrient inputs, and embodied emissions.

7.4 Integration into OverseerFM

Since the completion of the original specification, EcoPond™ Generation 2 has been implemented within OverseerFM. This update reflects both the maturation of the technology and its commercial availability within New Zealand, where it is actively distributed to farmers (e.g., via Ravensdown/EcoPond supply channels).

The implementation of Gen 2 does not require structural modifications to the model. As anticipated, the integration is achieved through updates to parameterisation only, including:

- Revised sulphur application rates
- Updated product composition (PFS–sulphuric acid blend)
- Adjusted nutrient impurity inputs (Mg, Na)
- Updated embodied emission and energy factors

The underlying modelling framework, covering methane emissions, nutrient flows, and effluent system behaviour, remains unchanged and consistent with the Gen 1 formulation.

From a user perspective, the availability of Gen 2 introduces a product that is operationally simpler (shock dosing) and commercially accessible, allowing farmers to adopt methane mitigation practices without the infrastructure requirements associated with Gen 1 systems.

For further information:

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