Cronfa Datblygu Rhanbarthol Ewrop
European Regional Development Fund

Tywi Farm Nutrient Partnership:
Final Report

Foreword

This project was led by Coleg Sir Gâr (CSG) and delivered by the team based at the Agriculture Research Centre at Gelli Aur in conjunction with project partners:

- GEA
- Netafim
- N2 Applied
- Aquatreat
- Power & Water
- Honesty Foods
- Cyfoeth Naturiol Cymru/Natural Resources Wales
- Dŵr Cymru/Welsh Water

The project received funding through the Welsh Government's SMART Expertise Programme 2014-2023 and aims to facilitate the increase in commercialisation opportunities within Research, Development and Innovation (R, D & I) by forming collaborations between research institutions and industry. Coleg Sir Gâr is the first Further Education College to receive SMART Funding, an achievement that we are very proud of.

Farm slurry should be viewed as a resource to be used effectively as a recyclable source of nutrients for food production. Careful and targeted use can improve efficiency, reduce the need for chemical fertiliser and have zero detrimental effects on the environment.
Slurry has been managed in the same way for decades with little or no innovative developments to keep pace with livestock intensification. The widespread uptake of umbilical spreading systems alongside expansion has allowed potential over-application on accessible land near the farm yard.

The Tywi Farm Nutrient Partnership, with funding from the Welsh Government Water and Flood Division set out to build upon the success of ProsiectSlyri project, to provide an alternative management system capable of separating nutrients from the water. Perversely we believe that because slurry is 90% water, it's the water that is the main source of pollution through surface and groundwater runoff, multiple benefits are achieved by de-watering such as reduced storage capacity, the opportunity to efficiently move the nutrient further away from the farm yard and benefits to soil biodiversity and health.

The potential for multiple applications to the core developments has emerged from the success of the modular processes developed, the forced air constructed wetland treatment process can be used to treat dirty water produced on farms, and separated solids are potentially a stable feedstock for anaerobic digestion.

We are delighted that our commercial partners have sold two units to farms and that they are in discussions with a further six farmers. But how can we create a greater impact from successful developments? Our vision is that we look at regional treatment hubs in combination with anaerobic digestion to produce energy, some of the energy produced could be used to power road tankers to pick up the slurry from farms and for incineration of de-watered digestate to produce bio-secure biochar suitable for distribution on to less intensively farmed land. Surplus energy could be sold to the electricity or gas grid.

A prosperous rural economy in Wales relies on a vibrant agricultural industry, our cultural heritage and the Welsh language are underpinned by the diverse and numerous family farms, we cannot allow unintended consequences of the introduction of the Control of Agricultural Pollutions (Wales) Regulations 2021 to contribute towards the decline in this prosperity. As the regulations stand, it is inevitable that the more intensive farms will need more land to reduce their stocking rate, pushing up the cost of buying and renting land beyond the reach of smaller farms and new entrants. This will lead to overall reduced production of milk and red meat as well as a reduction in the nutrient resource that could be used to reduce the reliance on chemical fertiliser, all of which will have an indirect detrimental effect on the rural economy.

The technical processes developed at Gelli Aur with the support of the Welsh Government has the potential to mitigate what could be the unintentional consequences of the Act. Larger more intensive units could invest in de-watering technology to produce and capture nutrients in a solid form, the excess nutrient could easily and cost-effectively be exported off the farm and used on less intensively farmed land, reducing the need for chemical fertiliser. Carefully monitored export of nutrients would be allowed to be classified as a reduction in the overall stocking rate as part of the organic nitrogen calculation, thus reducing the need to purchase or rent more land. To benefit the smaller units, further evaluation needs to be carried out on the potential of regional treatment hubs. De-watering alongside anaerobic digestion and the production of biochar through pyrolysis to mitigate any bio-security risk of multiple nutrient sources, could be self-financing through energy and nutrient sales, and any concern about slurry transportation to a centralised treatment plant could be mitigated by using bio-fuel produced at the plant to power the tankers. To benefit as many businesses as possible, we envisage taking only surplus nutrient which falls above the agreed ceiling (170kg organic N or any licenced derogated ceiling), in return

the farmer would reduce their overall slurry storage capacity needed and benefit from reducing the calculated stocking rate on the farm.

Innovation is key and the advances that we have achieved through this development should allow Wales to lead on and not follow legislation in other countries. We have an opportunity to maintain our productivity and allow controlled expansion at the same time as reducing concentrated overapplication of nutrients. As I said at the start, farm-produced nutrients are a national resource and, if used effectively, can positively affect the environment.

I would like to thank the Welsh Government for their support and encouragement throughout the project duration, our project partners and my colleagues, Neil Nicholas, Iwan Jones, Beau Gray, Gruff Huw and Ann Owen for their dedication and enthusiasm which has made working on this project a real pleasure.

John Owen - Project Manager.

Executive Summary

Farm slurry run-off from fields is a major cause of river pollution in Wales. The project was designed to address this issue through the use of existing technology, combined and repackaged to aid farm slurry management. The objective was to treat raw slurry in such a way as to remove as much of the water contaminating elements of slurry before discharging the 'cleaned' liquid into a local watercourse under licence. This would be done through a process of primary course solids removal by mechanical separation followed by chemical dewatering and nutrient recovery. A further secondary coagulation/flocculation and solid/liquid separation stage was employed in the form of Dissolved Air Flotation (DAF) to remove any remaining solids. A constructed wetland was incorporated in the overall treatment process as a polishing step to oxidise and reduce levels of ammoniacal nitrogen, chemical oxygen demand (COD), biological oxygen demand (BOD) and turbidity.

Recent innovations in dewatering technologies now increases its suitability for the agriculture sector. The separation of liquid and solid from dairy slurry is demonstrated to reduce bulk volume, alleviating the pressure on farm storage capacity. Alongside successive wastewater treatment, we have seen overall reduction rates of 98.9% Nitrogen (N), 99.9% Phosphate (P) and 98.3% Potassium (K), in the separation of raw slurry (typically ~4-5% total solids) in addition to the treatment of dilute slurry and 'dirty water'. Capturing these nutrients presents an opportunity to reduce the need for artificial fertilisers. Importantly, this also helps farmers in Wales to meet compliance with recent changes to legislation, such as The Water Resources (Control of Agricultural Pollution) (Wales) Regulations 2021.

The key to improved and more stable separation efficiency has been the incorporation of a chemical reaction tank. Getting the best performance out of this required a better understanding of both the slurry matrix and the reaction tank parameters themselves, for example, the retention time needed to allow enough contact time with the chemicals, pH, mixing intensity and slurry viscosity. These all have an important role to play in floc formation and subsequent removal and therefore considerable time was given to accomplish this. At the point of solid/liquid separation in the decanter centrifuge, the centrate (liquid fraction) contained less Total Nitrogen than the 0.5kg/m3 permitted under The Nutrient Management Guide – RB209 for 'dirty water'. Therefore, under current guidelines, this separated liquid could be spread year-round, alleviating pressure on slurry stores.

Subsequent treatment in the DAF and constructed wetland (when fully established) improved the quality of the water to a point where it meets the Wales Bathing Water Quality Standards. Microbiological analysis indicates that the final effluent is no more contaminated than that of regular cattle water troughs. Currently, the water is re-used on the farm for washing down, but, airing on the side of caution, it is hoped that a simple UV treatment system should mean that the water could be returned to the animals to drink – subject to farm vet approval. This, alongside nutrient recovery and re-use would consequently close the circular economy loop when it comes to farm slurries.

Of course, the natural processes used by reedbeds in the treatment of wastewater is nothing new. However, a re-thinking of the process leads to much improved outcomes in efficiency. A 'constructed wetland' then, introduces forced aeration and enormously increased surface area for biofilm to grow and thrive. Areas of aerobic and anaerobic microbial activity can now be controlled, both of which are essential to nitrification and denitrification processes respectively. As a result of the various processes, the final effluent has seen overall reduction rates for COD (99.96%), TP (99.91%), TN (98.98%), TK (98.34%), OP (99.81%), TSS (99.95%) and a turbidity of ~0.6NTU, which is comparable to mains tap water supply. In addition, bacteriology indicates that it falls within current bathing water standards.

Investigations into precision application of nutrients were undertaken with some mixed results, particularly for the mechanical application machinery where prolonged technical issues and procurement delays severely hampered progress. Nutrients delivered through a new sub-soil drip irrigation system however performed very well. Trials using nitrogen enriched organic fertiliser (NEO) were inconclusive, although to fully ascertain the true value and effectiveness of all these technologies, investigations should be carried out over a number of growing seasons and not limited to one as was the case here.

We have welcomed many stakeholders over the course of the project, to experience for themselves the progress made, including farmers, AD operators, and government officials alike.

To further disseminate our work, a very successful open day on the 15th September 2022 was held, where working demonstrations, guest speakers, and a slurry management workshop proved very popular, alongside a tour of the site accompanied with an update of the current projects at the Agriculture Research Centre, Coleg Sir Gâr, Gelli Aur.

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1.0 Project Overview

Over recent years, the over-application of farm slurries has become increasingly evident, with excess nutrient leaching into streams and rivers. This pollution of the waterways is having a dramatic negative effect not only on river ecosystems, but also on local stakeholders through its impact on water quality and watercourse biodiversity in many Welsh rivers, the unexplained decrease in salmon population, income from tourism and angling decline.

On 13th December 2017, to ensure water courses receive greater protection from agricultural pollution, Lesley Griffiths the Cabinet Secretary for Energy, Planning and Rural Affairs stated that she intended to introduce a whole Wales approach to tackling pollution from agriculture. This new legislation was due to be introduced in January 2020, but was delayed by COVID 19.

Current slurry management regulation will from Jan 2024 require 5 months storage, but high rainfall causes capacity problems. Climate change is leading to extremes in both rainfall and prolonged drought, exacerbating slurry management problems.

Overuse of slurry on land causes pollution, therefore farmers are looking for alternatives to traditional methods to build more resilience into the landscape and to reduce siltation and diffuse pollution from farms. Economic market pressures are driving expansion & intensification of farms making the slurry problem worse, but creating a new market for nutrient management. Over application of slurry, in particular, is creating farming inefficiencies, therefore farms are not as profitable as they could be. ProsiectSlyri project identified possible efficiency gains to the Welsh dairy industry to the value of £50M through improved nutrient management, including appropriate application rates and timing for optimum crop growth with better utilisation of available nutrients.

Agricultural slurry is a valuable organic manure, concentrated in nutrients essential to plant growth and organic matter which can improve soil health. Effective slurry utilisation has repeatedly been shown to improve overall soil fertility across multiple settings, whilst producing yields equal to (or better) than those gained from NPK compound and standalone N fertilisers[1][2]. Nevertheless, farmers can be left with surplus slurry due to intensive systems of livestock production; land-use changes limiting the area suitable for spreading; and the introduction of new regulation such as Water Resources (Control of Agricultural Pollution) (Wales) Regulations which will prohibit traditional spreading between 15th October and 15th January, depending on soil/field type[3]. Across the UK, the dairy industry is the single largest producer of slurry and as demonstrated by the ~7.8 metric tonnes produced per farm each day, considering an average herd size of 148 and 53kg of excreta per milking cow[4]. Overall, there is growing need for technologies which help alleviate pressure placed on farm storage, support effective nutrient management, and mitigate the environment impacts associated with traditional storage and spreading.

Dewatering has been shown to reduce bulk slurry volume and the demand for costly artificial fertilisers, when coupled with good agri-practice (right amount, right time, right place), it has the potential to reduce pollution such as nutrient leaching and agricultural runoff. A sector-wide review[5] indicated that potential for dewatering is becoming increasingly popular within intensive indoor systems of dairy and beef production. Essentially, it is the process of separating liquids from solids, producing a liquid fraction which can undergo wastewater treatment or be used in irrigation/fertigation, and a solid fraction which can be used as a stable and stackable fertiliser that is higher in dry matter and more nutrient-dense than raw slurry.

Too much water is wasted and the industry needs to explore opportunities to improve efficiency. By extracting water from cattle slurry, which on average is 90% of the total volume, the dairy industry could reduce dramatically the demand on clean water. Even in Wales, recent dry summers have demonstrated the pressures on the supply of sufficient clean water. The implications of developments for recycling has far-reaching worldwide environmental benefits. The majority of farmers are working within limits of current best practice, but technological advancements have not always kept pace with the need for expansion. Farmers therefore feel they are regulated but not supported with tools to deliver an effective solution.

Project Aims

What We Proposed To Do...

This project brought together a collaborative research, development & innovation partnership combining industry with Further/ Higher Education to:

1

Apply innovative and proven concept technology, to the agriculture sector.

2

Reduce significantly the risk of pollution from farm slurry.

3

Maximise the potential recycling nutrient value.

4

Reduce considerably the storage and handling cost of slurry.

5

Design, develop and test, bespoke economically viable systems that can be scaled up to work on all dairy herd sizes.

This project helped develop and apply new techniques and technology to change the way that we manage nutrients.

The overall treatment plant design is illustrated in Figure 1.1 and indicates the flow of the material through the plant, from raw yard slurry at the inlet to treated and reused water at the outlet.

The TFNP project was designed to carry on where ProsiectSlyri project left off, which was to innovatively reduce farm waste, help safeguard the environment and address the agricultural industry's impact on ecosystems by developing a dewatering and purification system, with nutrient capture and reuse to better manage nutrients on farms.

The project applied innovative, proven concept technology to reduce air and water pollution and to reduce the overall volume of slurry by up to 80%. A de-watering and purification system was developed that removed the water from slurry and treated the separated water with the aim that it would be acceptable for reuse on the farm or be suitable for safe discharge. The system also utilised nutrients from the slurry to produce good quality fertiliser. Efficiently extracting and recovering nutrients from manures could save on the cost of inorganic fertilisers and considerably reduce environmental impact.

The approach allowed the independent evaluation of new technology in combination with existing farming methods in a research environment that maximised the opportunity for dissemination and exploitation.

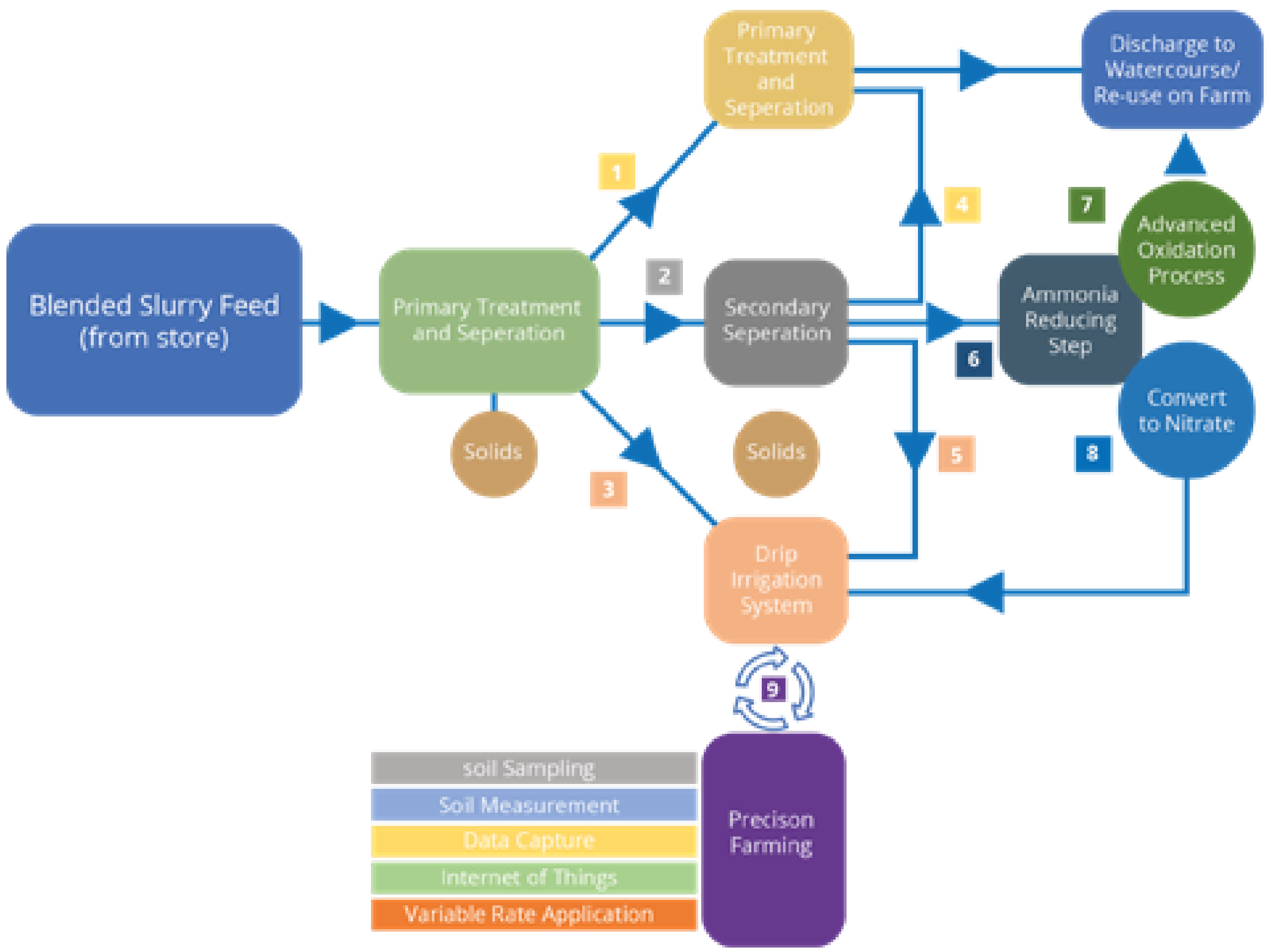
The success of the modular approach meant that the process is suitable for multiple tapping's at various treatment stages. This allows different applications to be adopted; part treatment would be suitable for precision irrigation or allow redirection of the water to constructed wetlands (reedbeds) and on to water purification and recycling. Further development in the way that the separated nutrients are stored and applied to land using high tech precision application methods was also investigated.

To support the Welsh Government Clean Air Plan, the developments also looked at ways of reducing the release of ammonia to the atmosphere. Project partners, N2 Applied have developed a technology to produce nitrogen fertilizer on the farm, through fixing nitrogen from air and absorbing into the livestock slurry. The reaction stops the ammonia losses through acidification and increases the nitrogen content in the manure or digestate. It also removes the odour from the nitrogen-enriched fertilizer product.

Precision application techniques were utilised in order to make sure that no surplus nitrogen is applied to areas that are above optimum capacity. Project partners Netafim installed a subsoil drip-irrigation system in order to study the effects of using dewatered slurry had on plant growth and how to maximise the line spacings and flow.

Separated solid was applied to silage growing areas and the water was recycled for use elsewhere on the farm.

Figure 1.1: Illustration of the Expansion of Existing Collaboration's Modular Foundation Around Wider Nutrient Management and Water Recycling



Primary treatment and separation developeded in conjunction with GEA and Aquatreat prior to:

1. Level of contamination is appropriate for reed bed application
2. Level of contamination requires further mechanical separation (GEA)
3. Level of contamination is appropriate for drip irrigation system (Netafim)
4. Secondary separation allows discharge to constructed wetland system
5. Secondary separation allows discharge to drip irrigation system (Netafim)
6. Secondary separation allows for further treatment to remove ammonia
7. Removal of ammonia residues via Advanced Oxidation Processes (AOP) will allow for the effluent to be discharged or reused on farm (Power and Water)
8. Treatment to stabilise and reduce ammonia losses and provide additional sources of nitrogenous compounds for use as a fertilizer and which are available for plant root uptake (N_2-Applied)
9. Precision farming techniques coupled with the 'internet of things' will provide feedback monitoring of field conditions and nutrient application rates (Map of Ag)

Climate Change Challenges

Intensification of the dairy industry and climate change challenges has put the industry in a position where its current nutrient management strategy is no longer fit for purpose.

The injection of capital based on the success of ProsiectSlyri project allowed the development of additional processes in order to maximise the initial impact. For example, adding reedbed technology for scrubbing of the separated water led to discharge quality water, whilst precision application equipment enabled the targeted delivery of slurry, partly treated water or separated solids.

Legislation due to be introduced on the 1st January 2024 stipulates that there will be a closed spreading period between the 15th of October and the 15th of January. With further stipulation that there needs to sufficient storage capacity to hold all slurry produced between the 1st October and the 1st March.

However, storage facilities are not necessary for slurry sent off the holding or spread on land that has a low run-off risk (provided that this is done in accordance with the other measures on spreading). Nevertheless, storage facilities for an additional one week's manure must be provided as a contingency measure in the event of spreading not being possible on some dates. This offers opportunity for effective de-watering to concentrate nutrients and reduce transport capacity.

The success of the project will only have an impact on farm efficiency and improved environmental conditions if it is adopted widely. The partnerships have developed processes and systems to maximise the practical application of the initial separation results. Applying wetland technology will further reduce the Chemical Oxygen Demand (COD) making the water both more suitable for discharge and recycling. The project could also reduce the treatment reduction percentage making savings in treatment costs but apply irrigation as a means of making efficient use of the separated liquid. The basis of the success to date opens up many potential modular processes to improve efficiency and encourage uptake.

TFNP was borne out of the success of ProsiectSlyri project and made full use of the research facilities that Coleg Sir Gâr have developed at the Agriculture Research Centre based at Gelli Aur Farm Campus. TFNP has brought together a mix of international and Wales-based players in the field of nutrient management all with common goals. As commercial companies, their first aim is to increase market opportunities by optimising the suitability of their processes and systems by further research and development. At the same time, they wish to maximise the efficiency and scope of their modular processes by aligning with other TFNP partner processes to offer a complete nutrient management package.

The value to Wales and the Welsh dairy industry includes direct efficiency gains through better use of homegrown nutrients and reduced purchases of chemical fertilizer. The value to Wales is far-reaching including cleaner rivers, improved biodiversity and increased tourism. It also delivers direct benefit to the commercial partners, bringing increased job opportunities in fabrication, sales and service; economic gain from more efficient agriculture; improved opportunities for tourism; and establishes Wales as the go-to country for research and development into agricultural nutrient management and environmental practices.

The environmental impact of agriculture is the effect that different farming practices have on the ecosystems around them and how those effects can be traced back to these practices. This varies based on the wide variety of agricultural practices employed around the world.

the world. Ultimately, the environmental impact depends on the production practices of the system used by farmers. The connection between emissions into the environment and the farming system is indirect, as it also depends on other climate variables such as rainfall and temperature. Some other factors can include types of machinery used for agriculture purposes as well as the farmer's choice of how they handle their livestock and manage nutrients.

There are two types of indicators of environmental impact: 'means-based', which is centered on the farmer's production methods, and 'effect-based', which is the impact that farming methods have on the farming system or emissions to the environment The environmental impact of agriculture involves a variety of factors from the soil, to water, the air, animal and soil variety, people, plants, and the food itself. Environmental issues that are related to agriculture in general include; climate change, deforestation, dead zones, genetic engineering, irrigation problems, pollutants, soil degradation and waste.

The Current State

Currently, agriculture accounts for 10% of the EU's total greenhouse-gas emissions. A significant decline in livestock numbers, but an increase in productivity, more efficient application of fertilizers and better manure management reduced the EU's emissions from agriculture by 24% in the last 20 years - so improvements can be made. Ongoing research and development have to keep up with herd expansion particularly in the dairy industry. High rainfall in North-West Europe makes managing manure a particular challenge and we continue to see a reduction in water quality in those areas. Wales is no exception to this, but positive impact on environmental emissions can also benefit the financial performance of Welsh agriculture. ProsiectSlyri project identified possible savings of up to £50M to the Welsh dairy industry, by making better use of home-grown nutrients and reducing waste.

The National Farmers Union (NFU), for example, has set the ambitious target of reaching net-zero greenhouse gas (GHG) emissions across the whole of agriculture in England and Wales by 2040. This will contribute to the UK's ambition of net zero by 2050. Farmers have a special responsibility to protect carbon reserves already in soils and vegetation. However, more must and can be done. Emissions from UK farms presently amount to 45.6 million tonnes of carbon dioxide (CO_2) equivalent a year – about one-tenth of UK GHG emissions. But in stark contrast to the rest of the economy, only 10 per cent of this is CO_2. Around 40% is nitrous dioxide (N_2O) and 50% is methane (CH_4). Adopting new technology and management systems will have a major part to play in achieving that goal.

TFNP aligns with Welsh Government strategic policy to safeguard the environment. The Clean Air Plan for Wales sets out its commitment and long-term ambition to improve air quality to deliver healthy air and a healthy Wales, and the Environmental (Wales) Act 2016. It will also support farmers in meeting further legislative controls that are currently being drawn up and will be imminently imposed.

"Savings of up to £50M to the Welsh dairy industry..."

Socio-Economic Benefits

The economic benefit of fishing in Wales is significant, but under threat due to diminishing river water quality. A report published by Natural Resources Wales[6] in July 2018 titled 'A review of the economic value of angling in Welsh rivers' indicated that across Wales the market value for fishing rights was £90M and provides employment (FTE) for around 700 people. Furthermore, it is estimated that anglers spend around £40M (2016 figures) with 53,248-rod licenses issued, with the fishing of all species contributing some £20M to household income. Also, fishing trips to Welsh rivers by Welsh residents' amount to some £12M annually[7]. The annual economic impact from the loss of all river fishing in Wales would amount to £10M of household income and around 400 jobs.

The estimated attributable spend on domestic tourism (within Wales) including holidays and day visits by activity in 2015 indicated fishing accounted for £38M, compared to £22M for golf, £23M for water sports and £54M for cycling/mountain biking[6]. There is a distinct probability that increasing river pollution could have a dramatic effect on tourism numbers and economic benefit by way of river systems having poor biodiversity, low fish stocks, followed inevitably by negative angler communications.

TFNP aims to greatly improve the use and efficiency of organic manures to the land and increased crop yield through improved nutrient availability and less soil compaction. Furthermore, by making better use of recycled farm nutrient the use of bought-in chemical fertilizer would be reduced as well as a possible reduction in field trafficking and fuel use. Encouraging development and uptake of precision farming techniques through evaluation and demonstration will also improve efficiencies in the livestock sector, which has been slower than arable farmers to adopt this new technology. The projects Specific Objective is therefore, **to better utilise farm nutrients by developing appropriate sustainable farming practices that lead to cleaner air and water in river catchments, improved soil condition and business efficiencies through the development, understanding and adoption of new technology.** A data-driven agricultural industry can increase farm sustainability and improve water and air quality.

There is huge potential within the industry to close the nutrient recycling loop whilst supporting a circular economy. Resource Recovery and Reuse (RRR) initiatives, whilst often supported via public funds are mostly research driven pilot schemes with little private sector participation[8]. TFNP, through the SMART Expertise programme hoped to change this by closely involving our project partners and the sharing of information and ideas between relevant partners for the benefit all.

In future, the trading of nutrients may become a viable option. The separated solids which contain up to 99% of the nutrients could become perfectly exportable from areas where soil nutrient stocks are high to areas where they are deficient. Further work is required with regards to bio-security issues and how best to overcome this, but nonetheless, the potential and technology needed is already available. Theoretically, any excess solids could already be used for forestry, in landscaping or energy generation for example.

Research, Development & Innovation - RD&I

The overall vision is for 'clean rivers and sustainable farming systems' with the development of a more incorporated way of managing nutrients and water on farm. This will support part of the Welsh Government's wider approach to natural resource management. More integrated management of farm nutrient resources will help to promote the coordinated management of water, land and related resources. This, in turn, will maximise economic and social benefits equitably while protecting vital ecosystems and the environment. Agriculture has a very important part to play in this aspiration, particularly with the potential recycling of water from slurry, de-watering and rainwater capture.

The intention was to work alongside strategic partners to help develop and independently evaluate the potential of novel techniques aimed at further improving nutrient management techniques on farms, balance the optimal nutrient uptake by crops, whilst simultaneously reducing the potential over-application of both organic and inorganic fertilizers. This will result in less leaching of nutrients into watercourses and a reduction in airborne odours, consequently providing a positive impact on air and water quality and river catchment biodiversity in Wales, with socio-economic benefits for all stakeholder groups.

Investment in a constructed wetland and precision application methods will support the Agriculture Research Centre at Gelli Aur in providing first-class facilities for current and prospective partner research going forward. Adding constructed wetland technology to the facilities will enhance the opportunity to recycle water for reuse in the dairy system. Precision application equipment in conjunction with farm networking will identify specific areas which require nutrient application and apply nutrients only to those areas, resulting in efficiency and environmental gains.

Example Of RD&I Challenge Solutions

Contructed Wetlands

Constructed wetlands can deliver safe and efficient water treatment that would complement and reduce considerably the capital and running cost of the mechanical/chemical separation infrastructure. New developments in reedbed technology through the introduction of forced air ventilation have greatly improved the efficiency of treatment and a considerable reduction in the land area required. This allowed us to determine the appropriate level of treatment for the most effective and cost-efficient way of achieving dischargeable or recyclable water.

Precision Agriculture

Coleg Sir Gâr (CSG) engaged with Map of Ag, a global pioneer in agricultural analysis and modelling technology, to provide a detailed roadmap for farm nutrient management planning going forward. Providing access to intelligently sourced data and information from farms enable businesses within the agriculture industry and food chain to maximise the impact of planning and decision-making.

The partnership using a local agent supported the development of an electronic field monitoring system, combining both dedicated hardware/ software to support the efficient application of the nutrient-rich cake with a variable rate application system.

Solid/Liquid Separation with Dewatering and Nutrient Recovery

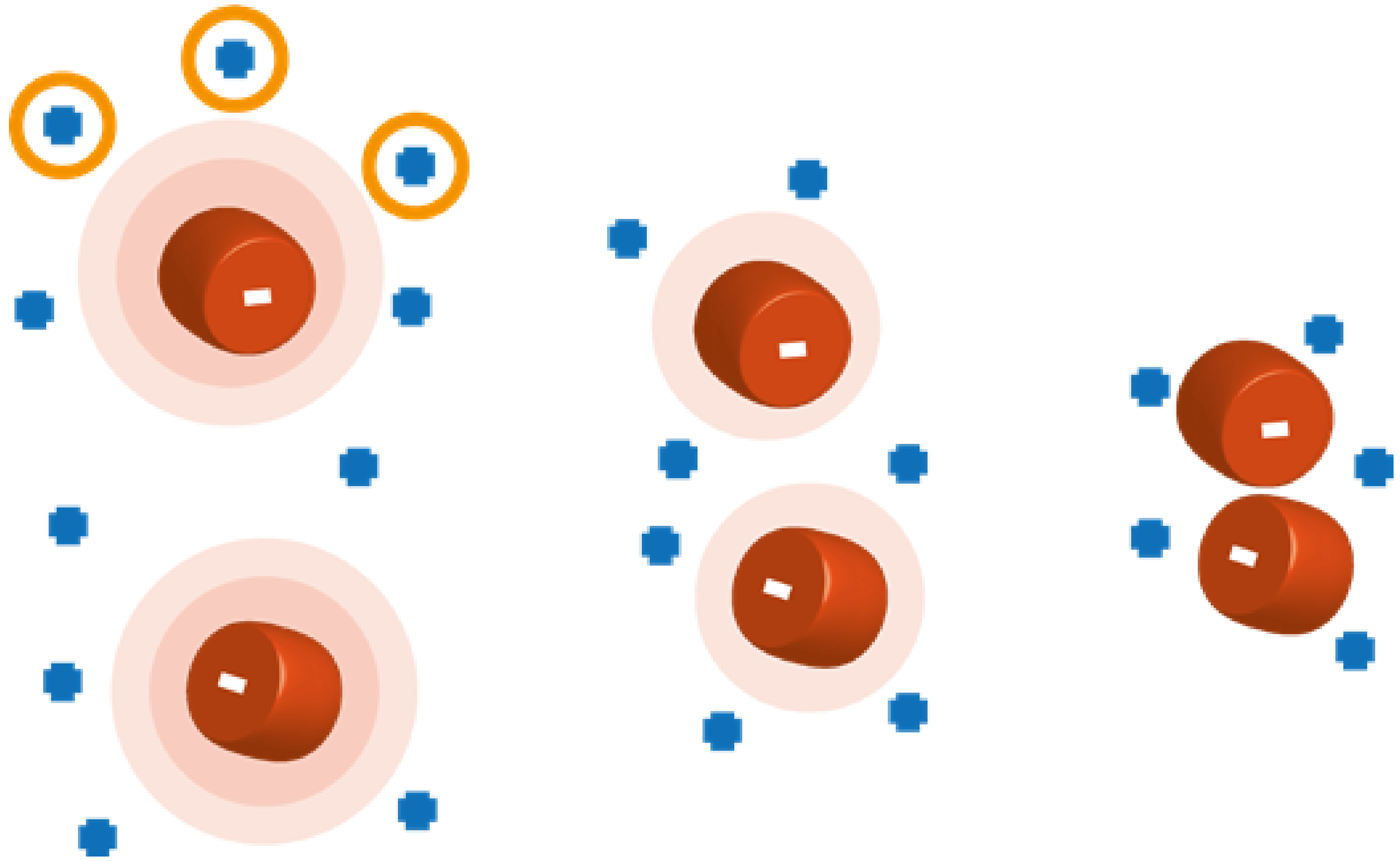
The mechanical plant is designed to remove coarse solids and suspended colloidal material as well as the dissolved charged particles found in cow slurry. This is accomplished through electrostatic mechanisms for particle coagulation and flocculation.

Two main mechanisms are employed for the general removal of charged particles from wastewater streams. These are 'charge neutralisation' and 'sweep flocculation', with a third – 'molecular bridging' also playing a role during the flocculation stage.

What is Charge Neutralisation

Coagulation is the process of neutralising the electronic surface charges of particles, fibres and colloidal material in water and keep them suspended. Colloidal material can be described as any matter that is one-tenth of a millimetre or smaller which is suspended in an aqueous solution. The addition of cationic charges neutralizes the anionic surface charges, allowing the particles to come within contact with one another as illustrated in Figure 1.2.

Fig 1.2: Illustration of Charge Neutralisation

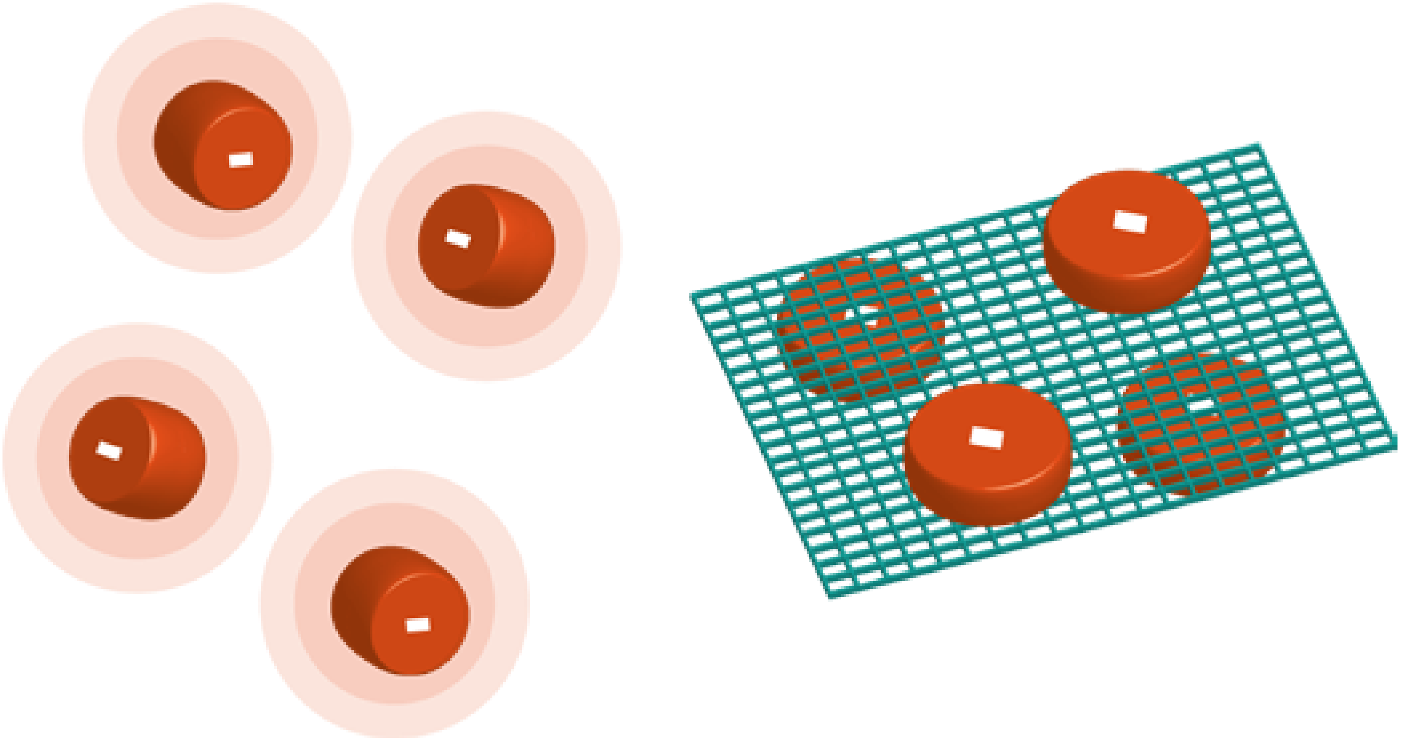


A flocculant can then be used to bind the coagulated particles together in order to make them easier to separate from the liquid stream.

What is Sweep Flocculation?

Sweep flocs can be described as large aggregates of mineral salt hydroxides e.g. $Al(OH)^3$ or $Fe(OH)^3$ that are formed when salts of aluminium (Al) e.g. Polyaluminium Chloride (PAC) or iron (Fe) e.g. Ferric Chloride are added to water. Further, the insoluble hydroxides (at neutral pH) form an electrostatically positively charged molecular net which attracts, captures and binds on to the negatively charged colloidal particles in the liquid, causing the colloids to become enmeshed in the sweep floc as illustrated in Figure 1.3.

Fig 1.3: Illustration of Sweep Flocculation

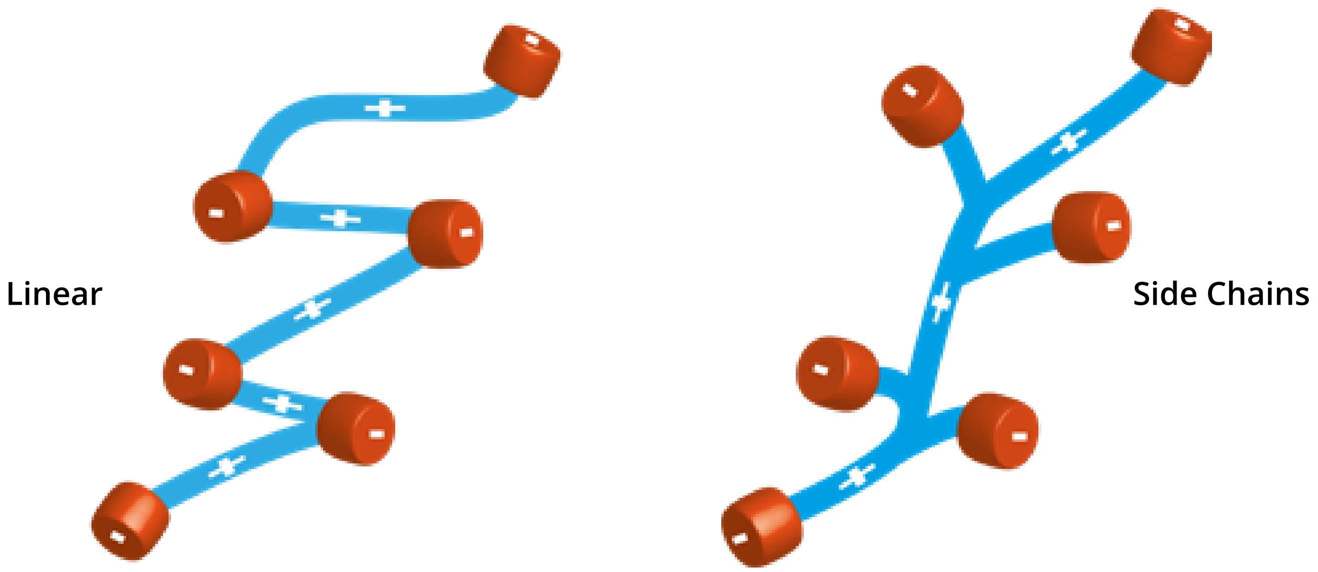


A third mechanism may also play a significant role during the flocculation process. This mechanism is 'molecular bridging'.

What is molecular Bridging?

Molecular bridging in wastewater treatment can be described as bridging between wastewater particles and the polymer flocculant. A bridge is formed between the ends of the linear charged polymer molecule and two oppositely charged wastewater molecules. Polymer molecules may also contain side chains/branches which can interact with additional wastewater molecules making the process more efficient (Figure 1.4).

Fig 1.4: Illustration of Molecular Bridging



Enhanced Coagulation Methods

More recently ultrasound has shown to be an effective water treatment technology. This innovative and ground-breaking technology is based on generating electrons and cavitation to accelerate the efficient removal of inorganic, organic and nutrient compounds as well as purifying the wastewater (and sludge) of pathogenic bacteria.

Cavitation is the formation of vapour cavities in a liquid – i.e. small liquid-free zones ("bubbles" or "voids") – that are the consequence of forces acting upon the liquid. The advantage of cavitation is the effect of high pressure (~500ATM) and temperatures (~5000K) achieved in the domain near the collapsed bubble, the rate of heating being sufficient to start and sustain reactions in aqueous and other solutions.

In the review article by *Hongmei Cui et al*,.[9], they highlight studies which have shown that ultrasonic irradiation combined with other technologies has better results than ultrasound alone. The principle of ultrasonic enhanced coagulation involves ultrasonic irradiation increasing molecular vibrations, improve the ion collision efficiency and make the flocs more compact - and easy to separate. In addition, ultrasonic irradiation can change the morphology and surface characteristics of ions, cause particle surface damage, significantly increasing specific surface area and particle aggregation.

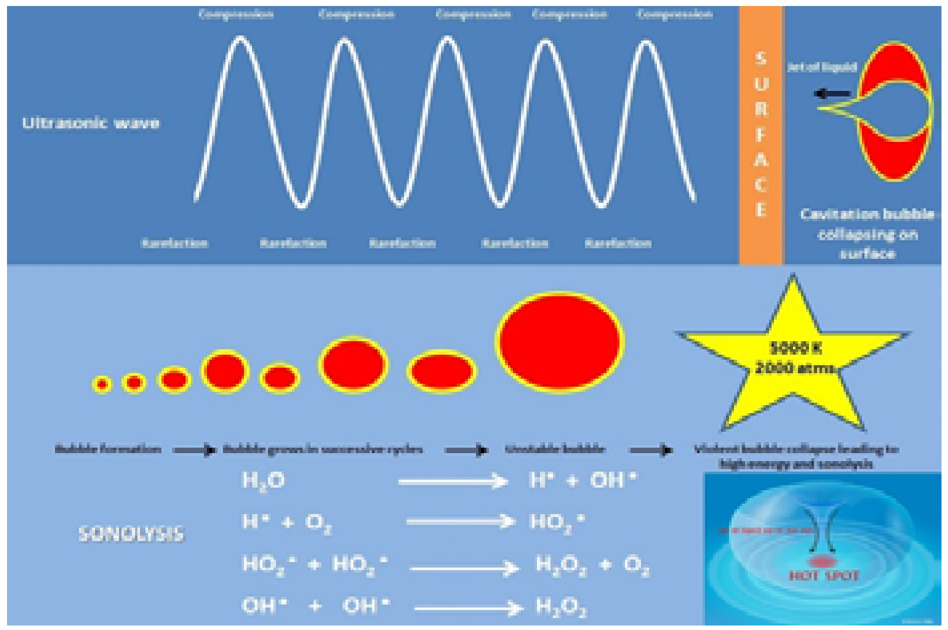


Figure 1.5: Effect of Ultrasound in Liquids[10]

Forms of Hydrolysed Aluminium Used as a Coagulant

The pH of the system plays a vital role in the coagulation process. The form in which the hydrolysed aluminium takes when dosed as an aluminium salt is very dependent on the pH of the effluent. Higher pH values will predominately form aluminium anions (soluble) whilst low pH values will predominately form aluminium cations (soluble). Aluminium hydroxide (solid) is present at both pH ranges respectively although the electronic charge on $Al(OH)_3$ will differ.

The isoelectric point of aluminium hydroxide has been found by others to be pH 7.7[11] and that the amphoteric aluminium hydroxide was more acidic than basic. For the purpose of using aluminium hydroxide in sweep flocculation, theoretically it should therefore be in its acidic form (i.e. below pH 7.7) as this will allow the negatively charged colloids to be attracted to positive charges on the hydroxide.

Conversely, *Ning Wei et al*,.[12] report that both charge neutralisation and sweep flocculation can achieve high coagulation efficiency under alkaline conditions ranging from final pH 7.0 – 10.0. The optimal mechanism at final pH<7.0 is charge neutralisation and that satisfactory coagulation efficiency could be obtained with either charge neutralisation or sweep coagulation within this pH range.

Through jar testing and scaled-up reaction tank trials we have found however, that the pH at the coagulation stage should be maintained between pH6.1 – 6.6 as this gives the best solid/liquid separation performance. It was also noted that the final pH is more important than the pH of the influent – i.e. it is better to correct the pH post coagulant dosing, than prior, as this has a positive influence on the flocculation stage where denser flocs are formed which are less prone to shearing. This was observed by *Ning Wei et al*,.[12], who also reports that when the final pH is not controlled and consequently decreases with increasing PAC dosage - and no sweep flocculation can be observed, the coagulant efficiency decreases at high PAC dosages. This may be the result of excess positive charges from the hydrolysed metal salt repelling each other on the surface of the coagulated material and preventing further growth.

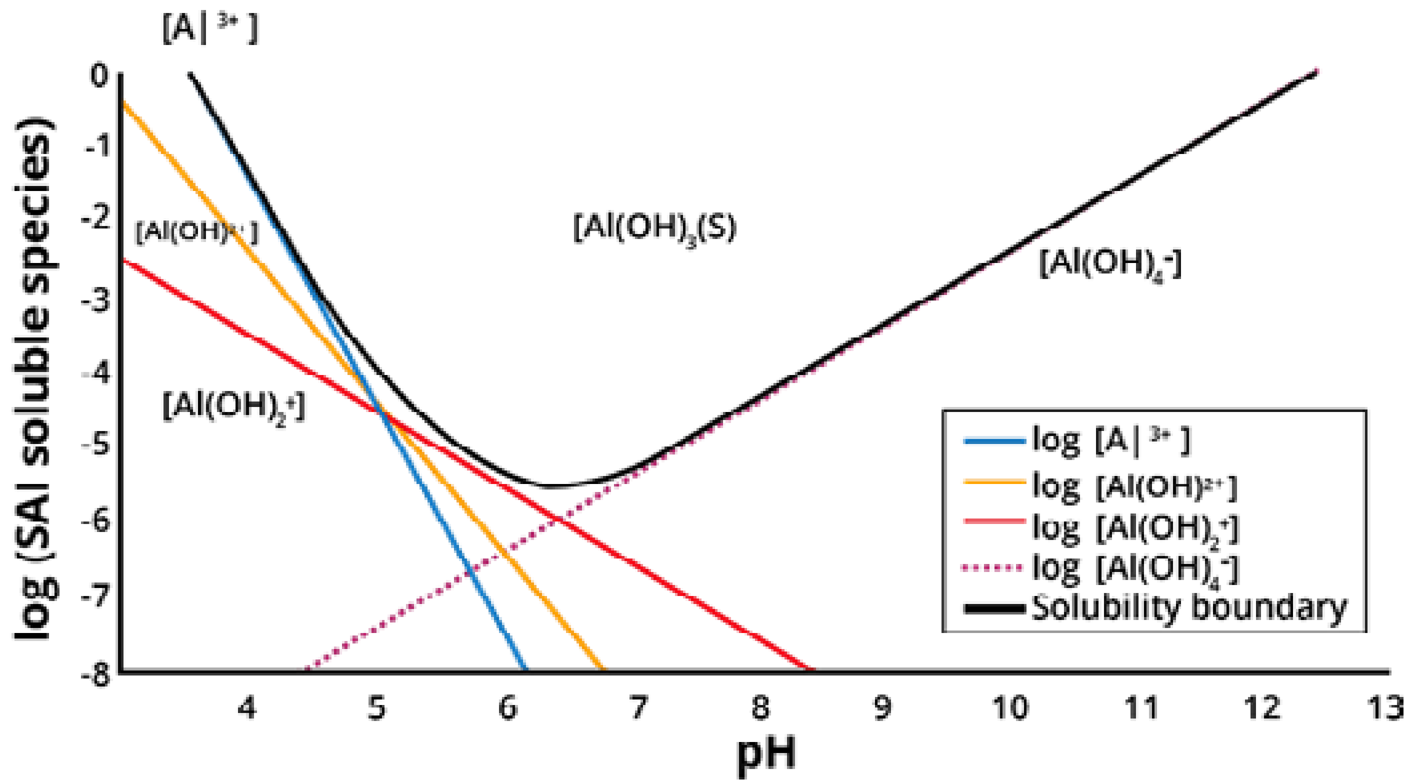
At low pH values, dissolved aluminium is present mainly as Al^{3+}. Hydrolysis occurs as pH rises, resulting in a series of less soluble hydroxide complexes (e.g. $Al(OH)^{2+}$, $Al(OH)_2^{+}$). Aluminium solubility is at a minimum near pH6.3 at 20°C and then increases as the anion $Al(OH)_4^-$ begins to form at higher pH[13][14]. Therefore, at 20°C and pH<5.7, aluminium is present primarily in the form Al^{3+} and $Al(OH)^{2+}$. In the range 5.7 to 6.7, aluminium hydroxide species dominate. Typically, at pH~6.3 $Al(OH)_3$ dominates over all other species. In this range aluminium solubility is low and availability to aquatic biota should therefore also be low. At pH>6.7 $Al(OH)_4^-$ becomes the dominant species. It is important to note that the various aluminium species described are always present simultaneously at any pH value albeit in differing concentrations.

Speciation Diagram for Aluminium

The solubility curves for aluminium hydroxide $Al(OH)_3$ is shown in Figure 1.6 [15]. In solution, the boundary which exists between $Al(OH)_3$ (s) and other ionic aluminium species denotes the thermdynamic equilibrium at a given pH. The minimum solubility of $Al(OH)_3$ (s) occurs at pH6.3 – 6.5 and increase as the pH increases or decreases. Only the mononuclear forms of Aluminium (Al) are represented, when in reality Al has the ability to form polynuclear complexes as the concentration of Al increases.

At pH6.3 – 6.5 the hydroxide formed is positively charged as it is below the iso-electric point of pH7.7 for $Al(OH)_3$. Al complexes acting as positively charged coagulants are adsorbed on the negatively charged wastewater particles and therefore neutralise the colloidal charges, resulting in destabilization of the emulsion. Once destabilisation is achieved, this allows the particles to aggregate which makes them easier to separate as precipitated solid particulate.

Fig 1.6: Aluminium Speciation at Varying pH Values



2.0 Process Testing and Sample Analysis

Jar Tests

A jar test is a common method used to determine the optimum operating conditions for water and wastewater treatment sites. It allows changes in pH, coagulant/polymer types and dose rates, mixing speeds and retention times to be investigated on a small laboratory scale prior to upscaling in a larger treatment plant.

Standard jar testing was initially used to determine the following:

Choice of chemicals (coagulant and flocculant)
Optimal coagulant dose rate
Optimal flocculant dose rate
Optimal pH
Mixing time
Velocity Gradient (incorporating slurry viscosity, impeller speed, volume of liquid, impeller/tank diameter etc.).

Photo of Flocculator

Fig 2.1: Lovibond ET740 Bench-top Flocculator

1000ml beakers were used to conduct the jar tests with 500ml of sample.

Flash Mixing

The samples were flash mixed during coagulant addition in order to generate turbulence in the liquid. This provides the greatest opportunity for the coagulant to come into contact with the target substrate.

Samples were pH corrected using sodium hydroxide NaOH (32%) or hydrochloric acid HCl (10%) where necessary.

Slow Mixing

To promote flocculation the liquid was slowly stirred to encourage floc particles to aggregate. Stirring too vigorously can cause the floc particles to break apart, while stirring too slowly may prevent the floc particles from aggregating. Ideally, slow mixing should start out relatively fast to promote aggregation and then slowed down to prevent larger aggregates from breaking apart. This is known as staged flocculation[16].

The results of jar testing samples containing 4%TS yielded the following operating parameters:

Flash mix = 150rpm for 2mins
pH adjustment in the range pH 6.1 – 6.6
Slow mix = 30rpm for 15mins
Coagulant dose (PAC 18%) = 5ml/l
Flocculant dose (PAM active concentration 0.2%) = 350ml/l
Velocity Gradient – G value (compensated);
PAC G value = 200sec^{-1} – 400sec^{-1}
PAM G value = 18sec^{-1} – 20sec^{-1}

Determinant Analysis

The samples collected during the course of the project were analysed for the following as and when required:

% Total Solids (TS)
% Total Suspended Solids (TSS)
Chemical Oxygen Demand (COD)
Biological Oxygen Demand (BOD)
Total Phosphorus
Ortho Phosphate (Dissolved Phosphate)
Total Nitrogen
Total Potassium
Total Aluminium
Alkalinity
pH

What Does BOD and COD mean?

- **BOD (Biological Oxygen Demand)**: The rate at which organisms use oxygen in the sample while stabilizing organic matter. This measures the strength of the water based on the amount of oxygen the bacteria consume, typically the test is run for 5 days (BOD_5) and incubated at 20 degrees C. The higher the BOD, the stronger the waste.
- **COD (Chemical Oxygen Demand)**: COD is a measure of the amount of oxygen that can be consumed by chemical reactions in a given volume of sample and is an important parameter for determining the amount of organic material in the sample and therefore potential pollution of watercourses (there is often a correlation between COD and BOD).

In general, the preference was to test for COD rather than BOD as analysis of BOD_5 requires 5 days, whereas COD can be analysed in a matter of hours, although samples taken from the constructed wetland were analysed for BOD regularly.

The Treatment Process

As demonstrated by the process flow schematic in Figure 2.2, raw slurry is initially fed through a screw press filter to remove the bulk of the coarse solids (>0.5mm), which are moved to a solids store - with the remaining liquid filtrate transferred to a storage tank and allowed time to equilibrate. The filtrate is then pumped into the reaction tank where the coagulation-flocculation process takes place, precipitating dissolved solids and binding suspended solids/colloids together through chemical addition. A decanter centrifuge then removes these solids through centrifugal force (again, these are moved to a solid store), and the separated liquid centrate is pumped to a Dissolved Air Flotation (DAF) system for further processing. The liquid subnatant at the DAF outlet can either be delivered via the drip irrigation system to growing crops, used to washdown the yard, or pumped to the constructed wetland where the residual contaminants are removed by natural processes.

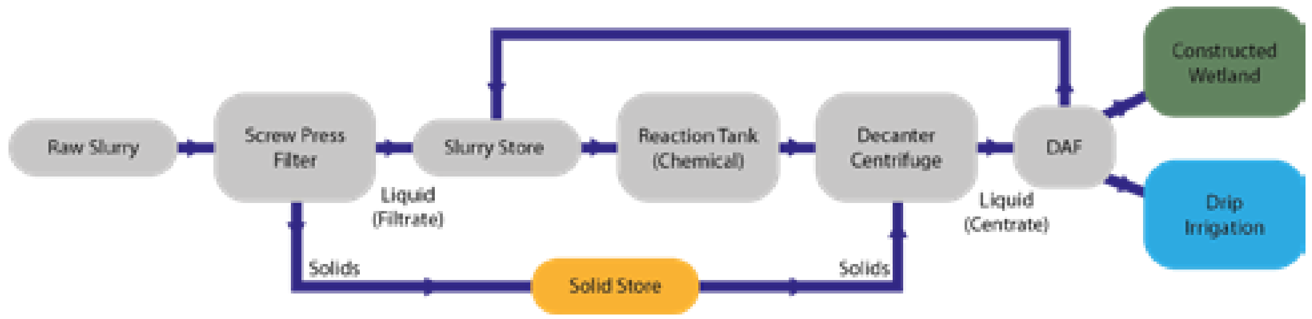


Fig 2.2: Flow Diagram of the Dewatering and Nutrient Capture Process

Dissolved Air Flotation (DAF)

The system utilises micro-bubbles to increase buoyancy of suspended solid particulate. For efficiency purposes, it is important to produce bubbles of the correct size. This is done by dissolving air into water under pressure and then decreasing the pressure on entry to the DAF cell using a controlled nozzle orifice[17]. As the pressure is reduced, the dissolved air expands and naturally comes out of solution in the form of micro bubbles. The micro-bubbles, also known as 'white water' attach themselves to suspended material within the wastewater stream, floating them to the surface, creating a 'sludge blanket'. The floated solids can then be easily removed via a scrapper mechanism and pumped away. As the sludge contains nutrients, these are recovered by pumping back to the start of the treatment process. Chemical conditioning is often used to increase the effectiveness of the process.

Fig 2.3: Photograph of DAF at TFNP – Gelli Aur

Analytical Results of Plant Treatment Performance

Liquid chemical coagulants are widely used in industrial and municipal wastewater treatment plants. The initial choice of chemical conditioners was originally determined during the previous ProsiectSlyri project, when varying chemical combinations were tested by current TFNP project partners Aquatreat, before settling on the use of Polyaluminium Chloride – PAC [$Al_2(OH)_nCl_{6-n}$]m, a pre-hydrolysed coagulant - and anionic Polyacrylamide - PAM [$CH_2CH(CONH_2)$]n, a polyelectrolyte flocculant. Further testing by Aquatreat confirmed this. In comparison to some other common coagulants, the relatively high basicity of the PAC used (35%) means that it consumes less of the alkalinity in the influent, therefore less pH correction chemical (caustic soda) is required to raise the pH.

Coagulation-flocculation is extensively used as a pre-treatment before mechanical separation in industrial wastewater treatment[18]. It is used to control particulates (i.e., suspended/dissolved solids, inorganic ions and heavy metals) by the inclusion of chemical coagulants and flocculants - in this instance PAC and PAM, respectively. Reliable floc formation has been a key challenge encounter when using dairy slurry due to the variability of the slurry matrix. Observations taken from the plant and during jar testing support the notion that pH is critical, and is one of many factors affecting the dewatering process. One explanation of poor/inconsistent floc formation relates to the limited capacity to resist acidification (alkalinity) within a feedstock that is highly fluctuating. Even relatively high basicity Polyaluminium Chloride can decrease the pH beyond the optimal ranges for high coagulation efficiency if the alkalinity is low.

Additionally, when feed is taken from pockets of increased alkalinity, more chemical coagulant is required to destabilise the wastewater particles and achieve charge neutralisation. This indicates a stoichiometric relationship between chemical dosage and feedstock alkalinity, which is supported by previous findings made in the literature[19][20]. By overcoming this challenge, dosing rates are now known for the treatment of both dilute and raw slurry, and provides a basis for a starting dose rate when making recommendations to other potential process operators (with other slurry types).

In order to overcome operating issues with varying feedstock impacting on treatment performance, the slurry was firstly agitated within the store using electrically driven mixers. This resulted in the homogenisation of the feedstock and reduced variance.

Agitating the slurry store whilst fixing the process parameters allowed stable treatment rates with the slurry store maintaining an average 4%TS (including rainwater ingress).

The percentage reduction of each of the determinands was calculated as follows:

$$\% \text{ Reduction} = \frac{Cin - Cout}{Cin} \times 100$$

Where:
Cin = concentration in the influent (mg/l)
Cout = concentration in the effluent (mg/l)

Table 2.1: Determinand Concentration and Reduction Rates

Substrate Material	Determinand (mean conc^{n})					
	COD (mg/l O_2)	TP (mg/l)	TN (mg/l)	TK (mg/l)	OP (mg/l)	TSS (mg/l)
Raw Slurry	59262.5	430.26	2168.39	2969.08	209.15	29020.0
Decanter Centrate	5163.41**	11.34	430.84	1083.88	6.59	234.55
Removal %*	91.29	97.37	80.13	63.49	96.85	99.19
DAF Subnatant	4475.28**	3.18	391.98	987.89	1.85	128.53
Removal %*	92.45	99.26	81.92	66.73	99.12	99.56

** Reduction rates compared to raw slurry values*
***Some unexpected high values in the raw data set heavily skewed the mean. Accounting for this, the adjusted values are 5,163.41mg/l and 4,475.28mg/l O2 respectively, meaning the reduction in COD is around 700mg/l O2*

Reducing the Total Suspended Solids (TSS) concentration has a positive effect on other determinand concentrations as outlined in Table 2.2. The closer the number is to 1.0 indicates a positive and very strong correlation between these determinands. Although it must be stipulated that correlation does not imply causation, only that there is a trend in the data. However, the hypothesis that TSS is a major factor when considering the other determinand concentrations is a valid one – and one that is supported by this data particularly when taking into account the precipitated solids (dissolved solids ⟶ suspended solids) from the coagulation stage.

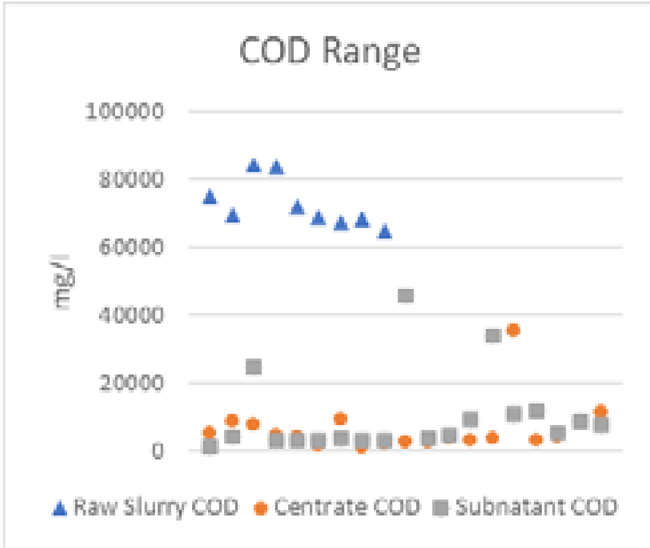
Table 2.2: Correlation Coefficients

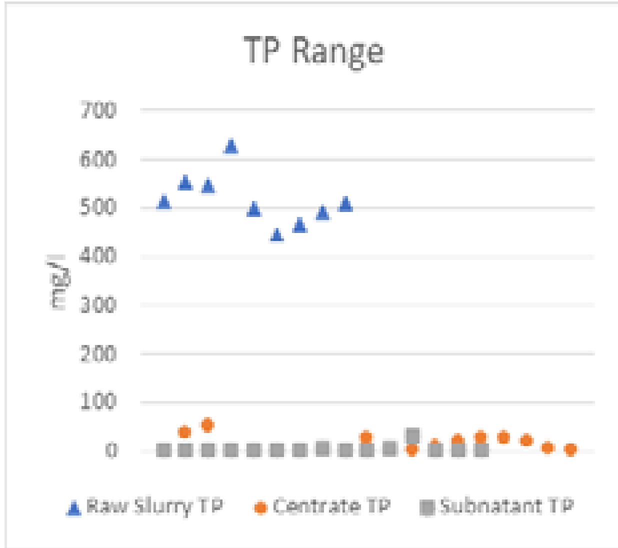
Correlation Between Treatment Process Determinands						
	COD	*TP*	*TN*	*TK*	*OP*	*TSS*
TSS	0.99192	0.999885	0.989548	0.955182	0.999806	1

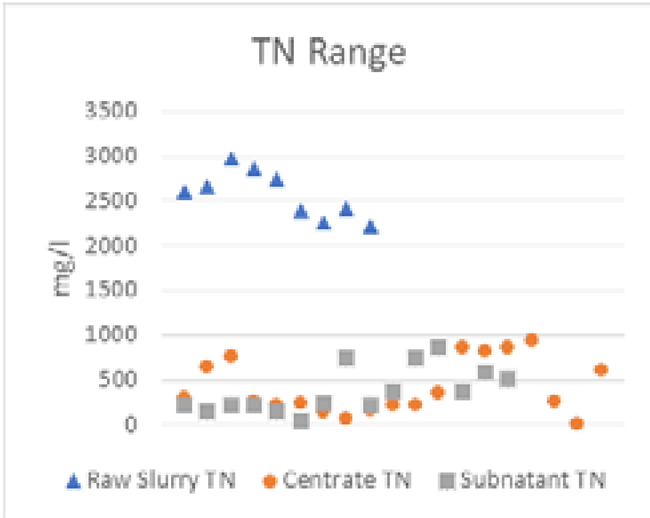
**Correlation does not imply causation, only that there is a trend in the data*

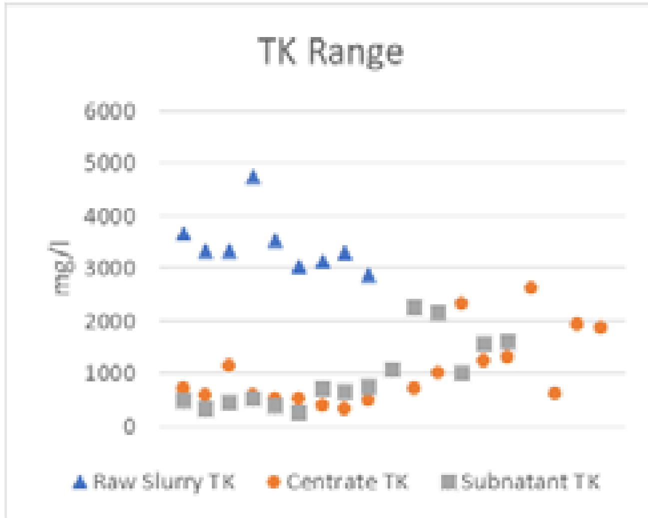
The range in determinand concentration can be viewed in Charts 2.1 – 2.5 for samples taken of the raw untreated slurry, decanter centrifuge centrate and DAF subnatant. The varying nature of raw slurry can impact the treatment process with increased chemical dosages required with increasing solid loadings in the slurry influent. Efforts were made to stabilise the influent concentrations by homogenising the slurry store prior to treatment.

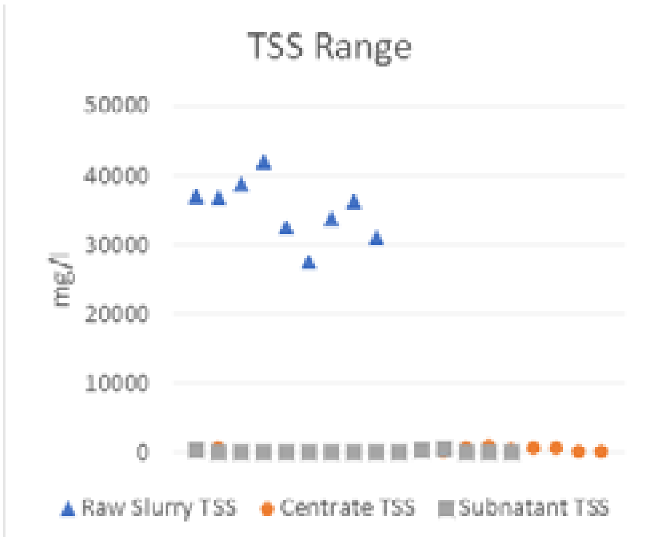
Charts 2.1 – 2.5: Reduction in Concentration of Contaminants Through the Mechanical Separation and Chemical Dewatering Treatment Process





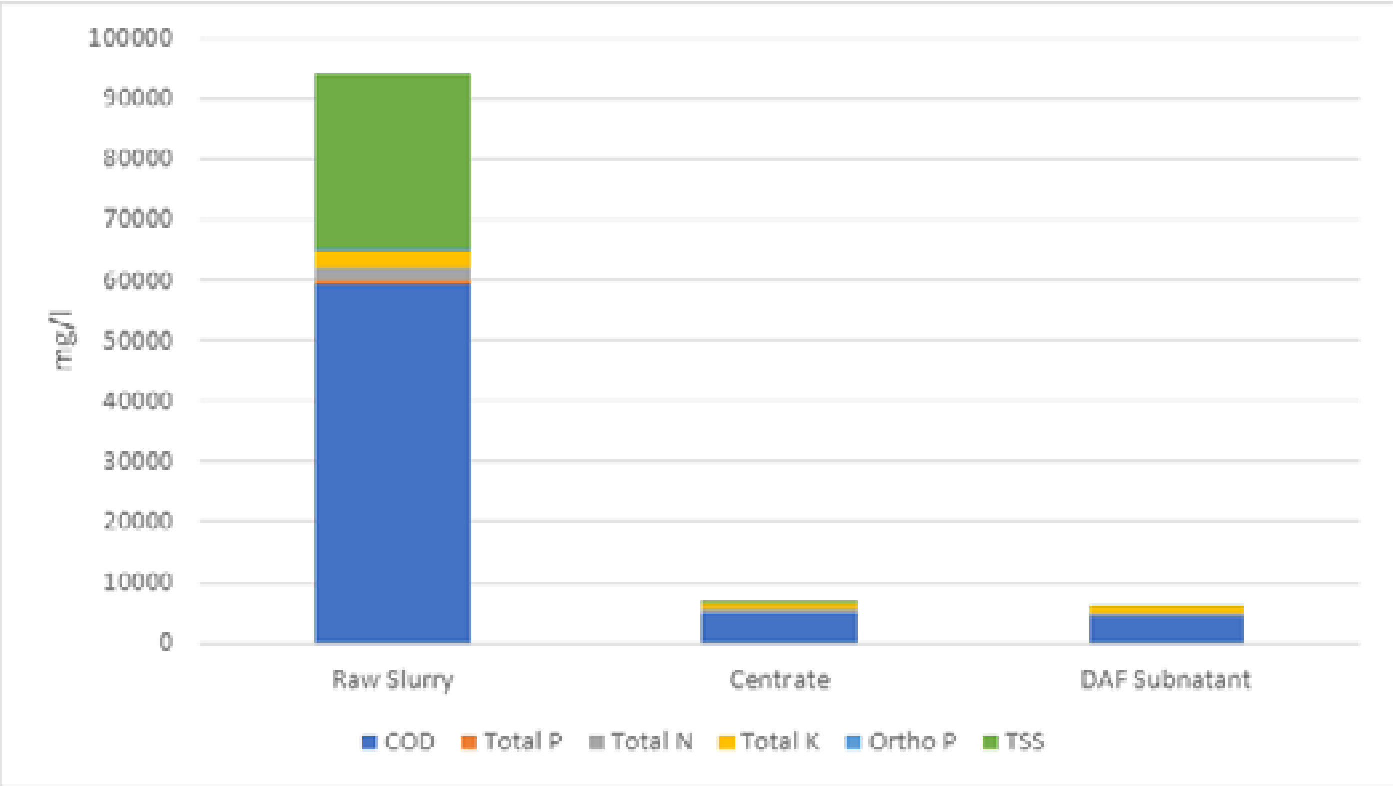






Progressive reductions in determinand concentrations through the mechanical separation with chemical dewatering stages can be viewed in Chart 2.6. Clearly there is a large reduction in determinand concentrations within the centrate when compared to the raw slurry, followed by much less of a reduction in the DAF subnatant.

Chart 2.6: Cumulative Contaminant Removal Through Mechanical Separation and Chemical Dewatering Process



Observed Floc Characteristics

The pH of the system has a strong effect on floc formation and physical properties. When the pH is <6.5 the flocs formed tended to be larger, but less dense with soft edges. This seems to cause the flocs to surface and may aid the DAF process in forming a sludge blanket which can be easily removed. Conversely, when the pH is >7.0 the floc formed tends to be smaller and more tightly packed and therefore denser, which causes the flocs to want to settle. This would aid solid/liquid separation in the decanter centrifuge as the flocs have a higher specific gravity than the liquid and could be easily separated according to gravitational force. However, over time water infiltrates these heavier flocs resulting in them becoming less dense and they will eventually rise to the surface. Because PAC is a metal salt, it lowers the pH of the system and caustic soda was added to pH correct. The cost of caustic soda addition in order to increase the pH for the flocs to better settle must be considered. For separated slurry (filtrate 4%TS) with a starting ~pH7.0, in order to maintain at working pH6.3 in the reaction tank ~0.4L of caustic soda (32%) was dosed for every 1L of PAC (18%).

In addition, at higher pH values, ammonia emissions are known to be increased, consequently the overall efficiency of the treatment process (including GHG emissions) may decrease – although this cannot be substantiated and would require further work.

Chemical Dosing Ratio (Stoichiometric Equivalents)

The term 'stoichiometric equivalents' refers to the quantity of one substance that reacts with a quantity of another.

The Minnesota Pollution Control Agency suggest that for target phosphorus (P) concentrations above 2 mg/L, a dose of 1.0 mole of aluminium (Al) per mole of phosphorus is sufficient. For lower P concentrations in the range of 0.3 – 1.0 mg/L, the dose can be in in the higher range of 1.2 to 4.0 moles Al per mole of P. The pH value is an important factor for efficient removal of P using Al or other salts, as the solubility of their precipitates vary with pH. Depending on the influent, P removal is most efficient in the pH range of 5 to 7 for Al salts[21].

The dose of chemical coagulant (PAC) in relation to total phosphorus concentration in the influent at 2m^3 flow rate and a TS% (mean) = 4.7, is given in Table 2.3 below:

Table 2.3: Coagulant Dosing Ratios

Dosing Point	P conc^n in influent (mean) mg/l	PAC conc^n dosed mg/l	Ratio
Primary Reaction Tank	344.3	360	1.04
DAF Reaction Tank	44.5	90	2.02
Total	344.3	450	1.3

Polyaluminium Chloride (18%): Total-P =1.3

The dose of chemical flocculant used with the influent flow rate at 2m^3 and a TS% (mean) = 4.7 is showed in Table 2.4 below.

Table 2.4: Flocculant Dosing Rates

Dosing Point	PAM (0.2%) volume dosed l/hr	PAM (0.2%) conc^n dosed g/hr
Primary Reaction Tank	345	690
DAF Reaction Tank	30	60
Total	375	750

Decanter Centrate v DAF Subnatant

DAF Performance

The analysis of samples taken of the decanter centrate (separated liquor) and DAF subnatant (clarified liquid) are given in Table 2.5 below. The data suggests that the high capital cost of the DAF cannot be warranted on the basis that statistically, there is no significant difference between the subnatant and the centrate for the determinands COD, TN, TK and TSS. Only TP and OP show a significant difference. However, the excess phosphorus can be utilised in the constructed wetland for reed growth and biofilm health. Indeed, this is a necessary component of constructed wetland well-being. Therefore, it is difficult to recommend the use of a DAF unit for tertiary separation of cattle slurry in this instance and solely for this purpose. However, the use of a DAF system may play an important part if aiming to deliver nutrient through a dripline irrigation system as it reduces the overall loading of suspended solids, preventing blockages.

Determinand	*p*
COD	>0.05
TP	<0.05
TN	>0.05
TK	>0.05
OP	<0.05
TSS	>0.05

At $p \leq 0.05$ the null hypothesis can be rejected for COD, TN, TK and TSS indicating that there is no significant difference overall between the Decanter Centrate and the DAF Subnatant for these determinands. However, the null hypothesis cannot be rejected for TP and OP ($p<0.05$), indicating a significant difference for these determinands.

Treatment Plant Operating Costs

Table 2.6 Treatment Plant Opex Costs

Treatment Plant Total Operating Costs	£/m3	£/100 cows
Chemical	£ 7.02	£ 14,575.15
Power @30p/kWh	£ 7.99	£ 16,586.44
Grand Total	**£ 15.01**	**£ 31,161.59**

3.0 Compliance Limits

The Urban Waste Water Treatment Directive Regulations (UWWTR)

The UWWTR sets out the checks and balances needed to comply if treated water is to be discharged to a water course. Although for the purposes of this project the treated water (final effluent) wasn't discharged, but recycled and re-used on the farm, it can however be used as a comparator.

Discharge Limits

The tables below highlight the discharge consent permit limits [22][23] for a number of determinands, including those tested for in TFNP.

Table 3.1: Determinant Concentration Standards

Determinand	Standard
Chlorine	5ug/l MAC as Total Available Chlorine
Aluminium	The standard is 1mg/l (total) MAC EQS but subject to a maximum concentration in the discharge of 10mg/l (dissolved) EMISSION STD if 1:10 dilution
Cationic Polyelectrolytes (polymer)	EQS will be 0.1 x 24h LC50 for appropriate fish species, as 95pc.Dilutions <x30 require case specific consideration
Anionic and Non-ionic Polyelectrolytes (polymer)	7.5mg/l 95pc, EQS OR 0.1 x 24h LC50 for appropriate fish species, if this is known.
Suspended Solids	100mg/l EMISSION STD OR Case-specific std.

AA = annual average; 95pc = 95 percentile; MAC = maximum allowable concentration; EQS = Environmental Quality Standard

Receiving Water Quality Standards

Determinant	Receiving Water Quality	
	pH<6.0 (lower 95pc) $CaCO_3$ <20mg/l AA	pH<6.0 (lower 95pc) $CaCO_3$ 20mg/l AA
Chlorine	5ug/l MAC as Total Available Chlorine	5ug/l MAC as Total Available Chlorine
Aluminium (Dissolved) (Total)	75ug/l 95pc EQS 100ug/l MAC EQS 500ug/l EMISSION STD	500ug/l 95pc EQS 1mg/l MAC EQS 1mg/l EMISSION STD
Cationic Polyelectrolytes	Adopt a case specific approach while analytical detection limit remains greater than 0.1 x fish 24h LC50	
Anionic and Non-ionic Polyelectrolytes	3.5mg/l EMISSION STD OR 0.05 x 24h LC50 for fish, if this is known as 95pc EQS	7.5mg/l EMISSION STD OR 0.1 x 24h LC50 for fish, if this is known as 95pc EQS
Suspended Solids	100mg/l EMISSION STD OR Case-specific std	

Table 3.2: Receiving Water Quality Standards

AA = annual average; 95p = 95 percentile; MAC = maximum allowable concentration; EQS = Environmental Quality Standard

The Urban Waste Water Treatment Directive Regulations (UWWTR)

The UWWTR sets out the checks and balances needed to comply if treated water is to be discharged to a water course. Although for the purposes of this project the treated water (final effluent) wasn't discharged, but recycled and re-used on the farm, it can however be used as a comparator.

BOD/COD Compliance Levels

Table 3.3: Look Up Table (LUT) Compliance

Parameter	Concentration	Minimum Percentage Reduction. (See Note 1.)
Biochemical Oxygen Demand (BOD_5 at 20 degrees C) without nitrification (See Note 2.)	25mg/l O_2	70 - 90
Chemical Oxygen Demand (COD)	125mg/l O_2	75
Note 1. Percentage reduction in relation to the load of the effluent. Note 2. The parameter can be replaced by another parameter: Total Organic Carbon (TOC) or Total Oxygen Demand (TOD) if a relationship can be established between BOD_5 and the suitable parameter.		

If the effluent sample failed to achieve the minimum percentage removal rate or where the removal rate cannot be calculated then the following limits may be imposed.

Table 3.4: Upper Tier (UT) Compliance

Parameter	Maximum Permitted Concentration
Biological Oxygen Demand (BOD_5 at 20 degrees C) without nitrification	50mg/l O_2
Chemical Oxygen Demand (COD)	250 mg/l O_2

Table 3.5: BOD Levels in Relation to Water Quality [24]

BOD level (mg/l)	Water Quality
1 - 2	Very Good – *There will not be much organic waste present in the water supply*
3 - 5	Fair: Moderately Clean
6 - 9	Poor: Somewhat Polluted – *Usually indicating organic matter is present and bacteria are decomposing this waste*
100 or greater	Very Poor: Very Polluted – *Contains high levels of organic waste*

Table 3.6: Discharge Limits for Phosphorus and Nitrogen

Parameter	Concentration (Annual Mean)	Minimum Percentage Reduction (Annual Mean) (See note 1)
Total Phosphorus	2mg/l P (10,000 – 100,000 population equivalent) 1mg/l P (>100,000 population equivalent)	80
Total Nitrogen (See note 2)	15mg/l N (10,00-100,000 population equivalent) 10mg/l N (>100,000 population equivalent)	70-80
Note 1 Percentage reduction in relation to the load of the influent. Note 2 Total Nitrogen means the sum of Total Kjeldahl Nitrogen - TKN (organic Nitrogen + NH_3), nitrate (NO_3^-) nitrogen and nitrite (NO_2^-) nitrogen		

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Use of Aluminium Salts as Coagulants in Wastewater Treatment

Aluminium is the most abundant metal element found in the earth's crust – constituting around ~8%. It naturally occurs in the environment in the form of oxides, hydroxides or silicates, combined with other elements, including sodium and fluoride and as complexes with organic matter.

The advantages of using aluminium salts during the coagulation phase of wastewater treatment is well known and understood. However, high dosing rates may lead to increased concentrations of aluminium in the final effluent. In natural water courses, the concentration of aluminium can vary significantly. Dissolved aluminium concentrations in waters with near neutral pH usually range from 0.001 to 0.05mg/l, but rise to 0.5-1.0mg/l in more acidic waters, or waters high in organic matter[25].

Drinking Water Quality Standards

The contribution of drinking water to the total human oral exposure of aluminium is around 4%. In experimental animals the absorption through the gastrointestinal tract is typically less than 1% and is effectively eliminated in the urine. In humans, aluminium and its compounds appear to be poorly absorbed, although the rate and extent of absorption have not been studied fully[25]. There is no indication that aluminium is carcinogenic nor has it shown to be mutagenic in mammalian cells in vitro. However, some chromosomal abnormalities have been observed in the bone marrow of mice and rats. In humans, there is little evidence that aluminium is acutely toxic by oral exposure despite its widespread occurrence in foods and drinking water.

The issues surrounding the idea that aluminium exposure can be a risk factor in the development of Alzheimer Disease in humans are rightly concerning. However, based on current knowledge and understanding it has been concluded that the present epidemiological evidence, does not support a casual association between Alzheimer Disease in humans and aluminium in drinking water[25].

Concentrations of Total Aluminium Found in the Final Effluent (for comparison)

Aluminium concentration in the final effluent at 95th Percentile = 0.65mg/l and 90th Percentile = 0.5mg/l with a maximum value of 2.0mg/l reported on a single sampling occasion. Lab analysis limits mean that concentrations are often reported as being below 0.5mg/l, but cannot be accurately detected. This is below the guidelines set out by NRW for discharge consent.

Under good operating conditions, concentrations of aluminium of 0.1 mg/litre or less are achievable in large drinking water treatment facilities. For smaller facilities, 0.2 mg/litre or less is a practicable level for aluminium in finished drinking water[26].

Nitrate and Nitrite Limits in Drinking Water

Guideline values for chemicals from agricultural activities that are of health significance in drinking-water for human consumption include: Nitrate (as NO_3^-) 50mg/l; Nitrite (as NO_2^-) 3mg/l[27]. Although the final effluent is never intended for human consumption it may be applicable nonetheless if the water was intended for animal consumption.

COD levels in drinking water

According to WHO recommends Chemical Oxygen Demand (COD) is 10mg/l O_2 in drinking water for human consumption. In July 2020, Health Canada released the Guidance on Natural Organic Matter in Drinking Water and most significantly, chemical oxygen demand (COD) was included as a suggested parameter to monitor with a suggested treated water quality target of <5 mg/L O_2 and DOC <4mg/l. The final effluent produced at TFNP has a mean concentration for COD and DOC of 25.46 mg/l O2 and 6.2mg/l respectively.

COD Levels in Drinking Water

Although some have commented that an acceptable concentration for Chemical Oxygen Demand (COD) is 10mg/l O_2 in drinking water for human consumption it cannot be easily corroborated. In July 2020, Health Canada released 'Guidance on Natural Organic Matter in Drinking Water'[28] and most significantly, chemical oxygen demand (COD) was included as a suggested parameter to monitor with a suggested treated water quality target of <5 mg/L O_2 and DOC <4mg/l. The final effluent produced at TFNP has a mean concentration for COD and DOC of 25.46 mg/l O_2 and 6.2mg/l respectively.

Chloride Levels in Final Effluent

Drinking water permissible levels for Chlorides is given as 250mg/l for human consumption[29]. The mean value for chloride in the final effluent at TFNP is reported as 194.5mg/l.

Free Acrylamide in Drinking Water

The Water Supply (Water Quality) Regulations 2018[29] states that the limit for free acrylamide should not exceed 0.1ug/l in drinking water for human consumption.

Currently, there seems to be very few analytical laboratories in the UK that have the capability of detecting acrylamide monomers (AMD). Instead, an inferred value is often used – based on the concentration in the working polymer. This is now commonplace across the water and wastewater industries. Table 3.7 below clearly indicates the levels of free acrylamide in the final effluent will be greater than 0.1ug/l according to the dose rate of PAM used at the

primary treatment stage and the levels of free acrylamide present in the working solution. There have been no studies to date in cattle relating to any ill effects of free acrylamide in drinking water and therefore must conclude that same limits to that of human consumption must apply.

Aquatreat 2087 Working Strength 0.2%

Table 3.7: Acrylamide Monomer Concentration Present in Polyacrylamide

PAM Dose Rate (ppm)	ml/l	Dilution Factor	Acrylamide (ppm)
10	10	100	0.0014
100	100	10	0.014

Table 3.8: Predicted No Effect Concentration

Compartment	Value (ppm)
Fresh Water	0.03
Aquatic Intermittent Release	0.3
Sewage Treatment Plant	0.2

- The residual acrylamide levels in Aquatreat 2087 liquid phase meet the Predicted No Effect Concentrations detailed in the Merck Material Safety Data Sheet[30].
- Further acrylamide dilution will occur when one takes into consideration partitioning of the residual acrylamide between the solid/liquid phases
- Working concentrations are below those limits outlined by NRW – *How to comply with your environmental permit.*

Transfer and Degradation of Polyacrylamide-Based Flocculants in the Environment

Polyacrylamide (PAM) is a high molecular weight water soluble polymeric compound widely used in wastewater treatment amongst others. However, due to the large quantities used around the world their fate in the environment is of considerable importance. A review by *Guezennec et al,*.[31] focused on the mechanisms of transfer and degradation of PAM, which can affect both PAM and residual acrylamide monomers (AMD), with a special attention given to the potential release of AMD during PAM degradation. Due to PAM's ability to adsorb onto mineral particles, its transport in surface water, groundwater and soils is rather limited and restricted to specific conditions. PAM can be also be the subject of biological, photolytic, mechanical and chemical degradation. The biodegradation pathway converts PAM to ammonia and polyacrylate with the ammonia being used as a nitrogen source for growth by microbes[32]. The very long retention times in agricultural soil increases the likelihood and degree of both photolytic and biological degradation[33]. *Feng Yu et al,*.[34] report that in their study, biodegradation of PAM did not accumulate acrylamide monomers.

Although some report PAM as being non-toxic to humans, animals and plants[35], its concentration and ionic form will determine its potential as a toxin in fish, where interference with gill function may result in suffocation[36].

In the contrary, the adsorption of AMD onto particles is very low, favouring its transfer in surface and ground waters. Indeed, AMD is highly soluble in water and is therefore highly mobile in the environment. However, AMD transfer is likely to be limited by quick microbial degradation. A number of studies have supported the hypothesis that naturally occurring microbes in soils and water systems can degrade AMD to the non-toxic products – ammonia and acrylic acid[37] which are utilised as sole carbon and nitrogen sources for growth and that in aquatic environments complete degradation of AMD is likely to occur within 2 weeks[37][38]. In addition, *Lande et al*,. reported that the half-life of AMD in agricultural soil was 18-45hrs[39]. Even if AMD is readily degradable in the environment, it is recommended that careful monitoring should be implemented to ensure there is no dangerous release of AMD into the wider environment. AMD can be absorbed via dermal exposure and inhalation and is a known neurotoxin and potential carcinogen[40], therefore care and attention must be used when using these products.

The PAM dose rates used in TFNP are such that the levels of AMD in the final effluent should be below limits set by NRW.

4.0 Reaction Tank Specifications

Blending Process

Much work has been undertaken to better understand the intricacies of the blending process. This is vital to achieve high performance whilst also being cost efficient. Mixing impellers are designed to both pump liquid through the impeller and also to produce turbulence, both of which are essential to achieving a good blend. Pumping produces fluid velocity, whilst turbulence creates fluid shear. Fluid velocity generates movement through the tank, mixing materials together and prevents solids from settling. Fluid shear is important for micro-mixing where fluids are often broken up in to smaller droplets[41]. However, care must be taken as shearing will also break up any flocs that have formed, into smaller particles or even re-solubilise precipitated particulates. The process of flocculation is therefore shear sensitive and requires high flow but low shear mixing, consequently the selection of a suitable impeller for each stage becomes dependent on several process factors including:

- Tank geometry
- Viscosity of the slurry
- Percentage solids
- Type of application (flow and shear requirements)
- Retention time/blend time/contact time needed

Parameters to control in the Reaction Tank

There are several parameters which need to be controlled in order to positively affect the coagulation/flocculation process. These are:

Flow rate – this is inversely proportional to the retention time.

Chemical dose rates - affects coagulation/flocculation efficiency and therefore overall costs

pH – vital for ensuring the correct form of aluminium species is produced during coagulation

Impeller speed – from flash mixing of the coagulant to the low speed needed for flocculation, the impeller speed is a very important factor to consider.

Reaction Tank Specification

Therefore, with the above in mind, in order to increase efficiency within the reaction tank, there are a number of parameters that require careful consideration. These include:

- Density and viscosity of the slurry
- Chemical delivery points
- pH correction
- Ratio of the diameter of the mixer impeller to the diameter of the tank
- Position of the impeller
- Multiple impellers
- Type of impeller
- Mixing intensity/Contact time
- Tank Turnovers required for completed blend/mix
- The use of baffles
- Velocity gradient
- Flow rate

Density and Viscosity

Density and viscosity of the slurry can be determined using % total solids and both are relatively simple to calculate[42]. However, the calculated result should only be used as a guide. How viscous the slurry is will determine the number of tank turnovers that are required to effectively mix the slurry and the chemical conditioner. Typical density and viscosity data can be viewed for a range of total solids content in the table included in the 'Tank Turnover' section. Viscosity plays a pivotal role in blending and can greatly affect the outcome. Density is important in calculating the power drawn by the impeller and should be used to properly size the mixer motor.

Chemical Delivery

The location of delivery points for both the coagulant and flocculant into the reaction tank is an important element to consider. The coagulant should be delivered directly to the most turbulent area of the reaction chamber. This should theoretically be just above/below the tips of the impeller blade. At the correct pH, this will encourage +ve charged metal ions to predominantly form (up to 1 sec after dosing) and promote charge neutralisation of the wastewater particles and therefore destabilisation. If the coagulant is delivered into a less turbulent area, then the predominant species would be a metal hydroxide, which produces greater volumes of sludge by means of 'sweep flocculation'. A solid metal pipe should be included in the tank fabrication to deliver the chemical where needed.

In contrast to the strong turbulence needed for coagulation, the delivery of the polymer flocculant requires more gentle stirring of the tank to allow the polymer to form bridges between coagulated particulate for example. Again, the polymer should be delivered low down in the tank but not so close to the impeller as to cause 'fluid shear'. It is suggested that the polymer should be introduced at two points in the primary reaction tank via metal pipes fitted near the dividing plate between the two chambers. This will allow the polymer to encounter the coagulated material as it enters the chamber from the bottom and permit a greater contact time before travelling up through the tank and exit over the weir at the top opposite side.

pH Correction

pH correction should be included in the design of the tank. At TFNP, both screw press and decanter centrifuge cause a slight increase in the pH of the separated liquid fraction. In addition, the metal salt coagulant lowers the pH of the slurry. The chemical coagulant used to treat slurry at this site works best when the pH is controlled at ~pH6.5. Jar testing should be carried out for each new site to ascertain the best pH for the chemicals specified.

Mixer Impeller Diameter : Tank Diameter Ratio

The ratio of impeller diameter to tank diameter has a direct relationship to blend time. As a guide the ratio should be in the range 0.25 to 0.4 with the primary reaction tank used at TFNP being 0.35 and the DAF reaction tank being 0.65 (mean tank diameter used as rectangular in shape). The low end of the range is used for water like viscosities and increases as the mixture viscosity increases. The position of the impeller in the tank should also be considered. As a guide and depending on the impeller type, a single pitched blade turbine (PBT) type impeller for example should be situated 0.67 x the diameter of the impeller from the bottom of the tank[41]. For a tank similar in dimension to the one at TFNP this would mean a distance from the bottom of 245mm. The impellers at TFNP are set to 400mm from the bottom of each chamber and are standard specification as received from the tank manufacturer – Watermark Projects.

Multiple Impellers

With increasing viscosity and to reduce blend time/power requirement, a second impeller should be considered higher up the shaft (increased torque loading on the shaft/motor may result and would require calculating). The impeller should be no less than 0.6 x the diameter of the impeller below the surface of the slurry and 0.67 x the level of the slurry in the chamber[41]. This would allow stirring of both top and bottom halves of the tank. Originally at TFNP, the flocculation chamber had a single low-level impeller which, when the viscosity increased, only allows for the mixing of the bottom half of the tank. This had the effect of essentially lowering the contact time of the chemical.

Impeller Type

Impellers are usually categorised as being one of two types, axial flow and radial flow. Radial flow impellers have flat blades mounted parallel to the shaft axis and are typically used in flash mixing applications amongst others and would therefore be better utilised in chamber 1 of both primary and DAF reaction tanks. Axial flow impellers have blades which are mounted at an angle of less than 90° to the shaft axis and can further be divided in to constant angle of attack and variable angle of attack and are used for applications such as flocculation and therefore better suited to chamber 2 of both primary and DAF reaction tanks.

All impellers used within the blending processes in TFNP are of the axial flow with constant angle of attack type – as received from the tank manufacturer. They produce a moderate flow through the impeller, but also a moderate shear and are typically used for moderate viscosity mixing. Hydrofoils on the other hand, have a variable angle of attack with high flow rates and low shear. These are positioned relatively high off the tank bottom and are effective at low to moderate viscosities. However, hydrofoils are more expensive to purchase. A 'happy medium' between the above two would be a High-Performance Pitched Blade Turbine impeller.

The removal of solid particulate can often be enhanced through shear-induced flocculation. In their study, *Patrick T. Spicer et al,*.[43] explains that by his process, particles initially grow by coagulation, forming irregular floc structures. As the flocs grow however, they become susceptible to breakage by fluid shear and it is widely accepted that the net flocculation results from a balance between these two. Balemans et al,.[44] confirms this principle. The removal efficiency therefore depends on the structure of the flocs, as this determines the relationship between floc size and density.

Reduced floc density with increasing size can usually be attributed to the incorporation of fluid into the floc structure. These porous flocs collide with one another until shear-induced fragmentation prevents further growth. The growth, breakage and regrowth processes control the development of floc structures and all three occur within the complex shear field of a stirred tank[43].

Fig 4.1: Axial Flow Impeller

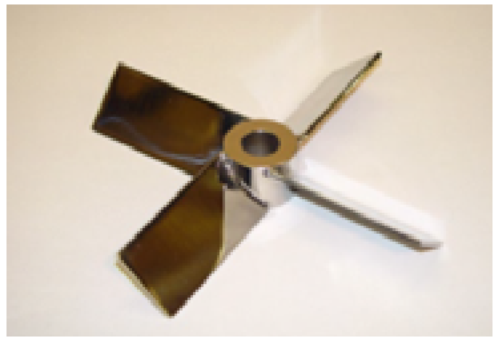


Fig 4.2: Radial Flow Impeller

Courtesy of The Plant Engineers Guide to Mixing and Agitation – Cleveland Mixer

Fig 4.3: Axial Flow Patterns in Baffled Tanks

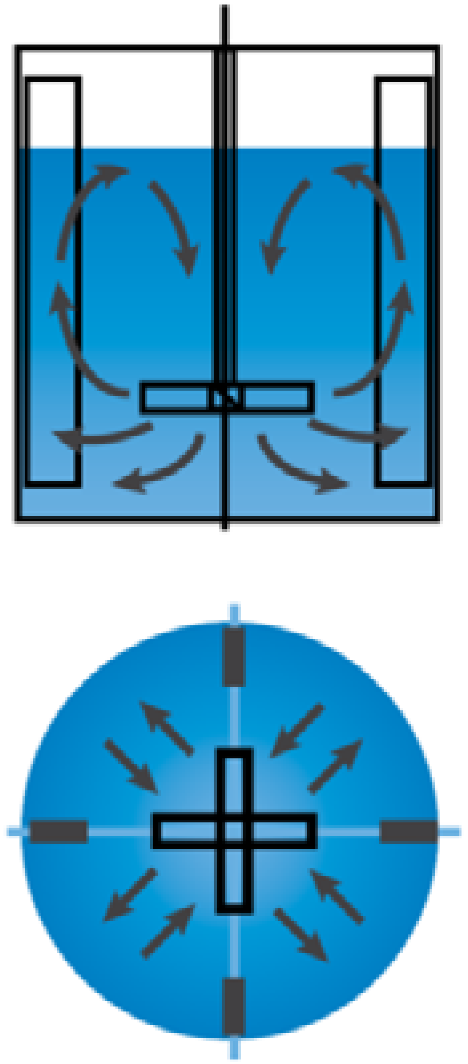
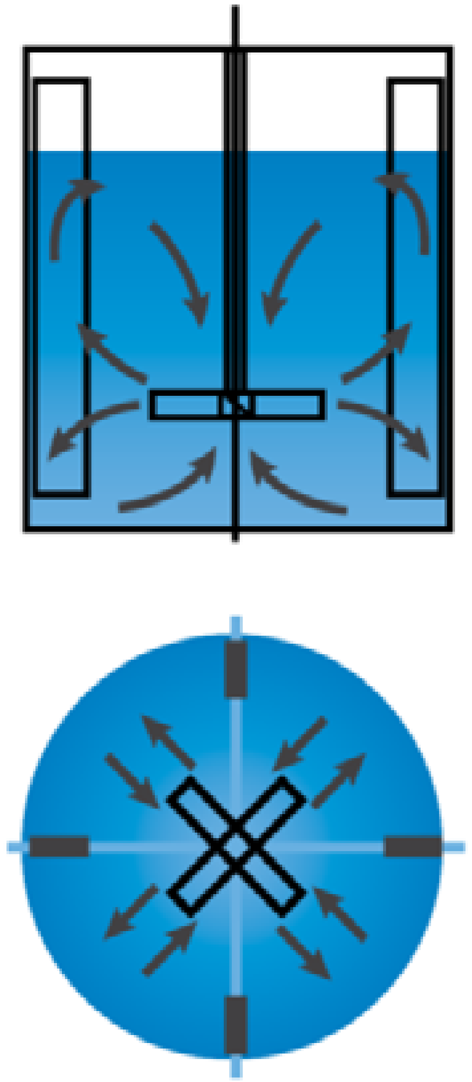


Fig 4.4: Radial Flow Pattern in Baffled Tanks



Courtesy of The Plant Engineers Guide to Mixing and Agitation – Cleveland Mixer

Mixing Intensity/Contact Time

Mixing intensity levels can be determined based on the ratio of the maximum viscosity component (i.e. slurry): minimum viscosity component (i.e. chemical conditioner) and the difference in the specific gravity (SG) of both components:

SG of slurry @4%TS = 1.02 kg/l
SG of PAC = 1.36kg/l
SG of anionic PAM = 1.05kg/l (as received)

This can broadly be used to class mixing intensities. For PAM, this would be mild/moderate and for PAC this would be moderate/strong. The number of tank turnovers required to completely mix the chemicals into the slurry heavily depends on the viscosities of each of the components. The following are taken from that used at TFNP as an example:

Viscosity of slurry @4% TS =~420cP (centipoise)
Viscosity of PAC @20 degrees C = 30cP
Viscosity of PAM (0.2%) @20 degrees C = ~5-15cP

For the effective mixing of PAC, a moderate-strong mixing intensity is required based on the relative viscosities resulting in a blend time of ~1-2mins at 4%TS. For the mixing of PAM, a mild to moderate mixing intensity is needed resulting in a blend time of ~30-60mins at 4%TS.

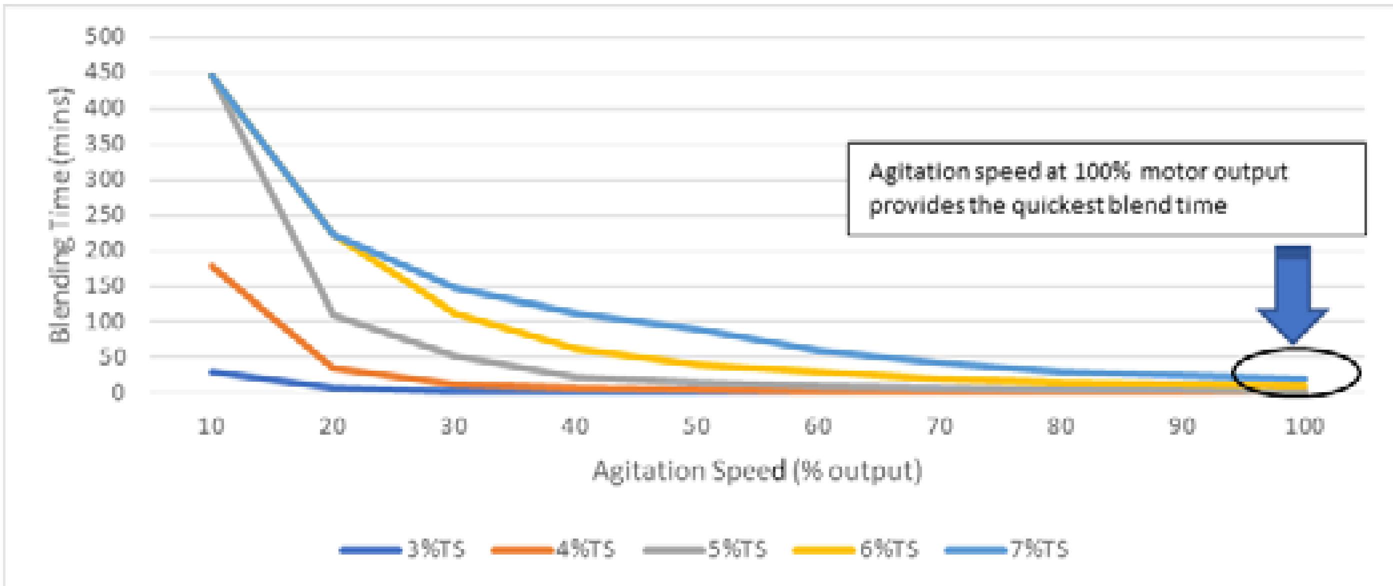
Tank diameter 1m : impeller diameter 0.44m
(primary reaction tank)

Table 4.1: Calculated Blending Time for Flash Mixing Coagulant

	Calculated Blending Time Required for Coagulation Flash Mix (minutes)									
	Agitation Speed (% output)									
%TS	10	20	30	40	50	60	70	80	90	100
1	2.9	1.4	0.9	0.7	0.5	0.4	0.4	0.3	0.3	0.3
2	6.7	2.4	1.4	1	0.8	0.6	0.5	0.4	0.4	0.4
3	29.4	7.1	3.3	2.1	1.5	1.2	1	0.8	0.6	0.5
4	178	35.6	11.9	6.7	4	2.7	2	1.6	1.3	1.1
5	445	109	53.4	22.3	14.2	10.4	6	4.7	3.7	2.9
6	445	222.5	111.3	61.2	40.1	29.7	19.1	13.9	11.1	8.9
7	>445	>222.5	148.3	111.3	89	59.3	41.3	30.6	25.7	20
8	>445	>222.5	>148.3	>111.3	>89	74.2	63.6	55.6	49.4	35.6
9	>445	>222.5	>148.3	>111.3	>89	>74.2	>63.6	>55.6	>49.4	44.5
10	>445	>222.5	>148.3	>111.3	>89	>74.2	>63.6	>55.6	>49.4	>44.5
Gr =	13.19	26.39	39.55	52.78	65.98	79.17	92.37	105.56	118.76	131.96

Optimum coagulation observed with slurry at 4%TS in the reaction tank is when power output was at 100%; therefore, a Gr value of ~132sec^{-1} and a retention time of 1.1min. Calculated values should be at doubled to ensure enough contact time with the chemical. Higher Gr values may be more effective but the available equipment only allowed a maximum Gr = 132sec^{-1}.

Chart 4.1: Correlation Between Blending Time and Agitation Speed for Flash Mixing of Coagulant



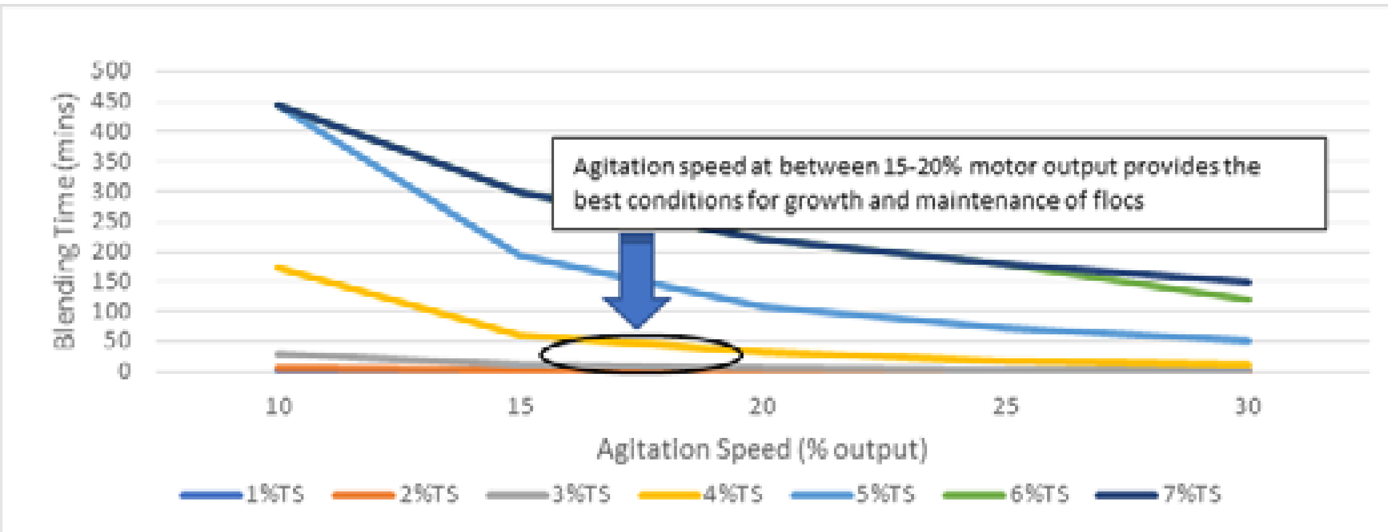
Gr Value = 132sec-1 (maximum motor output)

Table 4.2: Calculated Blending Time for Flocculation

%TS	Calculated Blending Time Required for Flocculation (minutes)				
	Agitation Speed (% Output)				
	10	15	20	25	30
1	4.9	1.9	1.4	1.1	0.9
2	6.7	3.7	2.4	1.8	1.4
3	29.4	11.9	6.7	4.6	3.3
4	173.6	59.5	33.4	17.8	11.9
5	445	193.3	109	71.2	51.9
6	>445	297.4	222.5	178	118.7
7	>445	>297.4	>222.5	>178	148.3
8	>445	>297.4	>222.5	>178	>148.3
9	>445	>297.4	>222.5	>178	>148.3
10	>445	>297.4	>222.5	>178	>148.3

Optimum value through observation with slurry at 4%TS in the reaction tank is when power output was at ~15-20%; therefore, a Gr value of ~18-24sec^{-1} and a retention time between 59.5 - 33.4min. It is advised that calculated values should be at least doubled to ensure enough contact time with the chemical.

Chart 4.2: Correlation Between Blending Time and Agitation Speed for Flocculation



Gr Value = 18sec^{-1} - 24sec^{-1}

Tank Turnovers

The viscosity of the slurry can have a significant impact on the overall mixer sizing. The theoretical tank turnovers for a range of slurry viscosities is given in Table 4.3:

Table 4.3: Physical Properties of Cattle Slurry at Varying %TS

%TS	Bulk Density	Dynamic Viscosity		Specific	Tank
	kg/m3	Pa.s	cP	Gravity	Turnovers
1	1012	0.000863	0.863	1.015	10
2	1019	0.0191	19.1	1.022	15
3	1023	0.117	117	1.026	20
4	1022	0.422	422	1.025	40
5	1018	1.144	1144	1.021	70
6	1009	2.583	2583	1.012	125
7	998	5.143	5143	1.001	185
8	983	9.338	9338	0.986	250
9	965	15.804	15804	0.968	N/A
10	944	25.304	25304	0.947	N/A
Water	997	0.00086	0.86	1	N/A

Slurry parameters based on % Total Solids derived from Landry et al,.[42]

Baffles

Baffles may be required to help prevent vortexing and swirling in the tank chambers and better promote turbulence, in particular chamber 1, where a strong 'flash' mix is required. Increasing the impeller speed without the use of baffles may counter-intuitively, adversely affect mixing. This will again depend on viscosity and the number of tank turnovers needed.

Velocity Gradient (G value)/Compensated Velocity Gradient (Gr value)

The velocity gradient (G value) is described in fluid mechanics as a measure of how the velocity of a fluid changes per unit distance. **The velocity gradient equation is given as:**

G = (Power/Dynamic Viscosity x Tank Volume))1/2

Where:
Power = Watts or Joule/sec or N m/S
Dynamic Viscosity = Ns/m2
Volume = m3

It can be helpful when transferring mixing parameters from lab based 'jar tests' to that of the scaled-up reaction tank. In addition to the velocity gradient, the compensated velocity gradient also takes into consideration the tank/impeller dimensions[45].
The Compensated Velocity Gradient is given as:

$$Gr = ((Power/(Dynamic\ Viscosity \times Tank\ Volume))^{1/2})x(Di^2/Dt^2)$$

Where:
Di = impeller diameter (m)
Dt = tank diameter (m)

Through observing floc characteristics, the calculated Gr value for the effective mixing in of PAC into 4% TS slurry is around ~132sec^{-1} (maximum at 100% motor power output), although others have described a higher value of between 300 – 390sec^{-1} - and that of PAM is between

~15 -20sec^{-1}.

Other important parameters such as the correlation between the Power Number and Reynolds Number, Mixer Motor Sizing, Torque, Power and Pumping Capacities, should also be considered when specifying a reaction tank.

Flocculation impeller tip speed is important because of its potential effect on shearing. The optimal tip speed in relation to floc characteristics was calculated to be 0.5 m/s.

Flow Rate

The flow rate is determined by the retention time needed in order to correctly mix the chemicals in to the slurry. In the reaction tank flocculation chamber, the growth of flocs has a greater time dependency than that of the coagulation chamber and therefore governs max throughput of the process.

Floc Structure

The optimum pH for the coagulation/flocculation process must be determined experimentally and would be specific to each farm, depending on slurry percentage solids, which chemicals are used, the quality of the separated water desired and its end use.

Observations indicate that there is a negative correlation between the floc porosity and the density. At pH7-7.5 the flocs form more compact aggregates that tend to settle, whereas at pH6-6.5 the flocs formed will tend to split into 2 regions:

- denser flocs which settle as compact aggregates
- less dense floc which float as softer, airier aggregates

The dense flocs are easier to separate in the decanter centrifuge due to gravitational force and the less dense flocs are easier to separate in the DAF. It is thought that some of the less dense flocs formed in the reaction tank remain in suspension and are only partly removed by the decanter centrifuge. Maintaining pH>7 in the reaction tank should yield better results from the decanter. Reducing the pH in the DAF to pH~6.3 would allow more of the suspended solids to float.

Over time, as water molecules infiltrate the floc structure and porosity increases, the flocs will become less dense and float, even at the higher pH range.

Reaction Tank Modifications Completed at TFNP - Gelli Aur

During the course of the project and to better facilitate the chemical blending process, a number of modifications were made to the primary reaction tank as outlined below:

- Automated pH correction to maintain pH between 6.0 and 6.6 in primary reaction tank
- Slow stirring of the 3rd outlet chamber to keep the solids in suspension and prevent stratification. This will better aid decanter performance as the feed will be more stable and therefore the decanter centrate and solid cake more consistent. Removing the dividing plate between chamber 2 and chamber 3 may result in incomplete mixing of the coagulated material with the polymer flocculant, as the inlet and outlet points would both be on the bottom of chamber 2. Currently the inlet point is at the bottom of chamber 2 and the outlet is across the weir at the top, allowing more chemical contact time.
- An increase in the height of the weir plate in chamber 1 of the primary reaction tank. Some backflow from chamber 2 into chamber 1 has been seen in the reaction tank at Gelli Aur. This would eventually be realised by an increase in the level of slurry in chamber 1 with an overall decrease in flowrate into chamber 2. Increasing the height by 100mm has prevented this from happening. As every farm will be slightly different it is suggested that an adjustable height plate should be specified/be made standard.
- Additional impeller retrofitted to the mixer shaft in chamber 2 of the primary reaction tank.
- Chemical delivery points upgraded on both primary reaction tank and DAF reaction tank to increase contact time and the mixing in of flocculant

5.0 The Effect of Mechanical Separation and Chemical Dewatering on Gaseous Emissions

In 1999, the agricultural sector in Wales was set a target by Welsh Government to decrease its GHG emissions by 28% by the year 2030, whilst also reducing NH_3. This is a considerable task, with over 20% of Wales' entire NH_3 emissions originating from manure management alone. Coupled with other environmental legislation, principally The Water Resources (Control of Agricultural Pollution) (Wales) Regulations 2021, there is growing need for technologies which help support effective nutrient management, and alleviate the environmental impacts associated with unsustainable practices. Therefore, the implementation of any solution must be pragmatic and holistic in approach, following a cradle-to-cradle design to best promote principles of sustainability in Welsh agriculture, and conserve Wales' natural resources.

Its principle benefit is to increase storage capacity on farm, consequently concentrating the nutrients into a 'stackable' solid fraction which is easier to handle and apply on field, and a liquid fraction which may be suitable for further wastewater treatment or fertigation. Nevertheless, there is no study within the literature alluding to the effects that a combined mechanical separation and chemical dewatering process has on dairy slurry emissions during storage and/or application. During storage, mechanical separation has been shown to increase nitrogen losses up to 86%[46] (note that this study used anaerobically co-digested slurries). Of this, over 90% of the total ammoniacal nitrogen content was lost from the solid fraction, whereas 31-35% was lost from storing the liquid fraction. These losses are assumed to have predominantly occurred as NH_3, and similar results are also reported by *Petersen & Sorensen (2008)* when separating pig slurry[47].

Perhaps the most similar in experimental design is a study of the use of a combined separation process (screw press + chemically enhanced settling using polyacrylamide - PAM) to treat dairy slurry in South West England[48]. The authors observed no significant difference in grass dry matter (DM), except from fractions which underwent composting, and a small increase in CH_4 was recorded. Conversely, *Amon et al*. found that slurry separation reduces GHG emissions, but is likely to result in an increase in NH_3 emissions[49], mainly due to the composting process. GHG emission were only reduced when composting was incorporated, avoiding the creation of anaerobic zones where CH_4 and N_2O are typically formed. Interestingly, upon application, slurry DM content is thought to enhance NH_3 losses. This would explain the functioning behind slurry dilution which can more rapidly infiltrate into the soil and therefore, reduce NH_3 losses (although significant effect is only seen if the water-slurry ratio is 2:1 and over)[50].

Separation and acidification, technologies are thought to decrease certain environmental impacts, with *Ten Hoeve et al*,. finding in-house slurry acidification to be the most beneficial scenario under both N and P regulations. In light of these findings, the authors conclude by debating whether emission savings due to acidification and separation are worthwhile monetary investments[51]. This is further supported by *Sommer et al*,.[52] stating that the expense of these technologies (alongside the associated costs such as operating, training, labour, and maintenance) will often not be matched by savings from a more efficient use of the slurry (e.g. cost savings on the purchase of mineral fertilisers and from increased yields). Nevertheless, future regulations may oblige farmers to alter their slurry management and introduce such technologies in Wales. Therefore, a financial feasibility study would need to be conducted within this context.

The formation of CH_4 and N_2O during storage can only be avoided if a sufficient oxygen supply is present, although this does little to negate the increase in NH_3 emissions from slurry separation (compared to untreated slurry). In consideration of the literature, it is important we determine what stage significant GHG and NH_3 emissions occur so that mitigation strategies can be recommended/implemented. Composting of the solids within the store would seem the most effective option in terms of GHG reduction. To some, it may appear that mechanically separating (and any subsequent dewatering of dairy slurry) would actually have more of an environmental impact, than effective storing/spreading of untreated slurry. Analogous to recent conclusions drawn by others[53], the precautionary principle should be adopted until a comprehensive Life Cycle Assessment (LCA) underpins any potential benefit/drawback of these technologies. This is especially important within the context of dairy slurry given the sectors' size and current environmental impact (with mechanical separation, in particular, demonstrated to almost double total NH_3 emissions than untreated slurry).

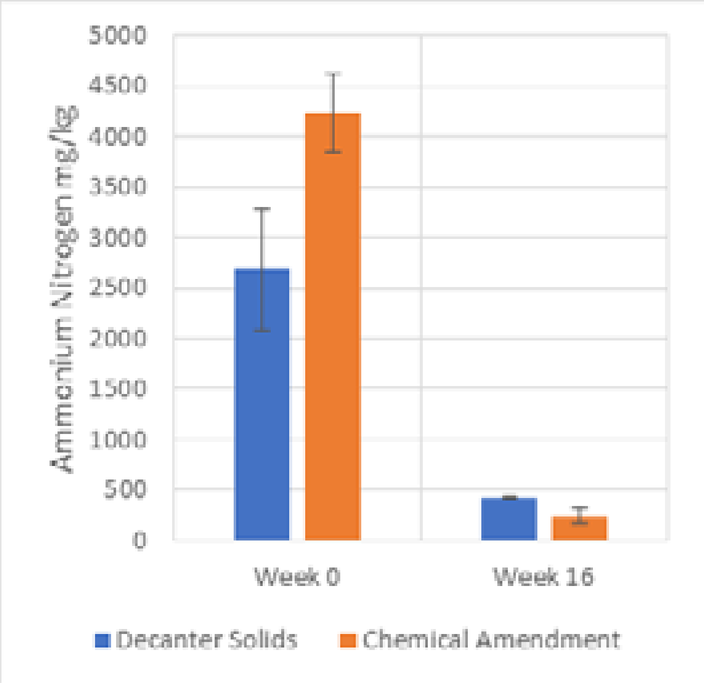
The incorporation of slurry acidification is becoming increasingly common practice, especially on the continent, and its efficiency with regard to the minimization of NH_3 emissions has been documented in many studies. Acidification has a number of benefits such as enhancing the fertilizer value of slurry, principally through the retention of N but also the supplementation of Sulphur (S). An extensive review by *Fangueiro et al*. [44] (2015) suggests that the combination of solid-liquid separation and acidification may not be compatible technologies. This is primarily highlighted by acidification causing dissolution of nutrients, thus, the concentrations of P, Mg, Ca, Cu, and Zn increased in the liquid fraction. Additionally, an increase of dry matter (DM), volatile solids, and protein was also observed in the liquid fraction from acidified slurry than in the control slurry. This has been explained by a more-rapid separation, causing flushing of nutrients to the filtrate or providing less time for settling of small particles upon centrifugation [45,46]. Therefore, acidification may lead to the loss of nutrient through a 'more concentrated' liquid fraction, than compared to separation alone.

Excluding subsequent dewatering, the combination of mechanical separation (such as a screw press) and acidification of the filtrate may be one approach in reducing the bulk volume needed for storage/spreading whilst simultaneously reducing NH_3 losses. Furthermore, the inclusion of a plasma-treatment unit (N2- Applied) may replace the need for stand-alone acidification, although further testing is needed to discover when it is best applied. Preferably, it would be beneficial if this was incorporated pre-separation (leading to greater nitrogen enrichment) whilst also acidifying both the solid/liquid fractions. There is some support for the idea that total N_2O emissions could be decreased by > 30% after soil application when in-house acidified slurry is separated [47]. In contrast, *Ten Hoeve et al.* [41] notes an increase of 30% compared to untreated slurry (the total N_2O emission after field application of non-acidified slurry was 0.43 kg N_2O or 128 kg CO_2e. For the liquid fraction of in-house acidified and separated slurry it was 0.43 kg N_2O, and for the solid fraction it was 0.13 kg N_2O, resulting in total N_2O emissions from the in-house acidified and separated fractions of 0.56 kg N_2O or 166 kg CO_2e).

Therefore, it is important to distinguish when/how acidification technologies are applied, as this can have converse effects in terms of the overall global warming potential of this technology. It has been reported that in the European Union, field acidification creates 24kg CO_2e, whereas in-house acidification produces some 14kg CO_2e, which differs only slightly to no acidification at 17kg CO_2e in the EU-28 (UNECE, 2016; UNFCCC, (2016)[58]. This suggests that field acidification only decreased NH_3 emissions during and shortly after field application, and actually has a higher Global Warming Potential (GWP) than non-acidified slurry. Whilst a lot more research has been conducted into acidification than separation/dewatering technologies, contrasting findings suggest that the effects of acidification are context specific (abiotic conditions), although the common consensus suggests that acidification does generally reduce gaseous emissions. Nevertheless, evidence regarding the suitability of acidification within a separation process suggests it may be unfavourable.

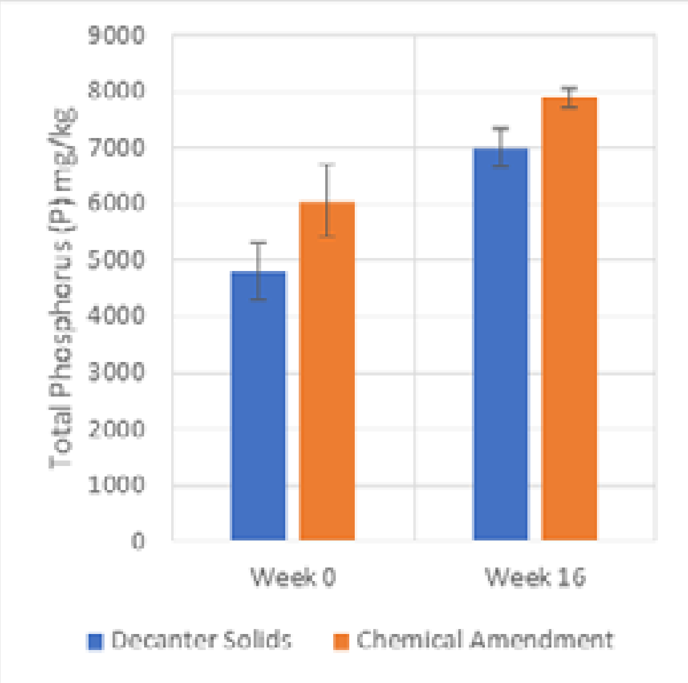
During the course of TFNP and as an aside, but relevant to the main project aims, samples were taken in order to investigate if chemical amendments have an effect on nutrient concentrations within the separated solid fractions and how this might change with time. Raw slurry was compared with separated solids from the decanter centrifuge and also decanter solids with chemical amendment. Samples were taken at t=0 and t=16 weeks. Charts 5.1-5.9 below highlight the trial results:

Chart 5.1: Change in Ammonium Concn Over Time



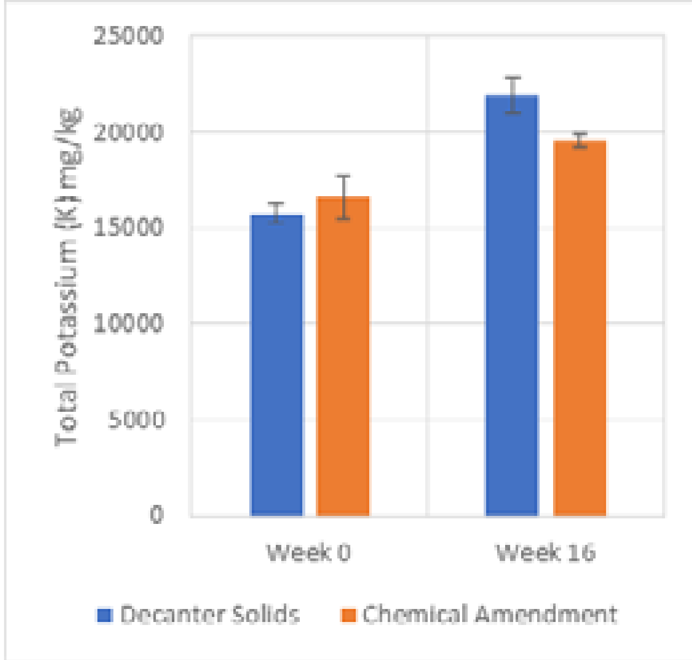
Chemical amendment led to a significant increase in the concentration of nitrogen (as ammonium) in week 0 (p= < 0.05). However, both parameters saw a marked reduction at week 16 when compared to week 0.

Chart 5.2: Change in Total Phosphorus Concn Over Time



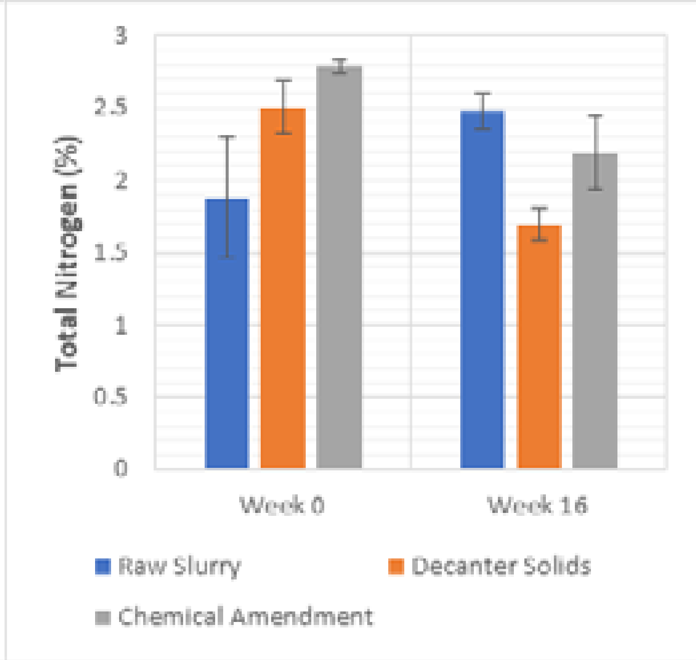
Chemical amendment led to a significant difference in Total Phosphorus (TP) concentration both in week 0 (p= < 0.05) and week 16 (p= < 0.05).

Chart 5.3: Change in Total Potassium Concn Over Time



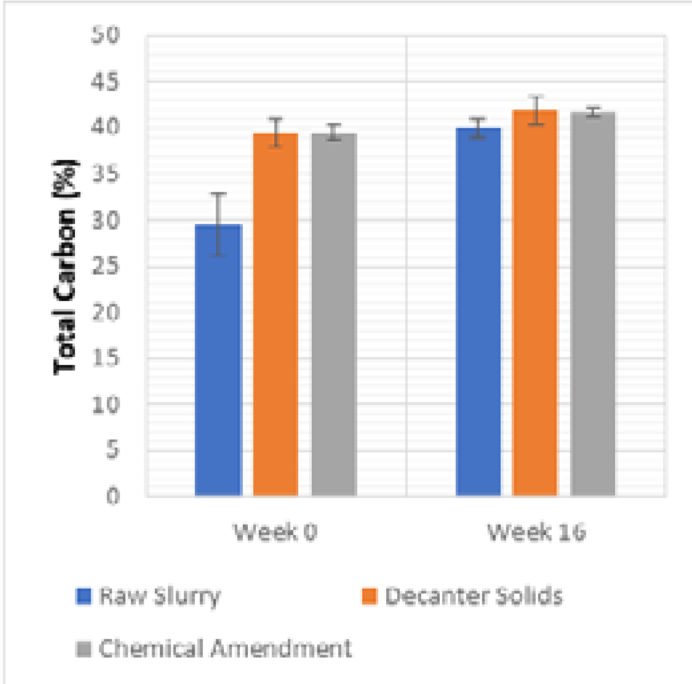
Chemical amendment led to an insignificant increase in Total Potassium (TK) concentration in week 0 (p= > 0.05), but a significant reduction was found at week 16 (p= < 0.05)

Chart 5.4: Change in Total Nitrogen Concn Over Time



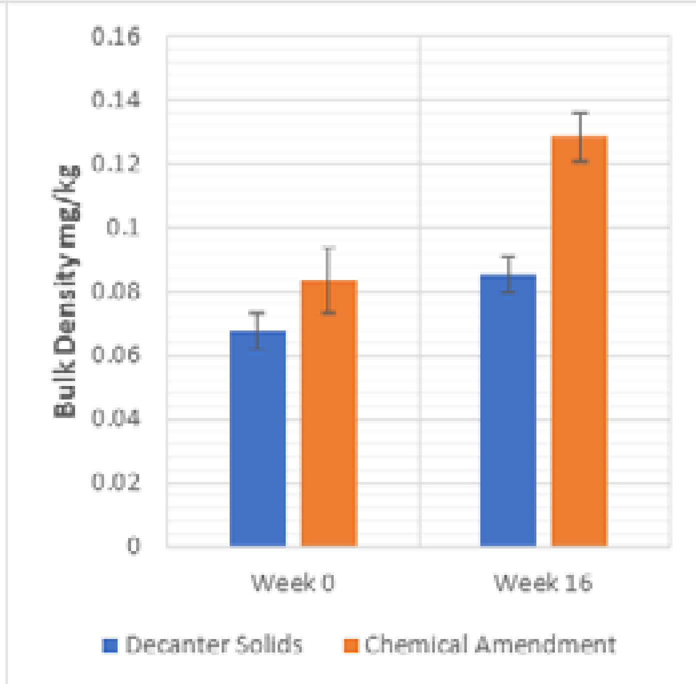
Raw slurry was found to have more nitrogen in week 16 compared to other parameters This is contrary to week 0, where the chemical amended slurry had the highest values.

Chart 5.5: Change in Carbon Concn Over Time



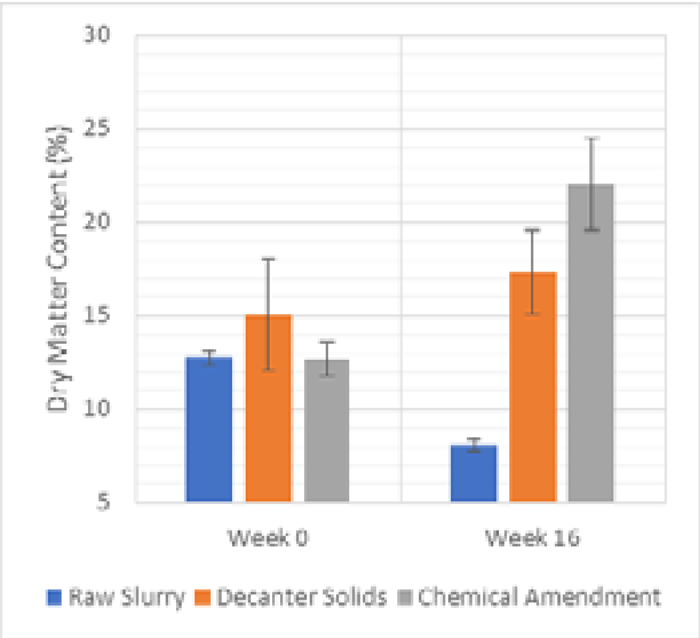
While there was little variation in the chemical amended slurry after 16 weeks, all three parameters saw an overall increase in total carbon.

Chart 5.6: Change in Bulk Density Over Time



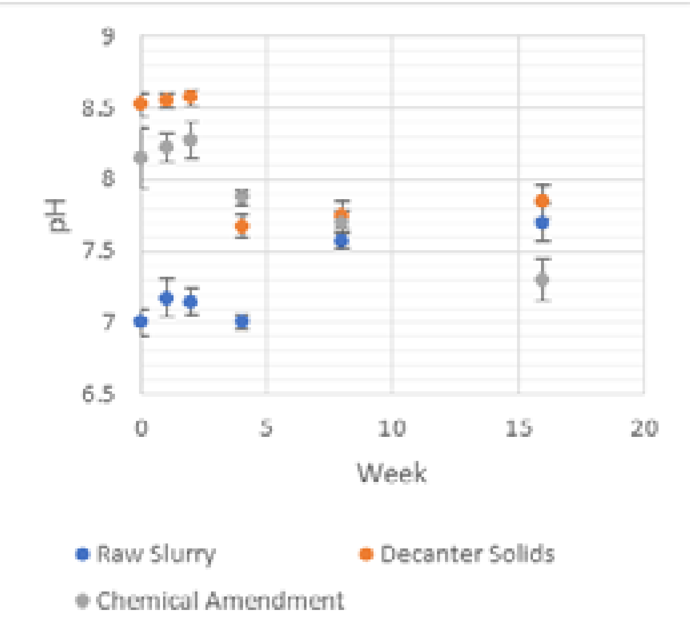
Bulk density was higher in the chemical amended slurry at both week 0 and week 16 suggesting the likelihood of maximising storage capacity.

Chart 5.7: Change in Dry Matter Over Time



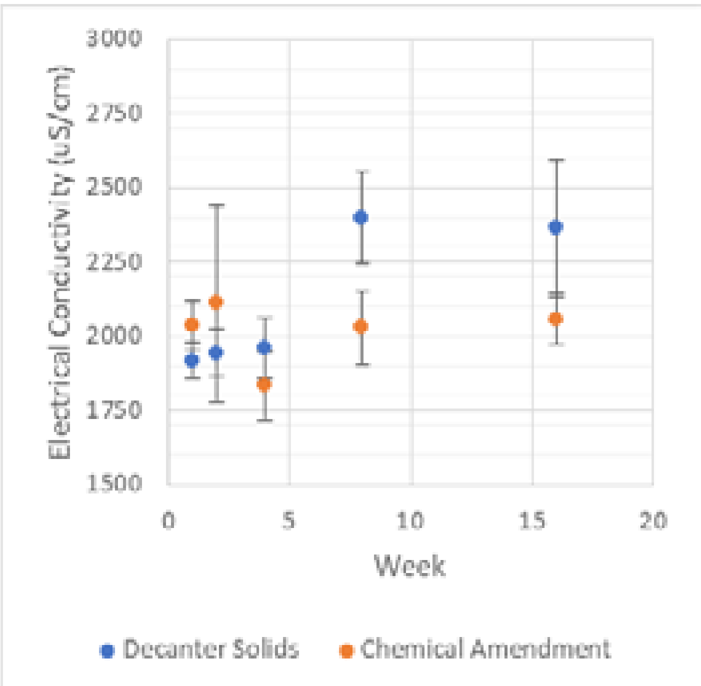
A significant increase in dry matter was seen for both decanter solids and chemical amended slurry after 16 weeks (p= < 0.05). However, there was a significant decrease in dry matter content of the raw slurry over the same timeframe.

Chart 5.8: Change in pH Over Time



Measurements indicate that the pH of both the decanter solids and chemically amended slurry decreases over time, while that of raw slurry increases.

Chart 5.9: Change in Electroconductivity Over Time



Measurements suggests that chemical amendment has little effect upon EC, whilst the decanter solids show an overall increase in conductivity over time.

6.0 Advanced Electrochemical Oxidation Process (AEOP)

The use of AOP is a promising alternative for the treatment of anthropogenic recalcitrant pollutants in process water and wastewater. These processes rely on generating hydroxyl free radicals (•OH) which are powerful oxidants that mineralize pollutants found in wastewater[59]. There are a number of means of generating •OH. TFNP project partners Power and Water focussed on use of electrochemical methods – Advanced Electrochemical Oxidation Processes (AEOP), including electrochemical and sono-electrochemical technologies in the treatment of ammonia and COD in particular.

AEOP generates these reactive radical species through the electrolysis of water. Anodes with specialised Mixed Metal Oxide (MMO) coatings, usually containing transition metals are often used, although alternative anodic materials have been investigated, with some showing great treatment potential (e.g.BDD)[60].

AEOP's are commonly divided into two groups depending on the location of the predominant mechanism of oxidation:

- Active. Reaction occurs on the surface of the anode – can promote the formation of stable oxidants.
- Non-active. Generates highly oxidant species e.g. H_2O_2, O_3, •OH, and reactions can occur away from the surface of the electrode in the bulk liquid.

Samples of the DAF subnatant were determined as being the best opportunity for treatment of both ammonia and COD and were first assessed to obtain a baseline composition. The samples were treated using EAOP with Power and Water bench top Soneco® reactor. Tests were completed at a range of doses, using two different anode materials, one in the active range and one in the non-active range. The pH was adjusted in a number of samples to examine its influence (see Appendix for further information).

There was no consistent performance shown for either ammonia or COD removal rates using the active MMO. The non-active MMO electrode however, demonstrated a greater COD removal rate (≤23.5%) compared to the active MMO electrode (≤17.5%). The non-active MMO electrode achieved a maximum ammonia removal rate of 9.2%.

7.0 Constructed Wetland

Commissioned in Spring 2021, the constructed wetland (reed bed) is an engineered system that uses natural ecological processes of plants and microorganisms (biofilm) to remove a number of pollutants (including pathogens, nutrients, and heavy metals) and reduce chemical/biological oxygen demand (COD/BOD). They have been used in traditional farm management for decades, however, what makes this design different from a standard system is the inclusion of forced aeration and the division into open water and closed gravel cells.

In order to achieve operational flexibility, the design allows the operator to adjust the flow, air supply and more importantly, provide cells will different and alternating oxygen and flow characteristics. In order to break down the contaminants, the dominant technique is to add oxygen (air - which contains about 20%) and to allow time for bacteria to breakdown the target compounds. Oxygenation somewhat also reduces the oxygen demand of the effluent by virtue of reacting with contaminating compounds prior to any discharge to receiving waters, reducing the risk of eutrophication.

However, in order for the decomposition process to be fully effective, the system needs to have both aerobic and anaerobic regions. This is particularly important to enable both nitrification and denitrification to take place. In addition, this process needs to alternate to allow successive partial reductions in contaminant concentrations to take place. This effect cannot be achieved in a single block aerated reed bed and consequently a sequential reaction system was designed that provides advanced operational flexibility and control.

The system is linear and contains cells with gravel fill, surmounted by reeds, and open water ponds. The design allows direct and easy access to the aeration system diffusers via the open water sections and allows ongoing adjustment of the air flow within each region, thus enabling the creation of oxygen rich (aerobic) and oxygen depleted (anaerobic) zones. The linear design forces the water to travel through each zone, thus overcoming the channelling issues that face most normal reed beds.

Some of the open water zones have aeration diffusers at the base of them. These cells are deigned to act as mixing zones which ensure that the effluent is homogeneous before passing into the next cell. This again overcomes the inherent issues faced by traditional reed beds, where there is no control over the direction of flow and little that can be done if the effluent chooses a channel through the bed which avoids active treatment.

The overall design provides 3 trench cells each 4m wide at the base, 100m long with a treatment depth of 0.7m. An approximation of the layout is provided in Figure 7.1. This provides a cross sectional area of just over 2.8m^2 and a total treatment volume of 840m^3.

Within each of the 3 treatment channels, 3 separate gravel treatment zones, each 20m long were included. The gravel beds are planted with reeds translocated from other naturally occurring reedbeds on the farm. This equates to a gravel bed volume of 540m^3 and a clear pond volume of 300m^3. The effluent entry point to the wetland comprises a 10m section without gravel. This part of the channel allows initial aeration followed by phosphoric acid dosing if required and sludge settlement.

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To enable full treatment of the effluent, chemical balancing may be required. Phosphoric acid (as a minimum) may be dosed to balance the phosphate concentration, an ingredient that is essential to conversion of the contaminants by the living bacteria within the facility.

When treated, the wastewater generates organic sludge. Whilst this can be accommodated within the wetland, too much sludge will blind the bed and make it impermeable, rendering it unfit for purpose. To avoid this, a sludge settlement zone was incorporated at the start of the system which can be easily maintained in the future to generate a solid that can be spread on land as an organic fertiliser.

Fig 7.1: Schematic Diagrams of the Constructed Wetland

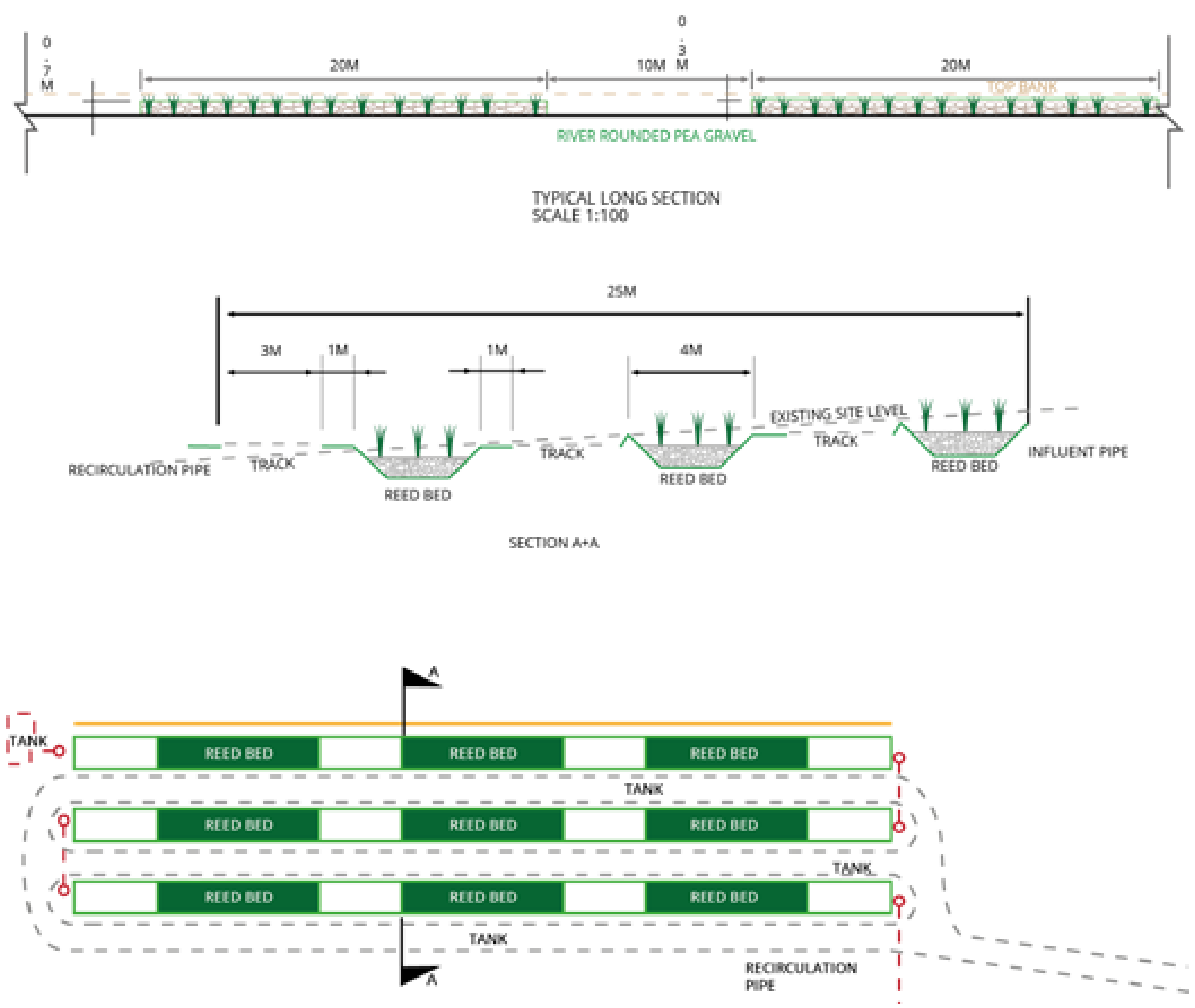
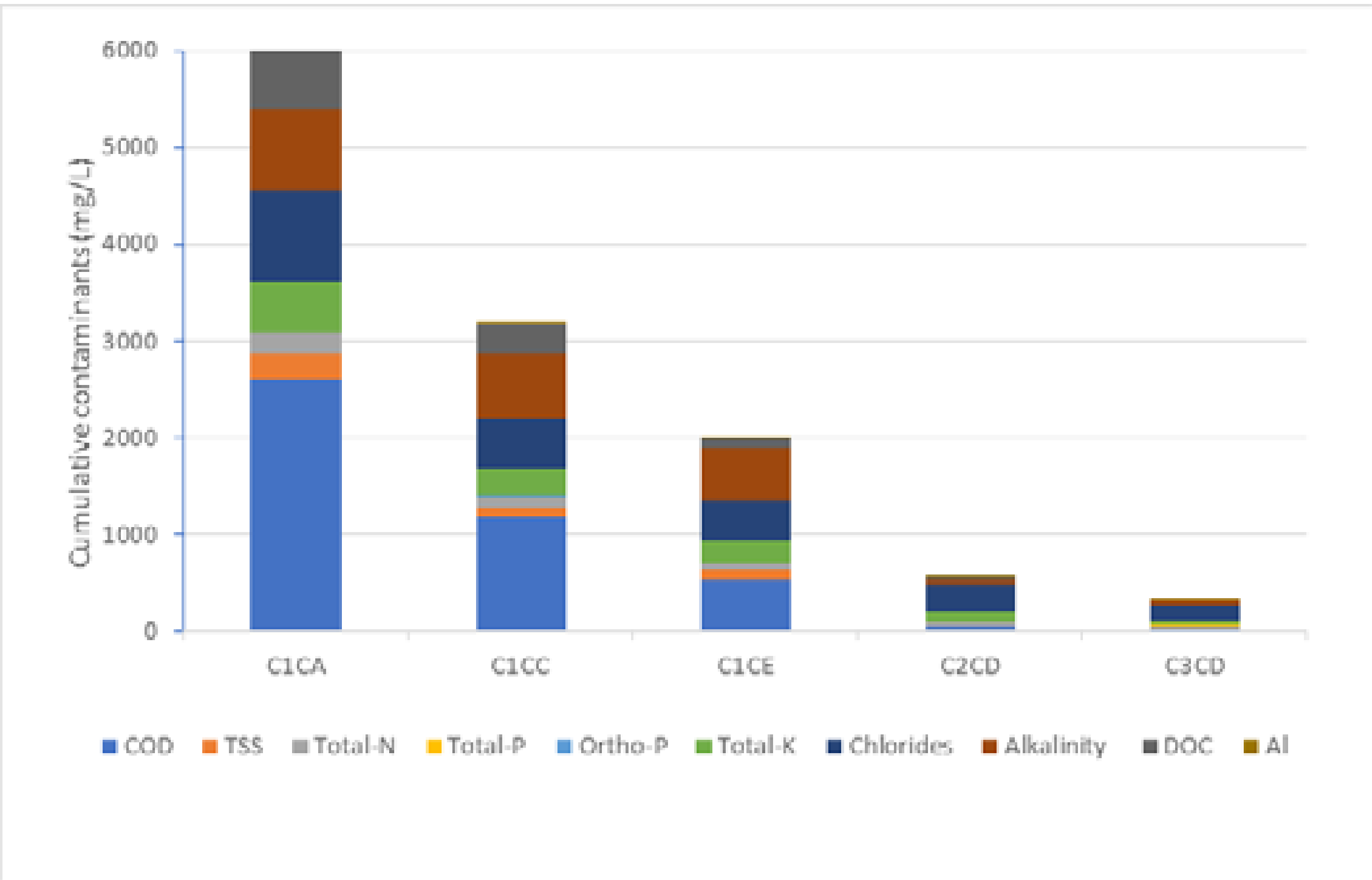


Fig 7.2: Photograph of Constructed Wetland Showing Individual Channels and Air-pump Hides

Chemical Analysis

Samples from the wetland were taken periodically at the inlet (influent) and outlet (final effluent) and analysed for the three macronutrients, Nitrogen (including ammonium, nitrites and nitrates), Phosphorus (including Ortho-P) and Potassium as well as pH, COD, BOD, TSS, Chlorides, Alkalinity, Aluminium and DOC

Chart 7.1: Cumulative Contaminant Concentrations Through Progressive Wetland Cells Where Cell C1CA is the Inlet and Cell C3CD is the Outlet.



Contaminant Reduction Rates

The contaminant reduction rates seen within the constructed wetland – from influent through final effluent can be seen in Table 7 .2.
The mean percentage reduction in determinand concentration was calculated as follows:

$$\% \text{ Reduction} = \frac{Cin - Cout}{Cin} \times 100$$

Where:
Cin = concentration in the influent (mg/l)
Cout = concentration in the effluent (mg/l)

Positive values indicate a decrease in concentration
Negative values indicate an increase in concentration

Table 7.2: Contaminant Reduction Rates

	Mean Reduction Rates (%) Between Influent and Final Effluent						
	BOD	**COD**	**Ammonia**	**Ortho-P**	**TSS**	**Nitrate**	**Nitrite**
Reduction Rate %	99.55	98.93	99.63	90.25	97.43	-3366.29*	13.87
p	<0.01	<0.01	<0.01	<0.05	<0.01	<0.01	>0.05

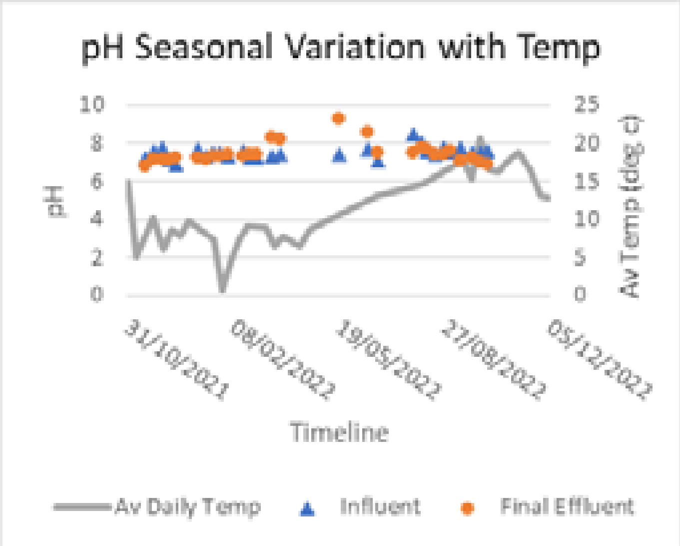
**Result indicates mean removal rate for the period (between July 2021 – September 2022). However, annually the results can be clearly divided between higher nitrate values in the final effluent (79.25mg/l) compared to the influent (0.5mg/l) up to June, when it is thought ammonia (influent 327.6mg/l; final effluent 1.2mg/l) was being converted to nitrate but not yet readily utilised by plants. From June the nitrate in the final effluent is reduced at a time which coincided with a significant growth of flora observed. Overall there was no significant difference between the nitrite levels in the influent and that recorded for the final effluent.*

Several UK water utility companies state that the United Kingdom and European standard for the concentration of nitrate in drinking water for human consumption is 50 parts per million (50 mg/l). The final effluent from the constructed wetland had a mean value for nitrate = 34.95mg/l with a standard deviation = 46.94. The data indicates that for the first 6 months of 2022 the nitrate levels were high (up to 130mg/l) and far above both the acceptable level for drinking water and the discharge consent level for Total Nitrogen (15mg/l) set by NRW. However, in July there was a marked reduction in nitrate concentration (down to <0.3mg/l) and it remained very low at the point of compiling this report.

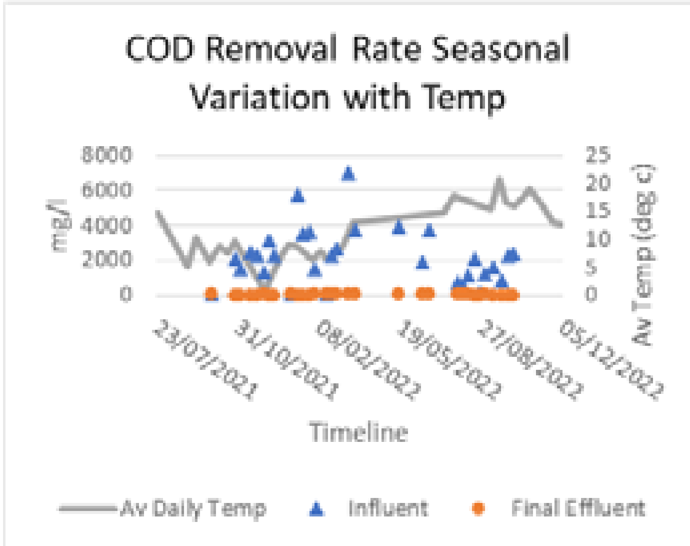
Effect of Temperature

Seasonal variations in wetland performance may prevent year-round contaminant removal. With reed growth and nutrient requirement all but stopping over the winter months. This perhaps, is the view of many, therefore it was an important task to monitor wetland removal rates over all seasons and varying temperatures. The results are shown in Charts 7.1-7.11.

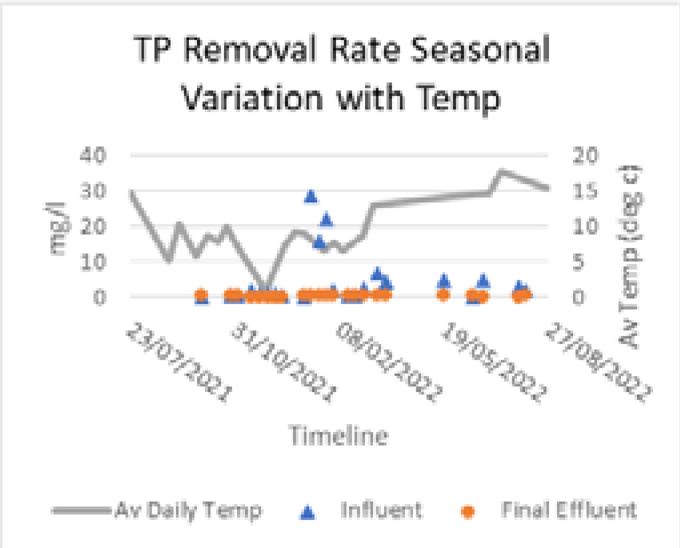
Charts 7.1- 7.11: Contaminant Concentration Reduction in Relation to Average Daily Ambient Air Temperature



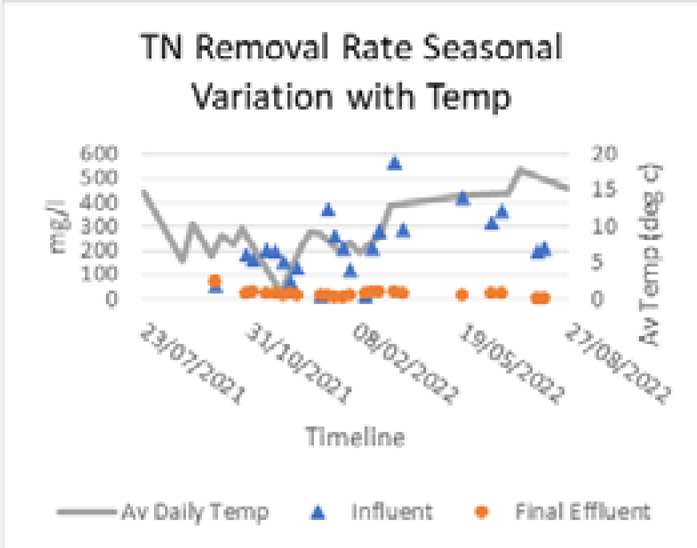
pH TTEST p <0.01 ; r = 0.37



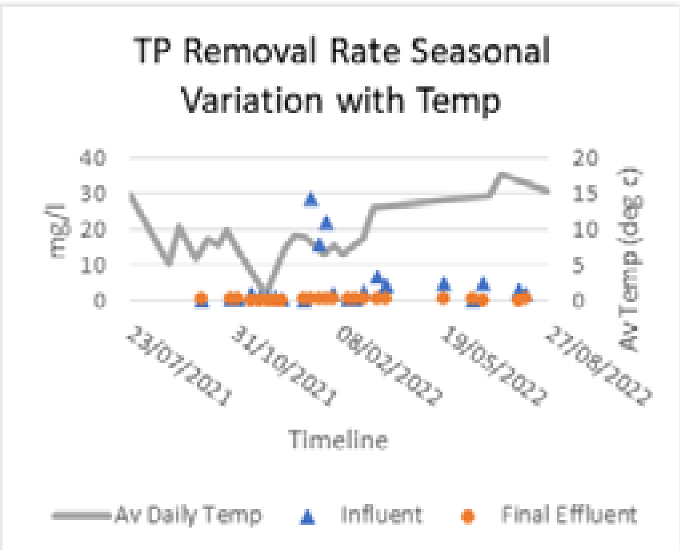
COD TTEST p <0.01 ; r = 0.16



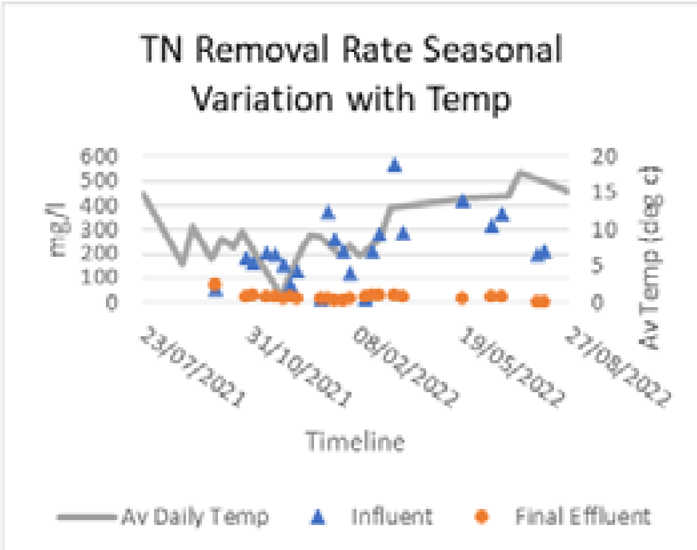
TP TTEST p <0.01 ; r = -0.10



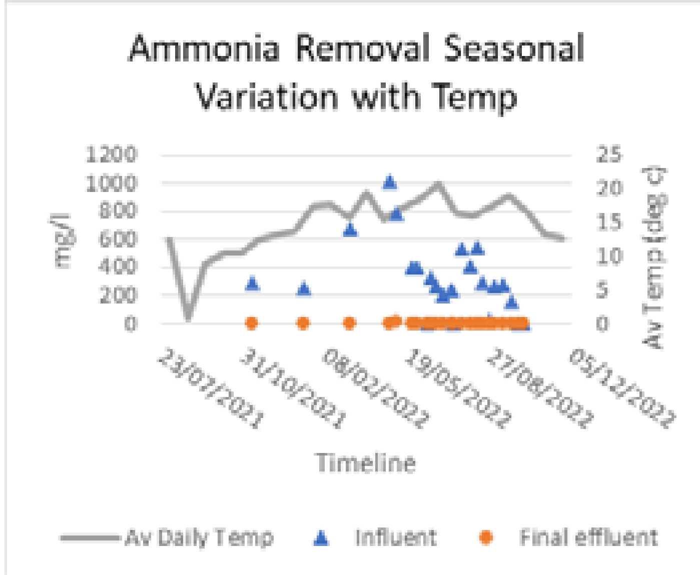
TN TTEST p <0.01 ; r =-0.33



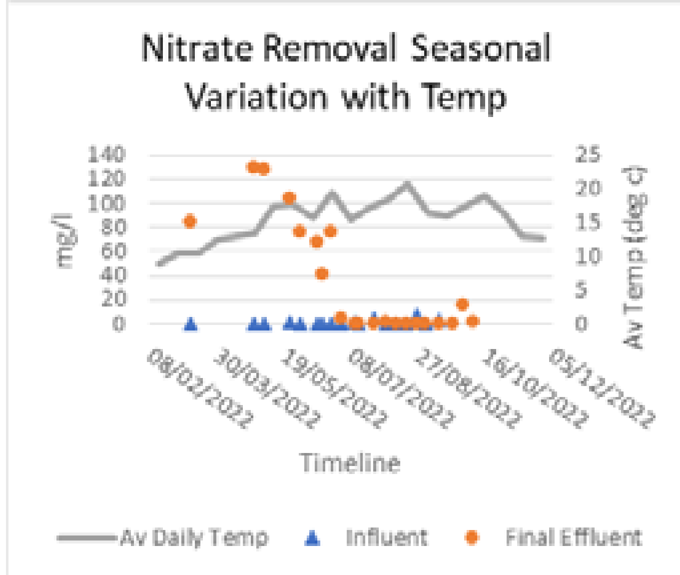
TK TTEST p <0.01 ; r = 0.47



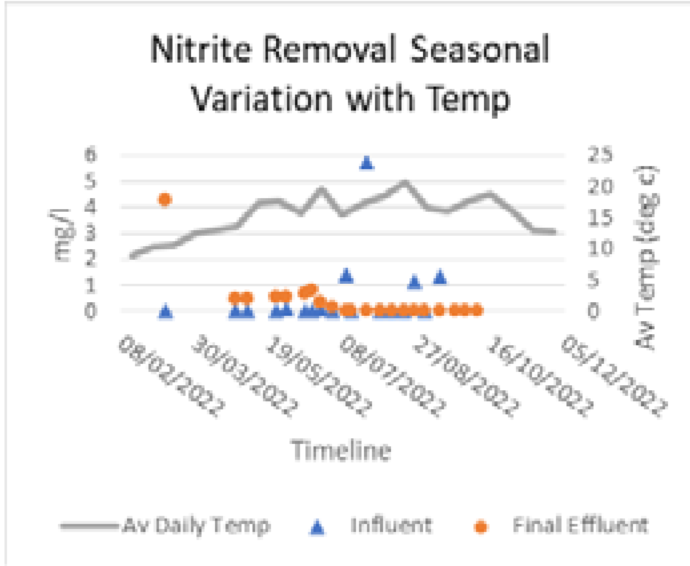
BOD TTEST p <0.01 ; r = 0.06



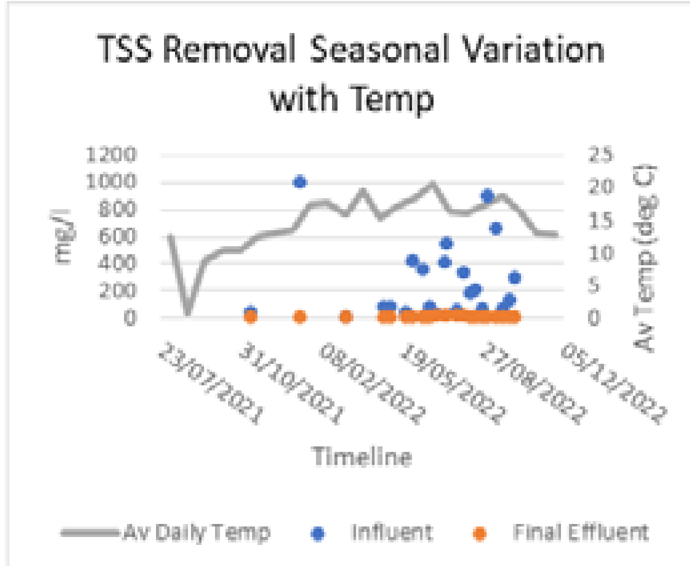
Ammonia TTEST p <0.01 ; r = -0.3



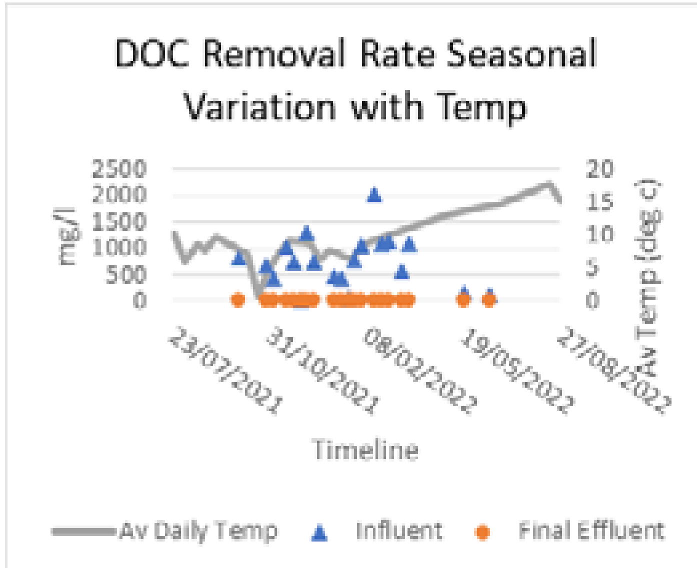
Nitrate TTEST p <0.01 ; r = -0.8



Nitrite TTEST p >0.05 ; r = -0.6



TSS TTEST p <0.01 ; r = 0.3



DOC TTEST p <0.01 ; r = 0.06

For explanation of *p* and *r* values please see page 90

Even though the ammonia levels in the influent are unevenly distributed, the levels in the final effluent remain consistently very low throughout the year. This may be expected as the ammonia is converted first to nitrite, then to nitrate (Nitrification) and is carried out exclusively by aerobic prokaryotes (bacteria), and is an important step in the Nitrogen Cycle. An increase in average daily temperature in Spring sees a reduction in the nitrite levels, as the nitrite is seemingly converted to nitrate. Also, during the Spring there is a significant increase in floral biomass observed as the wetland plants grow, taking up nitrate through their root systems. Nitrobacter bacteria proliferate making use of the available nitrogen. In addition, facultative anaerobic bacteria may also use nitrate as an alternative electron acceptor to oxygen under hypoxic conditions, further reducing the nitrate levels.

Nitrification occurs according to the following equations:

Step 1 Conversion of ammonia to nitrite by Nitrosomonas

$2NH_3 + 3O_2 \longrightarrow 2NO_2^- + 2H^+ + 2H_2O$

Step 2 Conversion of nitrite to nitrate by Nitrobacter

$2NO_2^- + O_2 \longrightarrow 2NO_3^-$

Additionally, pH also plays an important part in the nitrification process. The pH ranges between 7 – 9 in the wetland, with the optimum pH for nitrification being reported as between pH8.5[61].

There is a significant difference ($p<0.05$) in all determinand concentrations between the influent and the final effluent. Although nitrite levels decrease slightly in the springtime, statistically they remain fairly consistent over the year, with no significant difference seen. As samples were taken routinely from the first cell (influent) and last cell (final effluent) only, as part of a wetland maintenance contract with the installers, changes due to any nitrification in the more central cells were not recorded. Another contributing factor may be due to the wetland still establishing, resulting in some anomalous results. Further/continued monitoring is suggested.

Chart 7.12: Cumulative Contaminant Removal from Raw Slurry Through Final Effluent at the Wetland Outlet

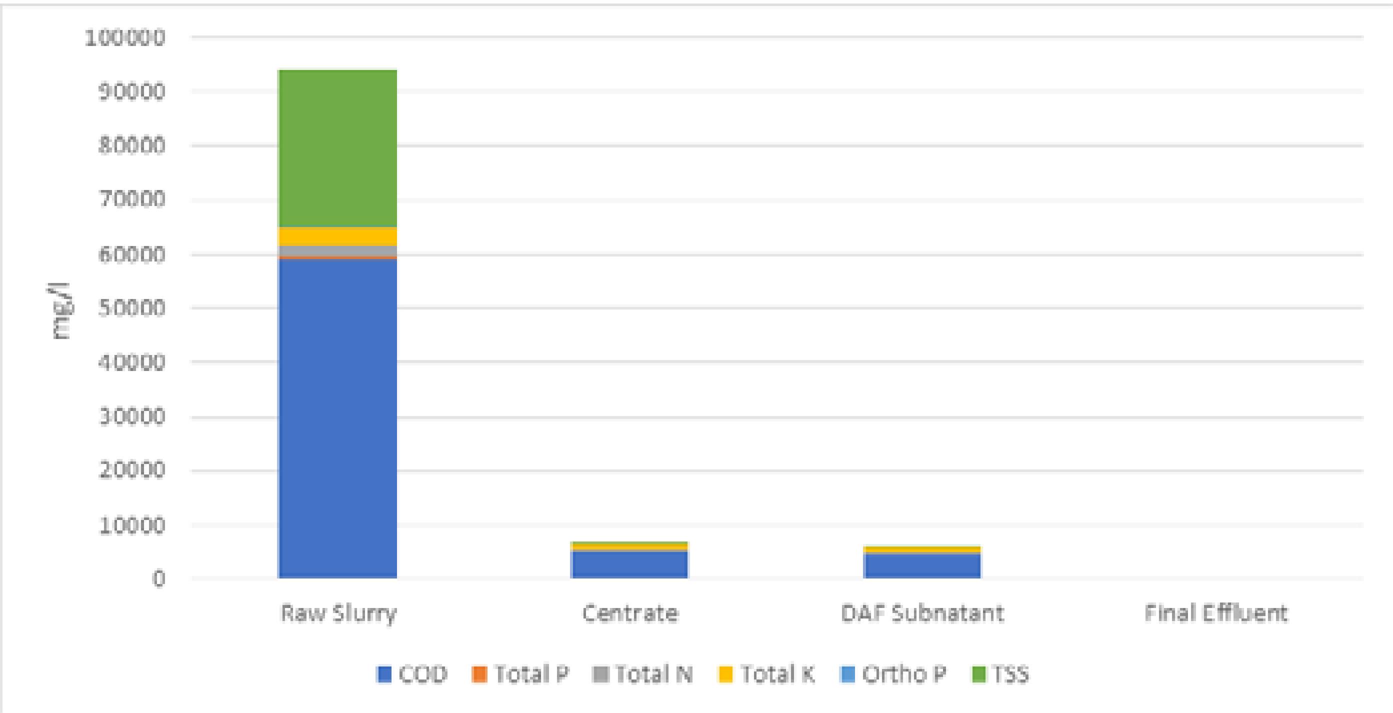


Table 7.3: Determinand Concentration and Overall Reduction Rates

Substrate Material	Determinand (mean concⁿ mg/l)					
	COD	TP	TN	TK	OP	TSS
Raw Slurry	59262.5	430.26	2168.39	2969.08	209.14	29020.0
Dec Centrate	5163.41**	11.33	430.84	1083.88	6.59	234.55
% Reduction*	91.28	97.36	80.13	63.49	96.84	99.19
DAF Subnatant	4475.28**	3.18	391.97	987.89	1.84	128.52
% Reduction*	92.45	99.26	81.92	66.73	99.12	99.56
RB Influent	2167.96	4.81	218.61	577.56	1.77	232.64
RB Final Effluent	25.46	0.39	22.15	49.38	0.39	14.29
Overall % Reduction*	99.96	99.91	98.98	98.34	99.81	99.95

** Reduction rates compared to raw slurry values*
***Some unexpected anomalous high values in the raw data set for decanter centrate and DAF subnatant heavily skewed the mean. Accounting for this, the adjusted values are 5,163.41mg/l and 4,475.28mg/l O_2 respectively. meaning the reduction in COD is around 700mg/l O_2*

Microbiology

For evaluation purposes we have compared the quality of the water exiting the wetland (final effluent) with known published standards, both for drinking water quality and also bathing water quality.

Drinking Water Quality

The values described in Table 7.4 are taken from Schedule 1 of the 'The Water Supply (Water Quality) Regulations 2018'

Table 7.4: Microbiological Limits

Directive Requirements		
Parameters	Concentration (max)	Units*
Enterococci	0	cfu/100ml
E. coli	0	cfu/100ml
Coliform Bacteria	0	cfu/100ml

**colony forming units*

Bathing Water Quality

Parameters Used for Classification of Inland Waters

Parameters measured are E. coli and IE (intestinal enterococci). Percentiles are values that should theoretically be compared with 90 or 95 percent of the time (based on the distribution of the data). They do not relate to the values compiled with by 90 or 95 percent of samples[62].

Table 7.5: Classification Limits for Bathing Water Quality

Classification	Parameter			
	E. coli 95th percentile*	*IE* 95th percentile*	*E. coli* 90th percentile*	*IE* 90th percentile*
Excellent	500	200		
Good	1000	400		
Sufficient			900	330
Poor	Fails to meet any of the above standards			
Not classified	Does not have enough samples in the four-year calculation period			

**colony forming units (cfu)/100ml*

Table 7.6: Microbiology Results From Samples Taken of the Final Effluent

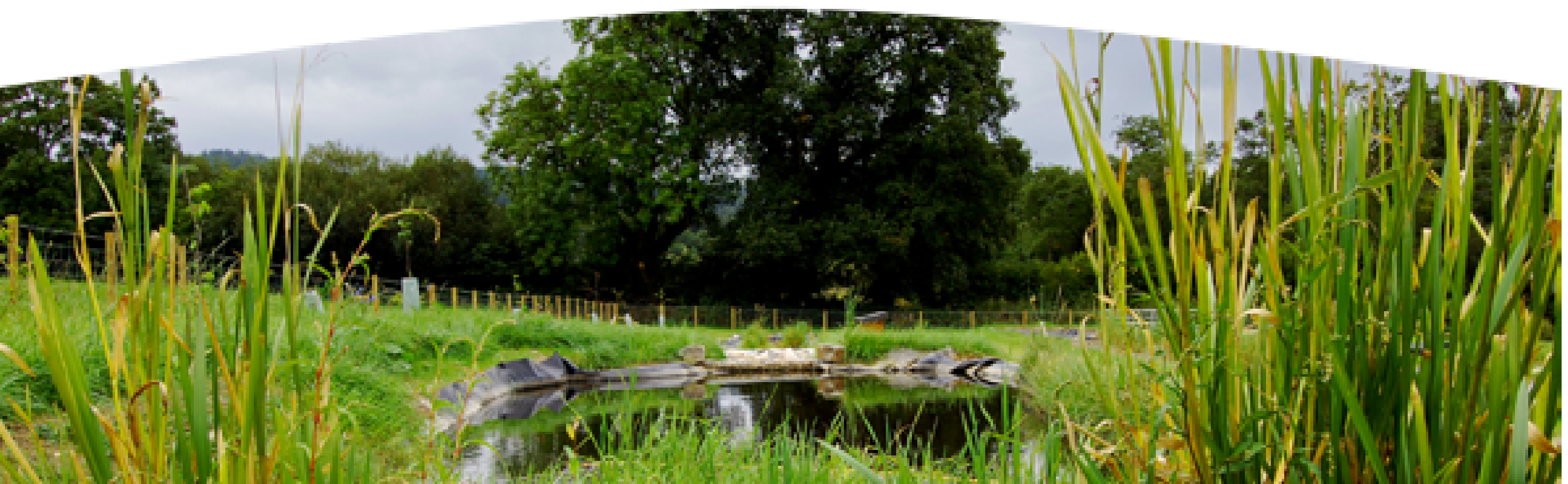
Percentile	Aerobic Colony Count 37° C cfu/ml	Aerobic Colony Count 22° C cfu/ml	Pres. Coliform Count 37° C cfu/100ml	Pres. E. coli Count 44° C cfu/100ml	Pres. Enterococci Count 37° C cfu/100ml	Sulphite Reducing Clostridia Count (cfu/50ml	Pres. Pseudomonas aeruginosa Count cfu/100ml
95th	285	300	150	133.5	33	4.4	267
90th	270	300	150	117	34	3.8	234
Limits							
95th				500	200		
90th				900	330		

It is clear from the final effluent analysis results that the quality of the water isn't acceptable for human consumption, however it does meet the Wales bathing water quality for inland waters. Furthermore, turbidity is reported as being low at 0.6NTU, a 99.9% reduction on the wetland influent, although further and continued monitoring is required.

For the water to be used for livestock consumption it is advised that it first needs to be treated to kill any remaining pathogenic bacteria. For ease of use this would likely be in the form of UV irradiation at the point of use.

Wetland Operating Costs

The power required to operate the pumps (both air and water) amounted to 100kWh per 24hrs. This equates to £30 per day at 30p/kWh, or £3/m^3. The cost of electricity is highly volatile at the time of compiling this report and should be taken into consideration.



8.0 Precision Agriculture

Poor nutrient management and traditional methods of slurry spreading can cause a significant impact on the surrounding environment, predominantly through over-fertilisation, field run-off/leaching, polluting water ways and emitting greenhouse gases. For example, the use of a 'splash' plate has been shown to result in ≤100% loss of the total ammonia content, impacting the climate and human health by reduced air quality[63]. This also poses a significant loss of nutrients and yield for the farmer. However, when combined with low impact methods of slurry spreading such as trailing shoe, dribble bars and slurry injection (and the right time, place, and amount), the high organic matter content of the produced solids is thought to regenerate soil health and increase soil carbon, hopefully preventing soil erosion and mitigating climate change. We have demonstrated several sustainable ways for the application of the concentrated solid and liquid fertilisers produced by the dewatering plant.

In October 2021, Netafim led the installation of a drip irrigation system in a grazing field adjacent to the treatment plant. This system will test the suitability of the liquid coming out of the DAF for fertigation (irrigation + fertiliser application) by means of two different dripper technologies, both of which are pressure compensated to ensure no variation in flow. Additionally, this may also lead to less gaseous emissions (specifically, ammonia and methane from nutrient volatilisation and carbon dioxide from spreading machinery), leading to better air quality. A key principle of this technology relates to the efficient uptake of nutrients as the fertiliser is delivered directly to the plant root system, leading to less chance of run-off when compared to more traditional nutrient application.

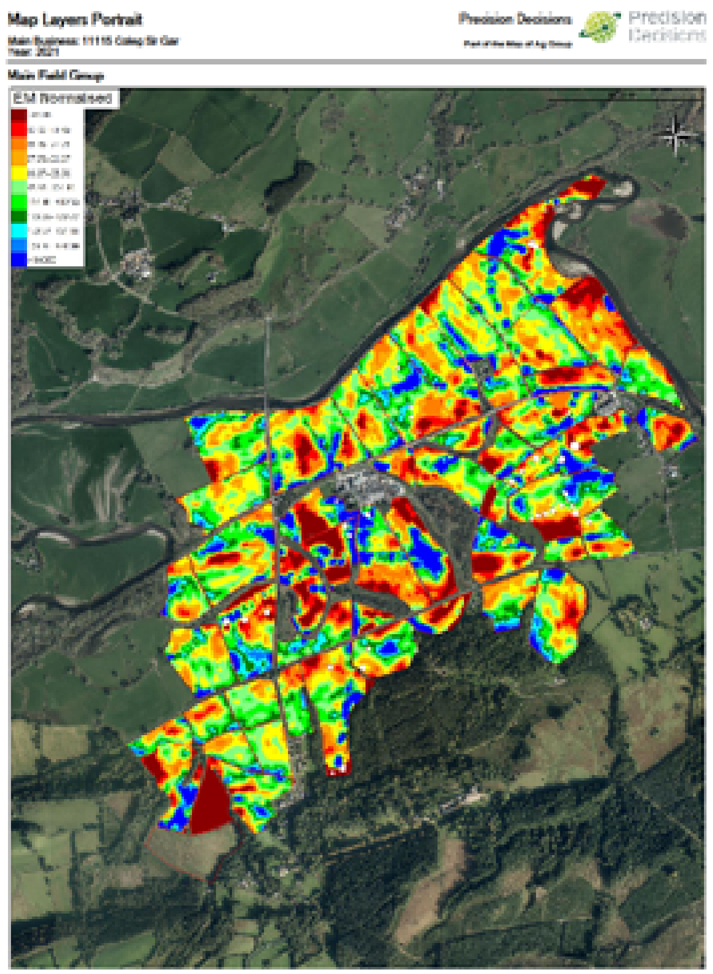


Figure 8.1: Electromagnetic Conductivity Scan of the Whole Farm.Blue Areas Show High Moisture and Deeper Soils, Whereas the Red Shows Shallower Soils Less Capable of Holding Water

In addition, nutrient mapping and soil analysis, conducted by Map of Ag, provided an overview of the soil nutrient levels on the farm. This ensured the delivery of the right amount of fertiliser/slurry, particularly in areas of nutrient deficiency but also nutrient surplus (where additional savings may be made). Over the long term, this will also show how the applied dewatered solids affect carbon stocks within soil.

Following on from the successes of ProsiectSlyri Project, Tywi Farm Nutrient Partnership (TFNP) set out to maximise and make best use of the nutrients captured from the slurry dewatering and separation process. Working with project partners and industry leaders we created a modular system that would allow each individual farm to select what best suits their farm business and practices. Further work to establish the benefits to the soil of applying separated solids needs to be carried out.

Evidence Group and their partners Precision Decisions, using their agronomic expertise and nutrient management advice, designed a protocol that would be able to acquire the relevant data to fulfil project aims. This included intensively soil sampling each field on the farm. This generated large amount of useful data and allow benchmarking against in future.

Soil Conductivity Mapping

Implementing a strategy for better management of nutrients produced on farm would require determining the nutrient status and soil type of each of the fields on the farm. This process was initiated by soil conductivity scanning, providing a high number of data points which could be translated into detailed maps of fields, where any variation allowed for more informed management decisions (Figure 8.1). Data was collected based on the physical soil characteristics largely influenced by moisture status, using a non-invasive EM (Electro-Magnetic) scanner with dual depth sensing technology. This one-time practice allowed soil types to be zoned and provided the basis for choosing the sampling points for chemical analysis of the soil.

Soil Sampling

Extensive soil sampling was conducted across the farm by means of a semi-autonomous system incorporating a GPS enabled ATV with automated soil sampling equipment fitted. This was linked to laboratory analysis, allowing full traceability and repeatability. Each soil sample was representative of ~5ha, with each sample being made up of 16 individual cores. Dual depth capabilities allowed the soil to be analysed at 0-30cm and again at 30-60cm. Using both the conductivity data and the soil chemical analysis, nutrient variable rate maps were constructed, drawing on both sets of data. Nutrient maps and recommendations made by an agronomist in the form of a shape file can then be used on isobus enabled tractors. Using variable rate technology enhances the efficiency of nutrient use ensuring we spread the right amount, in the right place and at the right time.

Soils are one of the major carbon sinks on the farm and it is therefore important that we can accurately measure and trace any changes made by farm practices to Soil Organic Carbon (SOC). The Intergovernmental Panel on Climate Change (IPCC) suggest that a minimum of 30cm should be sampled and any samples deeper than this should be tested separately. It is also suggested that larger changes of SOC occur in the top 30cm but long-term stabilisation occurs in deeper layers[64].

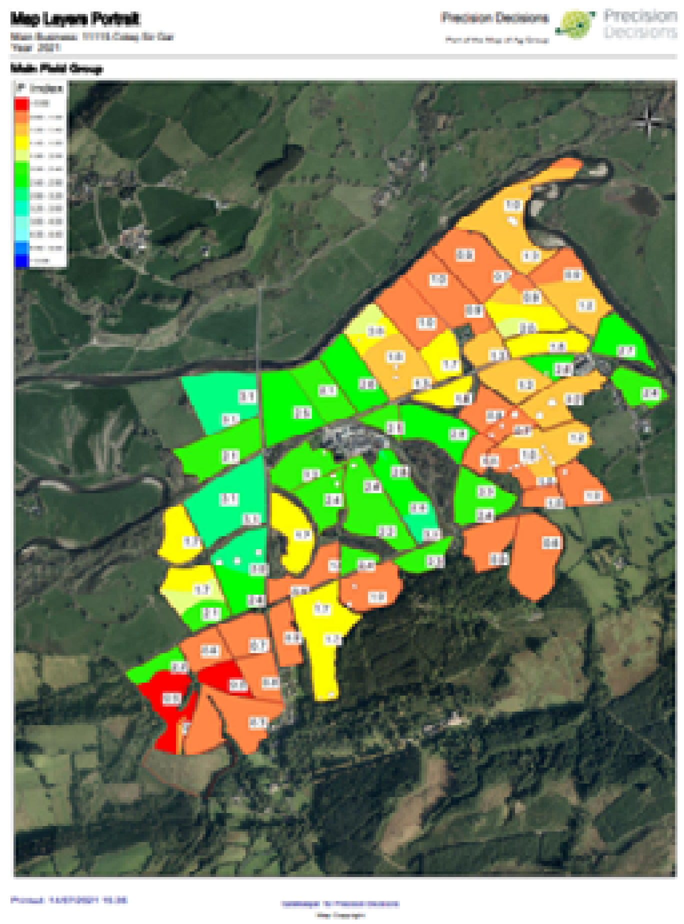


Figure 8.2: Farm Map Based on the P Index of the Soil

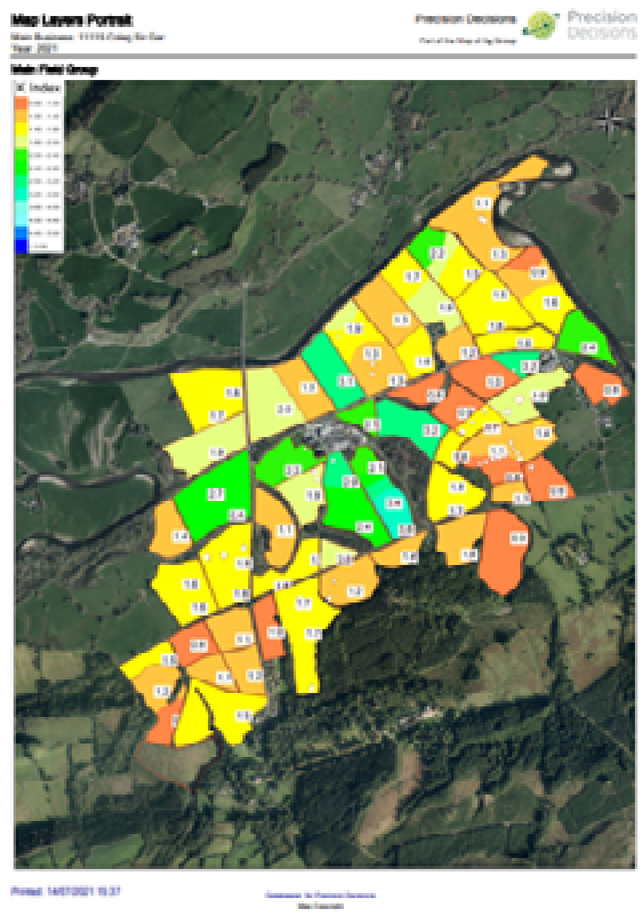


Figure 8.3: Farm Map Based on the K Index of the Soil

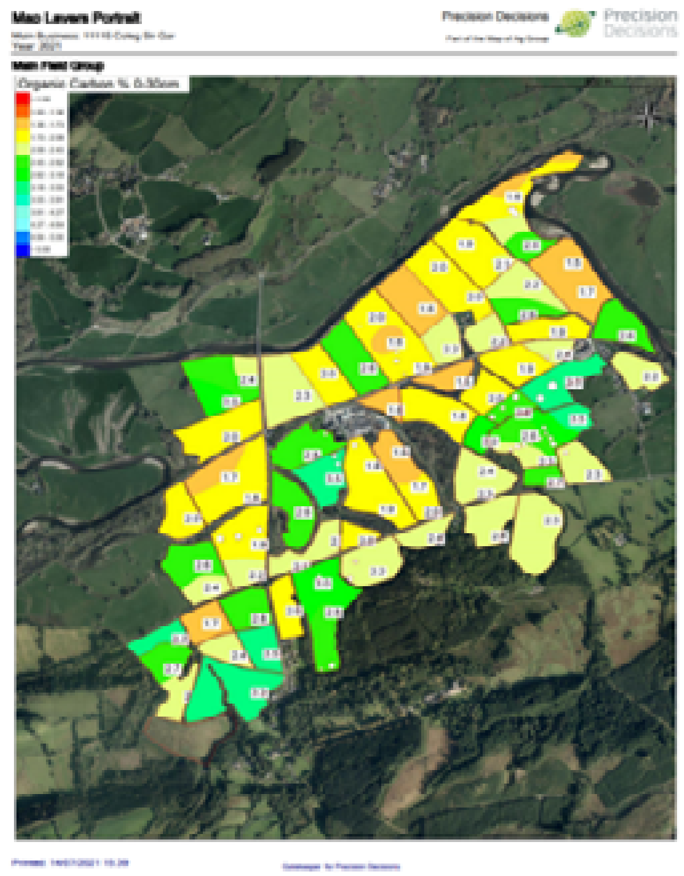


Figure 8.4: Soil Organic Carbon in the Top 0-30cm

Figures 8.2 - 8.4 show examples of maps generated by Precision Decisions. These are typical farm maps and demonstrate how fields further from the farm yard are harder to access with slurry meaning applications would be less frequent and application rates reduced compared to fields closer to the yards with easy accessibility. The concentrated and easily transportable solids from the separated slurry will help with management decision and be an alternative to pumping and moving slurry long distances to be spread.

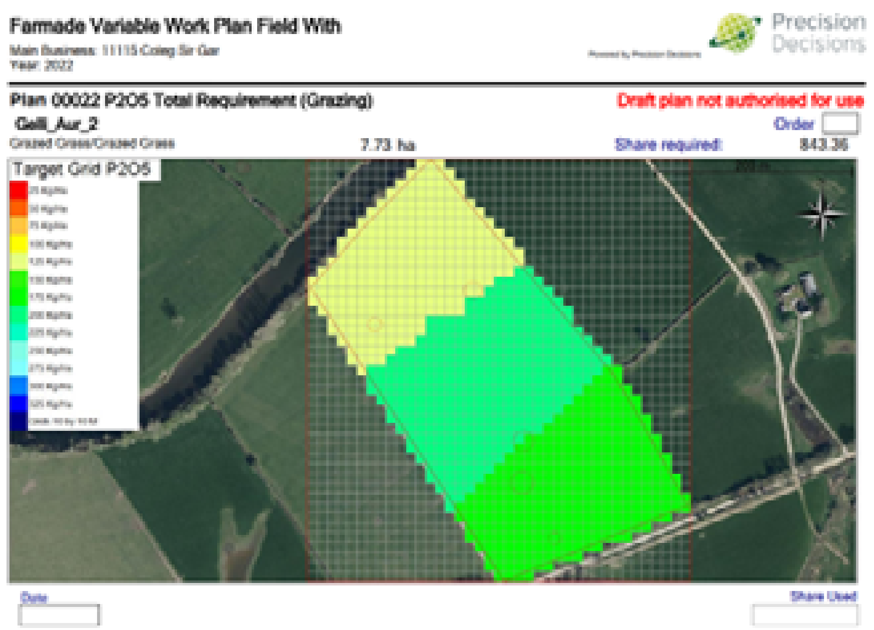


Figure 8.5: Example of a Shape File Generated for Spreading Nutrients. In This Case Phosphorus on a Grazing Field

Figure 8.5 highlights a shape file generated according to the required amount of phosphorus on one of the grazing fields. This map in particular indicates that there are three required rates within the one field. This variation can be down to simple farm management practices, or physical factors within the field, including soil type and ability to hold nutrients. The potential to reduce application rates and create borders where there may be features such as a watercourse, avoiding any environmental impacts. Using variable rate spreading may potentially reduce environmental risk, save money and nutrients for the farmer and will also ensure crop evenness.

Soil Analysis Costs

Single Depth
Basic Soil Analysis (P,K,Mg, pH) - £23.00
Basic Analysis + Organic Matter (DUMAS %) - £26.00
Basic Analysis + 2pH - £28.00
Broad Spectrum Analysis - £42.00
Broad Spectrum Extra (Includes Oragnic Matter % + Texture) - £48.00
Broad Spectrum Extra Solvita (Includes Soil Health/Respiration) - £63.00

Multi Depth
Soil Carbon Assessment (SCA) - £75.00
SCA + Broad Spectrum Extra - £114.00
SCA + Broad Spectrum Extra Solvita - £134.00
SCA + Broad Spectrum Extra + Nitrogen - £154.00
SCA Extra + Broad Spectrum Extra Solvita - £200.20

Additional
SA10 Soil Mineral Nitrogen Analysis - £16.00
Broad Spectrum (Composite) - £25.00

Broad Spectrum Extra (Composite) - £30.00
Broad Spectrum Extra Solvita (Composite) - £52.00
Animal Health (Soil) (Composite) - £30.00

Electro-Conductivity Scanning
EC scanning (one-time test)- £14.00

Soil sampling parameters are highlighted above, together with the cost of each test. Precision Decisions suggest that EC scanning only needs to be conducted once, as the physical properties of the soil are unlikely to change in the short to mid-term. It is however, possible to tailor the sampling to the requirements of the farmer/grower.

To allow the farm to accurately apply the nutrients captured from the separated slurry, precision application technology was utilised. This included a GPS and mapping system for the tractor and two applicators for both the liquid and solid fractions. This equipment was funded through the Welsh Government - Water and Flood Division.

To be able to accurately use precision technology the farms tractor was equipped with Greenstar GPS, a John Deere technology, paired with the John Deere portable display screen (JD LINK) and allows full rate control of the slurry, solids, and granular applicators.

For application of the solid fraction a Hi-Spec X-cel spreader with a capacity of 12 tonnes was used. This is a rear discharge spreader with full precision application capabilities which includes a shredding rotor inside a discharge chamber prior to spinning discs at the rear. This allows manure/solids to be spread up to widths of 24m depending on the nature of the solids. The manure spreader is also fitted with ‘Digi-star’ weigh cells that allow full control of application rate (Tonnes per Hectare) and to calculate the solids quantity applied as a total.

The slurry and liquid fractions were applied using a Hi-Spec 3000-gallon vacuum tanker, fully equipped with a Mastek dribble bar with macerator. Rate control technology includes flow meters for monitoring application rate and a John Deere Harvest Lab 3000 to allow monitoring of nutrient application. The John Deere technology records this data and will report it in the form of maps, allowing the farmer to build an archive of historical data that will directly affect future nutrient management decisions. The Harvest Lab 3000 fitted to the slurry tanker is a multi-purpose analyser which uses Near Infra-Red (NIR) spectroscopy to analyse various nutrients within harvested crops, silage or slurry. It is able to measure and record silage quality and quantity at harvest and then again when it is being fed, allowing precise rationing of the cattle feed. It is also able to analyse slurry at application and control rates whilst mobile.

The dribble bar system fitted to the tanker allows for a Low Emission Slurry Spreading (LESS) method which reduces ammonia and methane emissions. A reduced leaf area is contaminated when spreading, allowing faster turn-around times for grazing and silage. Also, more N is retained in the slurry, leading to quicker recovery times of the grass sward. It’s also possible to apply nutrients more accurately and more evenly over the land. Using a dribble bar alone will reduce ammonia loss by up to 30% according to a recent Teagasc publication[65].

As this technology becomes more commonly available and used on-farm, the relatively high CAPEX costs currently associated with this pioneering new technology will decrease, making it more affordable.

Netafim: subsoil drip irrigation

Drip irrigation systems are already in operation around the world, delivering much needed water and nutrients to high value crops such as soft fruits and potatoes in areas of low average rainfall. Project partners, Netafim aimed to carry out sub-soil drip irrigation/ fertigation of grassland for the first time, using their patented dripper technology.

By analysing grass growth data and historical weather data it was clear to see a decrease in the amount of precipitation and an increase in average daily temperature during recent growing seasons. This has subsequently led to a decrease in grass growth and overall grass quality. Netafim aimed to use the separated liquid from the chemical dewatering treatment plant to deliver water and the required nutrients for plugging the grass growth deficit gap.

Initial surface trials demonstrated no blockage of the drippers and therefore provided some assurance that the DAF process in conjunction with the inline Spin Klin 0.1mm filter that was installed was adequate to protect the drippers and ensures the longevity of the system.

In October 2021 Netafim installed a system of driplines that would deliver the liquid at a sub-surface depth of 200mm, the active root zone in most grass lays. This would allow the water to be delivered directly to where it is needed whilst also still allowing the farm to carry out shallow cultivations such as ploughing and power harrowing. Large areas of ground can be covered relatively quickly and easily using this system.

Fig 8.6: Trial plot immediately after the dripline installation indicating minimal ground disturbance

Fig 8.7: Photograph Showing the Drip Irrigation Pipe Layer

Fig 8.8: Photograph of Drip Irrigation Plot One Week On from Installation. Plots Also Rolled on Day of Installation Which Achieved a Better Finish

The overall trial design, including the difference between the two different types of dripper used within the trial plot can be viewed in Figure 8.9. In addition, the trial also explored using row spacing variations, and the drippers at different volume application rates, with a view to optimising grass growth and minimising the cost of the system to deploy.

A main concern was that using high-volume drip-irrigation lines at wider row spacings (80cm) would cause uneven growth patters to form. Therefore, for comparison, a lower volume dripper was included but at decreased row spacing (50cm). The overall plot area covered 0.33 hectares. Soil sensors were used to ensure no over irrigation.

In order to measure the differences between the irrigated plots and the control plots, soil and tissue samples were taken for laboratory analysis.

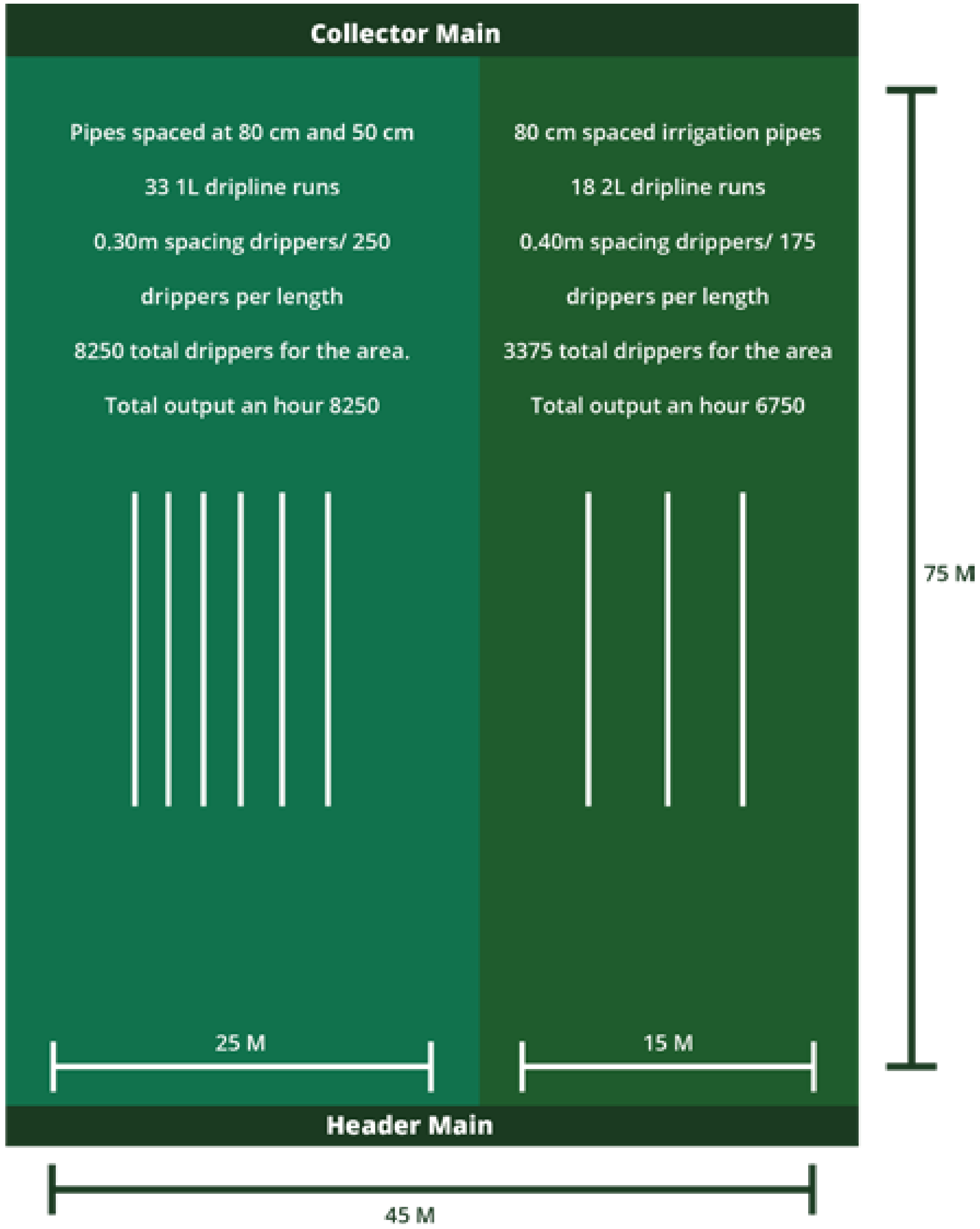


Figure 8.9: Plan of Trial Area Including Row Spacings and Other Relative Information

Laboratory results comparing two soil samples, one being an average of the irrigated plots and the other being the standard farm practice can be seen in Table 8.1. There is a natural variation within the field P-index between the irrigation plot and the control (standard farm practice plot), with the K-index being low on both plots. Industry standards state that the soil index should be 2 and additional maintenance applications can be made to adjust the nutrient levels if required.

	Field Details		Index			mg/l (Available)		
No.	Name	Soil pH	P	K	Mg	P	K	Mg
1	Irrigation Plot	6.8	3	1	2	26.8	118	99
2	Farm Practice	6.6	2	1	2	19.2	82	89

Table 8.1: Soil Analysis Results Showing the Difference Between Soil Samples from the Irrigated Plots and Standard Farm Practice.

The analytical methods used are as described in DEFRA reference Book 427.

The index values are determined from the AHDB Fertiliser Recommendations RB209 9th Edition.

It was demonstrated that medium wall thickness driplines were suitable for installation in a paddock frequented by dairy cattle. These driplines were fitted with pressure compensated drippers ensuring application uniformity across the area. The dripper flow rate means that liquid can be applied slowly and achieve a dripline length of up to 300m making the system efficient to deploy and install. Based on subsurface trials the spacing between driplines needs to be no greater than 50cm to provide uniform water movement through the top soil.

Using the mean nutrient analysis data from the DAF subnatant and converting to mm of liquid applied, it is possible to calculate the amount of nutrient delivered per unit depth as follows:

Nutrient	kg per Ltr	kg per mm
N	0.000392	3.92
P	0.000032	0.32
K	0.00988	9.88

Table 8.2: Amount of Nutrient Applied per mm Depth

Nutrient	kg per Ha
N	117.6
P	9.6
K	296.4

Table 8.3: Total Nutrient Application per Hectare

Table 8.3 indicates that the nitrogen level is below the proposed 170kg/Ha maximum permitted in new regulation. The potential impact of the high potassium is a cause for concern as this can be unhealthy to plants resulting in the inhibition of magnesium and calcium uptake from soils for example. An increase in soil K-index is also likely as a result, therefore further monitoring would be required.

In applying 30mm of liquid per hectare, this equates to 300,000ltrs of processed slurry, equivalent to the annual output of 45 cows (based on 6.57m^3 of slurry/cow/year). This means a 500-cow herd would need a minimum of 11.2hectares of subsurface driplines to make maximum use of the available nutrients which remain in the treated liquid post DAF.

N2 Applied: Nitrogen Enriched Organic Fertiliser (NEO)

Project partners N2-Applied have developed a novel process of nitrogen enrichment of the slurry by using nothing more than air and electricity.

The technology fixes nitrogen from the air and absorbs it into slurry, which increases the nitrogen content. The reaction also prevents the loss of ammonia and eliminates methane emissions, making it a real solution helping to achieve climate target commitments.

The technology operates solely on electricity which it uses to ionise a flow of air, splitting the nitrogen and oxygen molecules within, and generating a reactive nitrogen gas. The gas is then absorbed directly in the liquid phase of the livestock manure. Consequently, the manure is enriched with nitrate (NO_3) and its pH is lowered. This stabilises the ammonium in the manure, preventing its loss as NH_3, whilst also providing conditions which inhibit the formation of CH_4.

The end-product is a Nitrogen Enriched Organic fertiliser (NEO), which has the same physical characteristics as normal slurry, but contains more nitrogen and significantly less emissions. It can still be spread using existing farm equipment, enabling farmers to improve their own food production, reduce the need for chemical fertiliser and make farming more circular. A diagram demonstrating a simplified version of the N2 plasma process is shown in Figure 8.10.

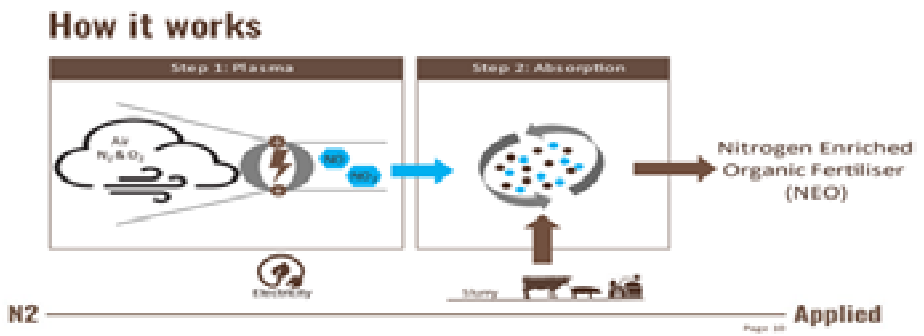


Fig 8.10: How the N2-Applied Unit Converts Slurry to NEO

A series of grassland trials were carried out using Nitrogen Enriched Organic fertiliser (NEO) supplied by N2 Applied for the 2022 growing season.

The aim of the trial was to investigate any yield and quality benefits from applying treated NEO to grassland used for grass silage by comparing to untreated slurry used in farm standard practice. The area marked out for trials was within a field that would be cropped three times for silage during the spring and summer seasons. Soil sampling data indicated the P-index was 3.1 and the K-index 2.7, with a pH of 6.7. Field trials included three separate parameters for overall comparison with each treatment applied in time for cropping.

Number	Plot	Treatment	Slurry Applied	NEO Applied	Inorganic Fertiliser (standard farm application rate)
3	Farm Standard Practice - untreated slurry	5L per plot	Yes	No	Yes
5		10L per plot	Yes	No	Yes
2	N2 Applied - NEO	5 L per plot	No	Yes	Yes
4		10L per plot	No	Yes	Yes
1	Control plots	None	No	No	Yes

Table 8.4: Trial Plot Nutrient Application

It is important to note that all plots received both nitrogen and sulphur in the form of 'Frontier SingleTop 27N $12SO_3$' during inorganic fertiliser application as part of the farm's standard routine.

Methodology: Using quadrats, small plot areas – 2m², were marked out and randomised using a basic random number generator. An even application of the slurry/NEO was conducted using a standard watering can.

To measure overall grass yield, an area 1m² was cut within the 2m² plot area and weighed. A sub-sample of this cutting was taken for DM% analysis.

Homogenised grass samples were sent to an accredited laboratory for wet chemistry analysis, indicating overall quality of the grass silage.

2	4	1	3	5	Rep 5
5	4	3	2	1	Rep 4
3	2	1	5	4	Rep 3
4	1	5	3	2	Rep 2
1	2	3	4	5	Rep 1

Chart 8.1: Randomised Trial Plot Layout Including Repeats

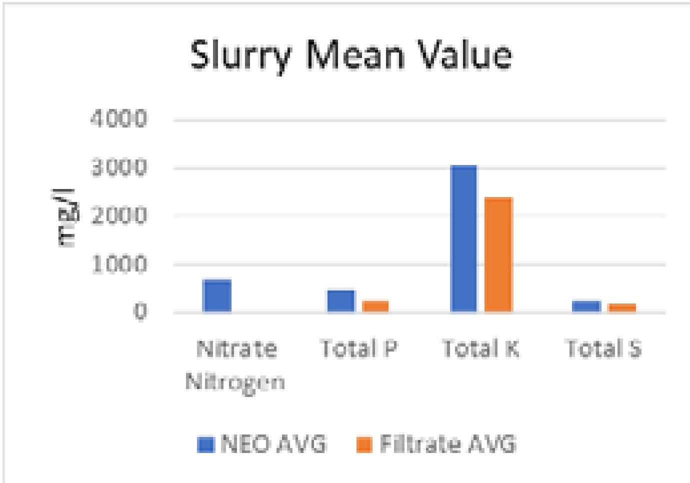


Chart 8.2: Mean Nutrient Concentrations for both NEO and Untreated Liquid Fraction of Separated Slurry

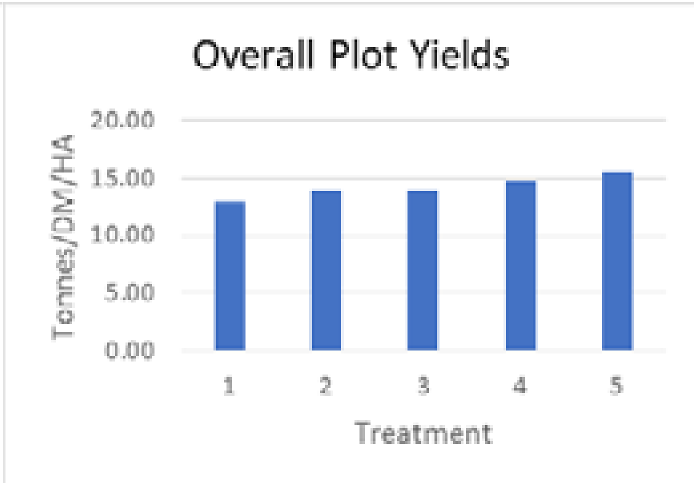


Chart 8.4: Overall Yields Per Treatment Over the Three Silage Cuts

The above data represents results from field trials undertaken using NEO and untreated slurry. As expected, all plots with standard farm slurry application yielded better results than those without.

During the growing season exceptionally low rainfall made for difficult growing conditions, with a high moisture deficit. This meant that the grass did not respond as imagined to the higher nitrates in the NEO slurry.

Statistical analysis of the overall yields indicated that there was no significant difference between yields from the standard farm slurry applied plots and NEO plots. However, it would be difficult to deduce the effectiveness of NEO given that the trials were conducted over a single growing season whilst also taking into consideration the growing conditions for the year. It is estimated that future trials would require a minimum of five years' worth of data to properly evaluate the added benefits.

Continued plot and larger field scale trials during the next growing season may offer better representation whilst providing a larger data set with which to draw conclusions.

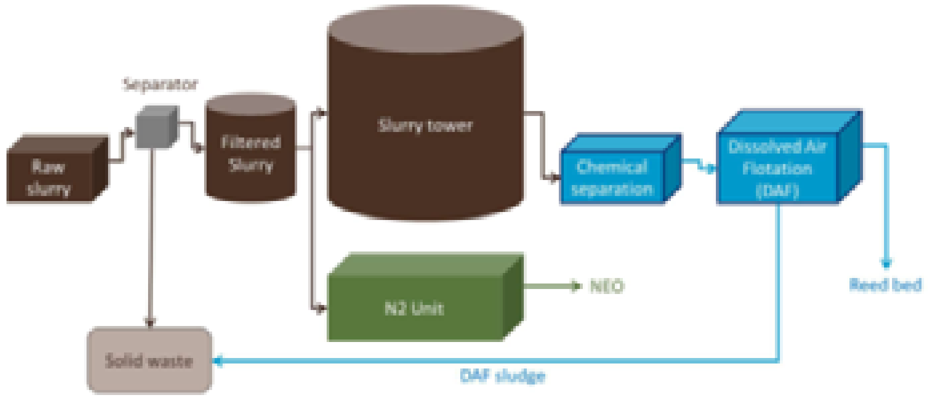


Figure 8.11: Implementing the N2 Unit as a Side Stream of Production to Generate NEO Fertiliser for Direct Field Application

Based on the analysis results of various substrates within the slurry dewatering process, the most optimal substrate for treatment with the N2 Applied plasma system appears to be slurry directly after primary mechanical separation in the screw press filter. At this point there is a high level of ammonium content in the slurry to allow for absorption and enrichment with nitrate, and to provide the maximum benefits in terms of ammonia and methane reduction. The N2 unit also requires separation of the solids before treatment, so this stage is the simplest to implement. However, treating the slurry at this stage, though providing a good option for the N2 system in isolation, may not allow for full integration with the slurry dewatering technologies. This is due to part of the dewatering process requiring the pH to be raised to pH~6.5. Raising the pH would likely undo the treatment process of the N2 unit, favouring the formation of ammonia gas and possibly leading to loss of the added nitrate.

9.0 Water Quality Monitoring

An important aspect of TFNP was to monitor the quality of surface water in a stream that runs through the farmland and adjacent to the mechanical treatment plant. Samples were taken form the point of entry to the farmland and again at the point where the stream empties into the River Towy in order to try and establish what effect – if any, the work conducted within the project boundaries was having on local watercourses. Project partners Dŵr Cymru/Welsh Water analysed the samples with the overall results indicating low levels of contamination present at both the upstream and downstream locations - see Tables 9.3, 9.4.

Table 9.1: Nutrient Analysis Results of Samples Taken from Upstream and Downstream Locations

		Determinand Concentration (mg/l)					
		Ammonium	Nitrate	TON	Ortho-P	TP	TK
Mean	**Upstream**	0.04	0.75	0.75	0.02	0.06	1.21
	Downstream	0.03	0.85	0.85	0.04	0.09	1.85
ST.DEV	**Upstream**	0.19	0.22	0.22	0.006	0.0004	1.23
	Downstream	0.04	0.29	0.29	0.04	0.08	0.91
p		>0.05	>0.05	>0.05	<0.05	>0.05	<0.05

Table 9.2: Microbiology Analysis Results of Samples Taken from Upstream and Downstream Locations

	Parameter (cfu/100ml)			
	Presumptive E. coli		Presumptive Enterococci	
Percentile	**95th**	**90th**	**95th**	**90th**
Upstream	225	200	146	45
Downstream	475	250	352	263
Limits*	**500**	**900**	**200**	**330**

**Relates to Wales Bathing Water Quality limits for comparison*

In terms of the physical chemistry DC/WW report no concern. In general, contamination levels were deemed low. However, a spike in phosphorus levels at the downstream location may have coincided with a slurry spreading event near that time. Although the likely cause, this cannot be fully determined at this stage and would require continued monitoring. Nevertheless, the phosphorus levels remained very low even with this increased concentration (Fig 9.1).

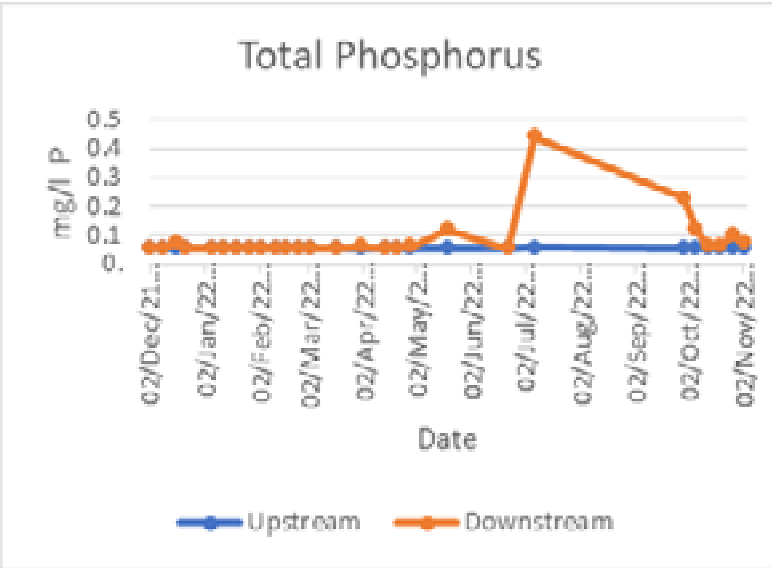


Fig 9.1: Phosphorus Concentrations Over Time

The microbial samples twice showed increased concentration at the downstream sampling location for Clostridia (Fig 9.2). Again, the application of slurry to fields adjacent to the sampling point may be the likely contributing factor. This may be of concern, although once more, this cannot be fully determined and would require further monitoring in order to rule out other potential causes.

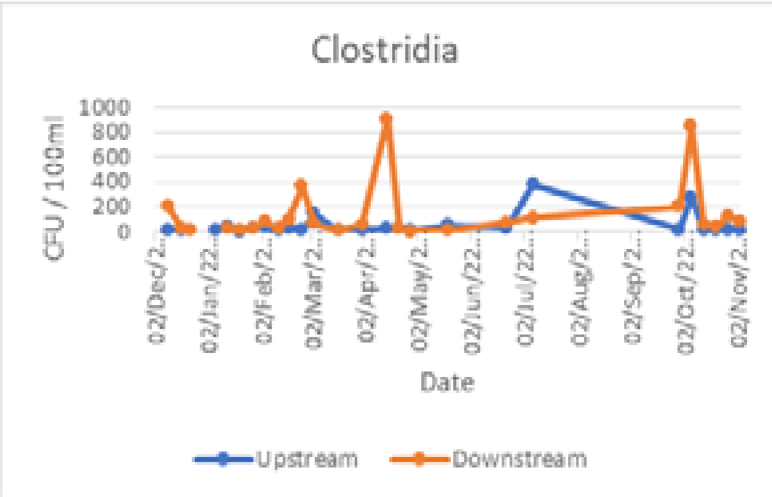


Fig 9.2: Clostridia Levels Over Time

All other microbiology parameters were low and indicated no concern.

10.0 Discussion

Tywi Farm Nutrient Partnership (TFNP) was borne from the success of ProsiectSlyri project and aimed to work in collaboration with industry partners in order to advance the research and development work already begun under that scheme. As a result, what has been achieved is a slurry treatment system which encompasses slurry dewatering and nutrient recovery, nutrient enhancement, precision application of nutrients on land – as well as within the soil, ensuring that the right amount of nutrient is applied - at the right time and in the right place. Finally, a constructed wetland was installed in order to ensure the final effluent from the treatment process achieves discharge consent permit limits, should the effluent be needed to be discharged to a local water course. Higher than desired TN levels in the final effluent while the wetland was still establishing meant that the mean values over the course of the project were higher than the discharge consent limits. As the wetland became more established this reduced to slightly below permit limits, although continuous monitoring would be required. The water is currently being re-used on the farm as wash down water in the parlour area and in the treatment plant for flushing the decanter centrifuge and for diluting base chemical to working concentrations.

Although microbiological analysis of the final effluent suggests that it is no more contaminated that an average cow drinking trough, it is with caution that any water finds its way into the cattle's diet. In order for the livestock to safely drink the re-cycled water it is recommended that it would first require UV treatment to further reduce the risk of pathogenic microorganisms being present in the drinking water. In addition, intensive UV treatment would aid in degrading any residual PAM/AMD to products of lesser concern. At the time of completing this report, this had yet to be concluded.

It has been reported that certain Pathogenic E. coli strains (e.g. O157:H7) can survive in open environments[66]. The ability to use nutrients and to attach to surfaces plays a crucial role in their survival. Escherichia coli strains can be found in soil, manure and irrigation water and can persist in farm environments for months. Strains of Escherichia coli may survive and even grow in sterile freshwater at low carbon concentrations[67]. Enterococci species also display an innate ability to survive in the environment for extended periods. Under certain conditions, some enterococcal species (e.g. E. faecalis) are able to survive as long as several months by activating a starvation response[68]. Therefore, it is unsurprising that E. coli and Enterococci species are present in the final effluent samples taken from the constructed wetland outlet, even with the long retention times associated with treatment. In order for this water to be determined as being microbiologically acceptable for cattle to drink, it must first be treated – UV light or otherwise, at the point of use on the farm.

The mean value recorded for primary reaction tank influent %TS was 4.5. This corresponds well with a self-imposed efficiency limit of ~4%TS at 2m^3/hr and the natural mean of the slurry store over the closed period. Treating separated filtrate with higher %TS would be possible albeit with less chemical efficiency and lower throughput. This is due to the higher viscosity and the greater retention time required in the reaction tank for the chemicals (flocculant in particular) to be correctly blended. The bulk density of dairy cattle slurry decreases with increasing %TS above 4%TS; however, the dynamic viscosity keeps increasing with increasing %TS. Building on work done *by Landry et al.*,[42] - slurry at 4%TS, is calculated to be 0.01 x denser, but 490 x more viscous when compared to 1%TS. At 5%TS, the density decreases to 0.006 x, however, the viscosity increases to 1,325 x when compared to 1%TS as follows:

Slurry at 4%TS γd (density) = 0.01α
γv (viscosity) = 490α

Slurry at 5%TS δd (density) = 0.006α
δv (viscosity) = 1325α

Where: α= 1%TS; γ = 4%TS; δ = 5%TS

This is essentially the difference between slurry and 'dirty water'. It is therefore clear to see the issues encountered when trying to treat thicker slurries. However, with careful consideration given to process design, it may be possible to treat raw slurry up to 7%TS, although with significant decrease in efficiency.

The Dissolved Air Flotation (DAF) system was installed in order to try and better manage the tertiary mechanical separation step identified as being required in ProsiectSlyri project. However, capital expenditure and operational issues experienced when the feed increased above 1% total solids, together with the minor reduction in some contaminant levels mean we must ask ourselves if the DAF is worth it? To help answer this, we compared the DAF subnatant data to the decanter centrate data. This showed that the DAF (in this instance) was only effective in lowering the Total Phosphorus (TP) and Ortho-Phosphate (OP) levels by a significant amount ($p<0.05$), all other determinands were reduced by insignificant amounts ($p>0.05$).

Comparing raw COD values for decanter centrate and DAF subnatant suggest that that there was an initial mean reduction of around ~3,000mg/l. This resulted from some unexpected high values which skewed the mean. Accounting for this and omitting these anomalous data points, the adjusted values were 5,163mg/l and 4,475mg/l O_2 respectively, meaning the reduction in COD of around 700mg/l O_2 or 13.3%. However, as TFNP has a final polishing stage in the form of a constructed wetland, it is advantageous for some phosphorus (P) to remain within the effluent stream for reed well-being and biofilm health. With this in mind, it becomes difficult to recommend the DAF

for this purpose alone. Nevertheless, it may be applicable to systems where land area required for a constructed wetland isn't available and P removal is the primary objective, or for use in combination with drip irrigation systems where only a small reduction in TSS can be the difference between drippers blocking or not.

COD:BOD$_5$ ratios were determined for the influent and final effluent from the constructed wetland. These indicated mean values = 2.56:1 and 6.23:1 respectively. When the result of a COD test is more than twice that of the BOD test, there is good reason to suspect that a significant portion of the organic material in the sample is not biodegradable by ordinary microorganisms. COD:BOD$_5$ ratios can be highly variable. The more variable the ratio values and the higher the COD:BOD$_5$ ratio, the greater the percentage of slowly biodegradable and non-biodegradable material in the sample. These results, as expected, indicate that the influent is moderately biodegradable, but the final effluent contains hardly any biodegradable material at all.

If we consider the removal of nitrate from the effluent stream as the constructed wetland became more established and ambient air temperature increased the mean amount of Total Nitrogen remaining in the final effluent =13.9mg/l – which is below the discharge consent limit.

There is an optimum temperature for nitrification to occur. This is between 28°C – 36°C with the maximum growth rate at ~30°C[69]. In the article, they have referenced a number of studies, including *JA Borchardt (1966)*, who found that 'no sharp optimum temperature can be defined and that there is a plateau of maximum activity between 15°C and 35°C. Below 15°C however, the nitrification rate drops sharply, and is reduced by 50 per cent at 12°C'. However, others found that an almost straight-line relationship exists between the nitrification rate and temperature[70].

This helps satisfy the laboratory results from samples taken from the wetland, where the conversion of ammonia through to nitrate seems to be at least in part - temperature related, with a strong negative correlation coefficient (r) = -0.8 (i.e. when the temperature increases the nitrate concentration in the final effluent decreases). It is thought that the sharp decrease in nitrate in the final effluent can be attributed to both plant and microbial activity further up the wetland.

According to AHDB dairy, 'dirty water' can be described where the total nitrogen content is listed as < 0.5kg N/m^3[71]. The mean concentration of total N in the decanter centrate was 0.43kg N/m^3. This was achieved with the mean of the raw slurry and that of the influent to the treatment process being ~7%TS and ~4.5%TS respectively. Therefore, the decanter centrate could theoretically be determined as being 'dirty water' and available for spreading all year round under current regulations. This provides an opportunity for reduced CAPEX and OPEX costs compared with any desire to achieve discharge consent permit levels.

With the huge increase in inorganic fertiliser costs seen over recent times, the costs of operating the treatment plant will be offset by making better use of the recovered nutrients on farm. Recent figures suggest that for a 200acre farm, milking 200 cows the annual savings per annum would be in the region of £65,000, up from circa £17,000 in 2019. The unprecedented rate of inflation in the UK and the volatile energy markets in 2022 have greatly impacted the running costs for the treatment plant, with the cost of chemical conditioner and power being the two greatest cost concerns. At current prices this would total around £62,000/annum. In addition, the costs of operating the constructed wetland would amount to almost £11,000/annum. Applying the separated solids to land would cost a further ~£50/hour.

Treatment plant operation costs, although very high, are reduced somewhat when offset against the very high costs of purchasing bagged, inorganic fertiliser. However, it is understood by the authors of this report that dewatering and nutrient recovery isn't going to suit all dairy farms with only the largest dairy farms likely able to absorb the associated capital/operational costs. Notwithstanding the capital and operational expense, the requirement for 3phase electricity supply will also deny around 50% of all dairy farms in Wales the opportunity because they are currently only connected to the national grid power supply via a 1phase connection, further adding to the capital expenditure required.

The precision agriculture work undertaken permitted a broader insight of nutrient management practices and precision agriculture techniques deployed on the college farm at Gelli Aur under TFNP. With the project being undertaken on a working farm, this enabled better understanding of what are achievable, viable options for farm businesses on a purely commercial basis. With the system also being modular, this would enable the farmer to 'pick and choose' which elements are most suitable for their farming practice.

Soil sampling and mapping proved to be a very beneficial exercise as it allows nutrient management to be undertaken on a more specific hectare by hectare basis, where nutrients can be applied and used more efficiently. The farm also benefitted in having benchmark values for the carbon and nutrient levels within the soil and this could aid management decisions moving forward. Over the last two years we have seen increases in bagged fertiliser costs from £280 to over £800 (Frontier Nitram 34.5% N). Moving forward, nutrients produced on farm will play a more vital role as farmers try to cut costs and increase profitability by utilising more of their on-farm organic fertiliser, matching application rates with crop demand.

The precision application equipment has enabled the farm to apply nutrients with a higher degree of accuracy, aided by both GPS and JD link technology. There is also the added possibility of using tractor auto steer systems, further increasing accuracy of applications, allowing precise repeatability of operations. In addition, the Harvest Lab 3000 can also be used to sample silage in the clamp and help to calculate dietary requirements.

From installation to irrigation, it has been a successful first season of using the Netafim drip irrigation/fertigation system. Limited to one full season of delivering nutrients through the drip lines, it may be too soon to draw meaningful conclusions and would require further investigation in order to fully quantify the value added by the drip irrigation compared to non-irrigated pasture, but the outlook is very positive. Netafim have also reported the possibility of a combined solution between the constructed wetland and the drip irrigation system which could form the basis of future work.

In addition, the need to compare energy consumption between pumping the liquid through the driplines opposed to applying nutrients using a vacuum tanker/fertiliser applicator requires consideration. Regardless of this Netafim have stated that 'overall we have a commercial solution now that we can take to market.'

With an N2-Applied unit very recently installed on site and currently being commissioned, more accurate comparisons of how the treated slurry (NEO) performs in comparison to un-treated slurry will be possible. Upscaling the trial in the next growing season to include full field trials and also comparing untreated slurry with NEO produced on the same farm, keeping variations to a minimum, would be advantageous. Investigations to include how the process of acidification and nitrogen enrichment effects grass quality and how well it stores over the closed period would be beneficial.

Storing the decanter separated solids in a covered shed over many months (closed period +) has shown to decrease the ammoniacal nitrogen content by 84%. This is further exacerbated for chemically amended solids where there is a decrease of 94%. This results from the microbial activity during the composting process as aerobic bacteria convert ammonia to nitrate for growth. This process occurs in raw slurry also but at a lesser degree, where nitrogen losses through ammonia volatilisation is well known. Bacteria are also involved in the degradation of polyacrylamide and monomeric acrylamide, releasing ammonia. Stabilising this ammonia through acidification is key to retaining as much of the nitrogen in the separated solids as possible, be that through N2 Applied technology or otherwise.
for chemically amended solids where there is a decrease of 94%. This results from the microbial activity during the composting process as aerobic bacteria convert ammonia to nitrate for growth. This process occurs in raw slurry also but at a lesser degree, where nitrogen losses through ammonia volatilisation is well known. Bacteria are also involved in the degradation of polyacrylamide and monomeric acrylamide, releasing ammonia. Stabilising this ammonia through acidification is key to retaining as much of the nitrogen in the separated solids as possible, be that through N2 Applied technology or otherwise.

There is a corresponding increase in concentrations for phosphorus in both the separated solids (~32%) and chemically amended solids (~25%) over time, with water evaporation being the likely cause. This is also observed for potassium, where there is a ~15% uplift in concentration in the chemically amended solids and a ~28% increase in decanter solids. Again, water evaporation is thought to be the obvious explanation.

Both types of mechanical separators produce a solid with elevated pH compared to raw slurry. Reasons for this have not been investigated although the release of CO_2 from the slurry via the process of pumping, agitation and separation is a likely candidate.

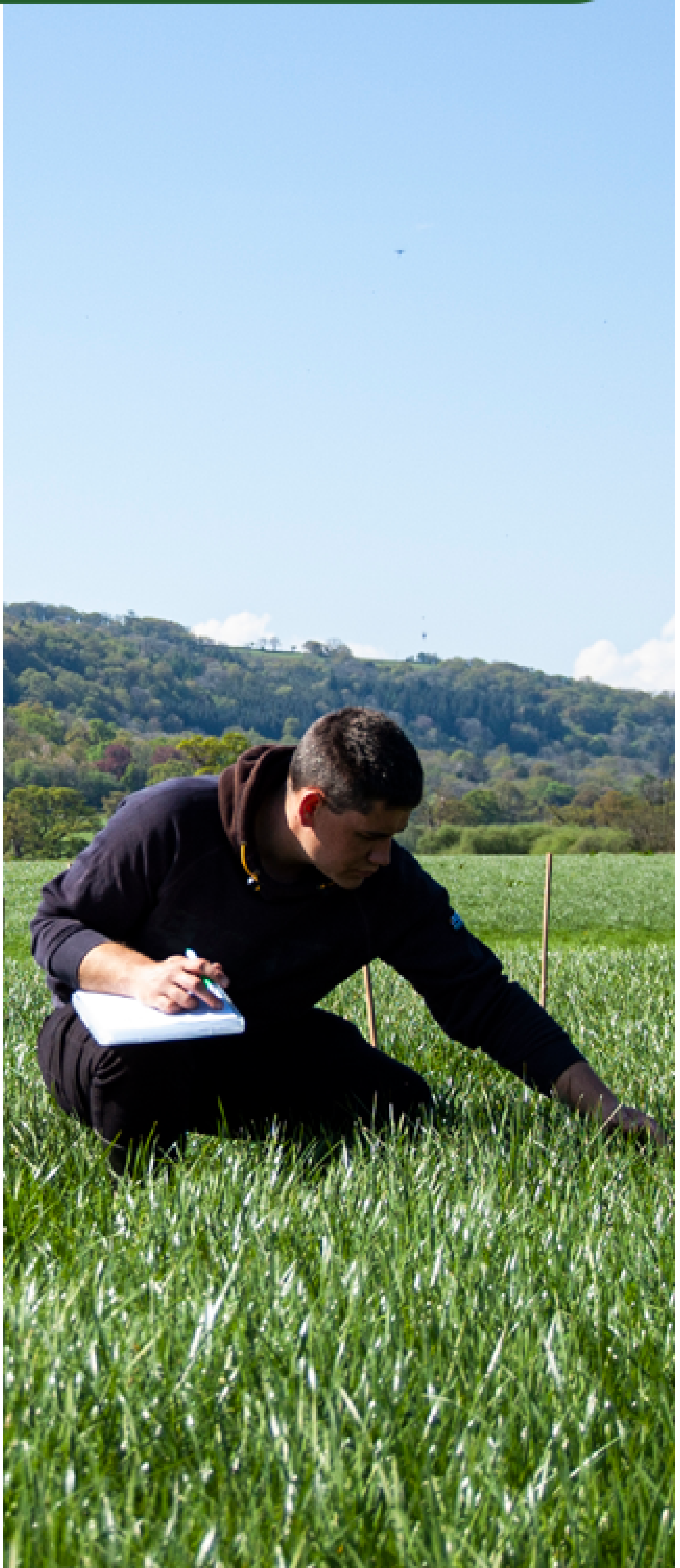
The separated and chemically amended solids behave as slow release fertiliser, having less of an immediate impact on crop growth response when compared to bagged inorganic forms. However, it also then follows that there is less of a possibility of any excess nutrients leaching into watercourses.

11.0 Conclusions

We ignore long term environmental pollution at our peril. Preventing excess nutrient from leaching off the land and reaching watercourses was therefore key to taking this project to the next logical step for both protecting the environment and also creating sustainable, profitable farming practices.

The use of chemical conditioners in wastewater treatment is well understood and is currently a cornerstone of municipal wastewater treatment plants. We have identified two wastewater chemical conditioners in Polyaluminium Chloride 18% (PAC) and anionic Polyacrylamide 0.2% (PAM) which give the best results when treating cattle slurry. However, much work had to be undertaken in order to achieve the best outcome, with the design and operation of the chemical reaction tank proving to be an essential part of the process and critical to achieving acceptable efficiencies. The reaction tank then, holds the key to unlocking the potential of the dewatering and nutrient recovery process.

The precision application of nutrient, including delivering it in the right amount, in the right place and at the right time can play an important role in mitigating environmental damage caused by over-use of fertilisers. This targeted approach allows the consideration of climatic conditions, where elongated growing seasons in Wales means that crops continue to take up nutrient long into the current closed period. Technical issues with mechanical spreading technology used in TFNP would require resolving with both manufacturer and supplier before being fully ready for deployment and used as a matter of normality in future.



It is too soon to determine if the separated solids spread to land will have a beneficial effect on the soil although it can be assumed that the organic carbon content and nutrient indices are likely to change over time. This would require monitoring over a suggested period of 5-6 years.

In areas where soil P indices are already high but crops require N application, there may be a potential means of separating out the individual nutrient constituents of farmyard slurry. Ion exchange technologies are already well established in certain industries and used in many contexts, including desalination and the deionization of water[72]. The principle of ion exchange can also be applied to the removal of P from wastewater. Whilst not as widely studied or applied as other physico-chemical P removal methods, the highly selective nature of some exchange media means that their consideration may be warranted. This technology is outside the current project remit, but may be something that would gain traction in future as we search for a viable method of individual nutrient separation on a commercial farm scale.

Trials using AEOP for removal for both COD and ammonia showed limited performance. If the ammonia removal rates were extrapolated, the energy required is expected to be prohibitive and considerably in excess of other existing solutions. However, Soneco® may be better considered as an option for polishing or disinfection process downstream when the majority of the contaminants had been removed.

The natural processes involved in treating wastewater in a constructed wetland have proved efficacious, with the quality of the final effluent being suitable for discharge. Moreover, the microbiology was considered better than bathing water quality. Additional UV treatment should ensure that the water is safe for the cattle to drink, closing the circular economy loop. Turbidity was recorded as 0.6NTU, a 99.9% decrease against the influent. For comparison, the World Health Organisation (WHO) report that potable water should ideally be kept below 1NTU[73].

Care must be taken however, not to overload the system with high solid loadings as this would blind the natural filtration process, preventing flow. High levels of contaminants outside the design parameters may also be detrimental to wetland health and therefore final effluent quality. The environment created has also provided a natural habitat for a number of plant, insect, mammal and bird species.

Recommendations

Primary Reaction Tank

The third stirrer in the series should be independently controlled and not fixed to the same speed as the stirrer in the flocculation chamber. This would allow staged flocculation and improved dewatering/separation. Specifying a reaction tank with high performance pitched blade turbine impellers should improve blending whilst also reducing shear in the flocculation chamber.

DAF Reaction Tank

The dimensions of the reaction tank should allow for a tank diameter : impeller diameter ratio of between 0.25 – 0.4. A sludge pump with increased capacity should be fitted for ease of operation/maintenance.

Next steps

Regional hubs are not a novel idea. There are several such schemes in operation, where slurry from a group of regional farms is delivered to a central AD treatment facility for processing, which the digestate being delivered back to the same farms. However, in order to truly manage farm slurry on a regional scale it is suggested that the integration of separate and distinct technologies would need to be combined in one complete treatment system, incorporating AD, de-watering/nutrient recovery and pyrolysis technologies. A feasibility design study would need to be implemented considering the technical and financial challenges associated with a regional treatment facility of this kind, including location; engineering; logistics; funding mechanisms; long term benefits, carbon footprint, operation etc. Should this study prove its viability, a small-scale pilot treatment hub would first need to be established in order to test the practicalities of such a scheme.

Long Term Vision

- Regional Treatment Hub incorporating slurry dewatering and nutrient recovery, AD, pyrolysis and constructed wetlands
- Slurry to be collected from farms in bulk volume tankers and delivered to the hub for processing
- Treated organic fertiliser (in the form of biochar) to be applied on permitted land (e.g soils with low/medium indices)
- Hub to be powered by AD CHP
- Tanker/Tipper lorries and handling equipment on site to be powered by methane from AD
- Heat treatment from pyrolysis process kills pathogens so biosecurity isn't an issue. Also potential for the sale of biproducts e.g. pyrolysis oil. Pyrolysis gas given off by the process can be used to fuel pyrolysis plant.
- Economy of scale means treatment costs are less per m3 of treated slurry
- Hub to be situated where excess electricity/heat can be distributed to local businesses

In addition to the eutrophication of water bodies through excess nutrient run off, another ever increasing area of pollution concern from farms is that of air quality. Both ammonia and nitrogen oxide emissions from fertilisers applied to fields play an important part in the formation of particulate matter in the atmosphere, particularly PM2.5. This is obviously not withstanding the nuisance odours which are associated with spreading farm manures/slurries. On the back of the important work carried out as part of the Tywi Farm Nutrient Partnership and Tywydd Tywi Weather projects, a more targeted use of nutrients, equating to lower air-borne emissions can be foreseen. The deployment of gas and particulate matter monitoring equipment alongside current weather stations installed by Tywydd Tywi Weather, current project partners Dŵr Cymru/Welsh Water and recently launched Four Rivers 4 Life project from NRW, would aim to capture and analyse gaseous emissions/particulate matter arising from traditional nutrient application methods and compare to more advanced technologies, including nutrient enhancement and acidification (NEO, N2 Applied) and fertigation (Netafim). The data generated could be tied into the data from the weather stations so that gaseous emissions can be correlated to PM2.5 depending on wind direction, wind speed and precipitation. Project partners NRW, have already expressed their interest in investigating air quality control measures in agriculture and are enthusiastic about working with CSG in future.

Sample Analysis

Sample analysis was primarily conducted by NRW Analytical Services. However, other UKAS accredited laboratories (AltAir Analytical Ltd; Decus Research Limited) were also utilised from time to time to conduct analyses not offered by NRW, as well as the Power and Water in-house laboratory and IBERS - University of Aberystwyth.

Statistical Analysis

Correlation Coefficients – (*r*)
The closer the correlation coefficient is to +1 or-1 the stronger the correlation
+1 = positive correlation (as one variable increases so does the other)
-1 = negative correlation (as one variable increases the other decreases)

Correlation coefficients whose magnitude are between 0.9 and 1.0 indicate variables which can be considered **very highly correlated.**
Correlation coefficients whose magnitude are between 0.7 and 0.9 indicate variables which can be considered **highly correlated.**
Correlation coefficients whose magnitude are between 0.5 and 0.7 indicate variables which can be considered **moderately correlated.**
Correlation coefficients whose magnitude are between 0.3 and 0.5 indicate variables which have a **low correlation.**
Correlation coefficients whose magnitude are less than 0.3 have **little if any (linear) correlation.**

Correlation Coefficients only outline a trend in data sets and do not signify causation.

Students T-Test

Students T-Test
A T-Test is a statistical test used to determine if there is a significant difference between the means of two sets of data and how they are related and is often used in hypothesis testing to determine whether a process or treatment actually has an effect. T-Test scores, with low *p*-values <0.05 indicate the data did not occur by chance i.e. there is a significant difference between the two sets of data. T-Test scores with high *p*-values >0.05 indicate the data occurred by chance i.e. there is no significant difference between the two sets of data.

T-Tests were conducted using the influent and effluent data only.

Percentile

A percentile (or centile) is a value of a variable below which a certain percent of observations in a data set fall. Percentiles tell you where an observed score stands in relation to other scores within that data set.

Standard Deviation

The standard deviation is a measure of how spread out the numbers in the dataset are from the mean.

Appendices

Appendix A - Partner Evaluations

Honesty Foods

SMARTExpertise2014 – 2020
Research Development & Innovation (RD&I)
Partner Progress Report

Partner Name
Honesty Foods
Project Title
Tywi Nutrient Farm Partnership
Lead University
Coleg Sir Gar
Period
April 2021 – September 2022

1. Project Activity
- Provide a summary of the activity undertaken this period
- How does this meet with the project objectives and work packages?
- What benefits have you seen from this work? Does this include collaboration with any of the other partners (if so, who have you worked with, has this led to any further unforeseen benefits?)

Consultations and meetings with a range of equipment, chemical suppliers and regulatory bodies regarding the better use of dairy slurry. Visits to many dairy farmers to discuss their attitudes to slurry handling, the value of slurry as a fertilizer and its contribution to climate change as a significant source of methane.

The rocketing of fertilizer prices has focussed their minds on how to make much better use of their slurry. The modular systems at Coleg Sir Gar allows them to pick and choose which process best meets their individual farm requirements as they start to realise that legislation with regard to climate change is going to force them to change their current working practices. Coleg Sir Gar is now recognised as the centre of excellence with regard to dairy slurry treatment and has become the go-to venue for discussions and further research on this subject.

2. Publicity

- Have there been any good news stories arising from the project activity to date?
- Please provide details of any project related publicity / marketing materials or papers published by the university/company to date.

Visits

Defra Civil Servants visit form London

WG Civil Servants visit form Cardiff

Welsh Government – 6 AM members of the Economy and Rural Affairs Committee

Lesley Griffiths Minister for Rural Affairs & Cefin Campbell AM

Andrew RT Davies - AM

Open Day – Jointly with Farming Connect & AHDB Dairying

Publicity

Website www.arc-csg.cymru
Facebook - @AgricultureResearchCentreCSG
Twitter - @arc_csg
Instrigram - @arc_csg

Technical Note 2.0
https://arc-csg.cymru/2021/12/01/separation-of-colloidal-and-dissolved-material/

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Technical Note 3.0 - Process Flow Concept

https://arc-csg.cymru/2021/12/16/technical-note-3-0/

Tywi Farm Nutrient Partnership – Interim report concluding 2021

https://arc-csg.cymru/wp-content/uploads/2022/09/Tywi-Farm-Nutrient-Partnership.pdf

TywiFarmNutrientPartnership – Semi Annual Report January – June 2022

https://arc-csg.cymru/2022/01/14/tywi-farm-nutrient-partnership-interim-report-concluding-2021/

River pollution solution trialled on dairy farm in Wales

https://www.bbc.co.uk/news/uk-wales-62753117

Energy event targets cost savings and efficiency improvements

https://www.nfu-cymru.org.uk/cy/newyddion-a-gwybodaeth/energy-event-targets-cost-savings-and-efficiency-improvements/

New app can help fine-tune NVZ pollution risks
https://www.walesfarmer.co.uk/news/20607826.new-app-can-help-fine-tune-nvz-pollution-risks/

Prosiecti 'chwyldroi' y broses o drincarthiongwartheg?

https://www.bbc.co.uk/cymrufyw/62727726?at_custom4=D63B4854-2A88-11ED-AD85-9B0616F31EAE&at_campaign=64&at_custom1=%5Bpost+type%5D&at_custom3=%40BBCCymruFyw&at_custom2=twitter&at_medium=custom7

3. Looking Forward

- Please provide a summary of planned actions for next quarter.

As more cost data comes out of the project the individual modules can be discussed in detail with dairy farmers. These options include basic slurry store covering, on-farm acidification of slurry, screw press and decanter processing (with or without chemicals), reed bed installation, drip line fertigation, farm soil mapping and weather dependant application advice.

Further work with N2 applied will also give the farmer the option to improve the nitrogen content of their own slurry using on farm generated electricity via an AD plant or solar panels.

The clamp down on methane emissions in Agriculture worldwide particularly in New Zealand and Holland together with the dramatic rise in fertilizer prices has brought slurry manage-

GEA

SMARTExpertise 2014 – 2020
Research Development & Innovation (RD&I)
Partner Progress Report

Undeb Ewropeaidd / European Union — Llywodraeth Cymru / Welsh Government
Cronfa Datblygu Rhanbarthol Ewrop
European Regional Development Fund

Partner Name
GEA
Project Title
Tywi Nutrient Farm Partnership

Lead University
Coleg Sir Gar

Period
April 2021 – September 2022

4. Project Activity

- Provide a summary of the activity undertaken this period
- How does this meet with the project objectives and work packages?
- What benefits have you seen from this work? Does this include collaboration with any of the other partners (if so, who have you worked with, has this led to any further unforeseen benefits?)

GEA have supported the project with on-site services and remote assistance in the development of slurry separation to get it as efficient as possible. We have carried out onsite testing as well as lab-based sampling on nutrient separation.

GEA have also promoted the project through marketing and the farming network within GEA.

The work on the project has allowed us to carryout testing and development which would otherwise mean travelling around farms to do the testing in different locations across a much longer time span. It also saves our process team a lot of time in doing this as it is done on our behalf when we are not on the project site.

GEA farm technologies division are now in collaboration with N2 applied who are also partners in the project. This has been arranged at divisional level.

There are many benefits to commercial companies from the project. The biggest is being able to bring potential clients along and speaking to the project team who are independent. This is invaluable when selling equipment into a new area. It gives more comfort to the buyer that the proposal has been backed and proven from an independent source.

5. Publicity

- Have there been any good news stories arising from the project activity to date?

- Please provide details of any project related publicity / marketing materials or papers published by the university/company to date.

GEA have had several potential customers visit the plant. At least one of these visits has turned into the sale of a machine with others in the pipeline. There have been other potential

clients visit from the biogas industry which could benefit from such system. These are also gathering pace and moving towards commercial orders.
GEA have written a marketing piece which has been distributed to the market. There is potential for several magazines and articles to come from it. This was done with our PR partner.
We use the data collected to put into proposals for potential clients having the confidence that we can meet the specified criteria.
Colleagues from Germany came to visit the plant with a view to gaining knowledge which can help farms worldwide. This is where the collaboration with N2 Applied came from.

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Prosiect i 'chwyldroi' y broses o drin carthion gwartheg?

https://www.bbc.co.uk/cymrufyw/62727726?at_custom4=D63B4854-2A88-11ED-AD85-9B0616F31EAE&at_campaign=64&at_custom1=%5Bpost+type%5D&at_custom3=%40BBCCymruFyw&at_custom2=twitter&at_medium=custom7

6. Looking Forward

- Please provide a summary of planned actions for next quarter.

GEA plan to roll out more systems whether it is through system integrators or direct to farms. The project has given us all the information we need to do this and an independent reference and report to back up our proposals.

The market is large and will continue to grow as will the need for slurry treatment. GEA has a good reach to the market having a division in farm technologies selling everything from feeding systems to milking to manure handling. This is another string to our bow so to speak. GEA will continue to support the college in the future with any further developments and research.

I confirm, to the best of my knowledge that all the details in this form are correct and that I have adhered to all relevant terms and conditions of the Collaboration Agreement.

Name Chris Clarke
Position Held	Head of Sales Separation - GEA
Date	15/11/2022

NRW

UNDEB EWROPEAIDD
EUROPEAN UNION
Llywodraeth Cymru
Welsh Government
Cronfa Datblygu Rhanbarthol Ewrop
European Regional Development Fund

SMARTExpertise 2014 – 2020
Research Development & Innovation (RD&I)
Partner Progress Report

Partner Name
Natural Resources Wales
Project Title
Tywi Nutrient Farm Partnership
Lead University
Coleg Sir Gar
Period
April 2021 – September 2022

7. Project Activity

- Provide a summary of the activity undertaken this period
- How does this meet with the project objectives and work packages?
- What benefits have you seen from this work? Does this include collaboration with any of the other partners (if so, who have you worked with, has this led to any further unforeseen benefits?)

Representatives from NRW, including the CEO and Board Members, have attended the site many times to see the innovative technology and to take part in meetings, particularly the Partnership Board meetings.

NRW have continued to analyse water samples as our in-kind contribution towards the project.

The work at Gelli Aur have featured in many discussions within NRW and the Wales Land Management Forum (WLMF) Sub Group meetings, particularly exploring the Tywydd Tywi App as real-time evidence for farmers to make decisions on spreading activities to land. NRW have been exploring the use of constructed wetlands for various treatments and this project has helped to understand the tertiary treatment of slurry on farms, with many discussions with waste and water policy teams.

We have worked closely with ARC at Gelli Aur to provide evidence as part of the Alternative Measures that the WLMF Sub Group submitted to Welsh Government.

8. Publicity

- Have there been any good news stories arising from the project activity to date?
- Please provide details of any project related publicity / marketing materials or papers published by the university/company to date.

NRW hosted a session at the Royal Welsh Agricultural Show in July 2022 on the NRW stand on management of slurry and invited ARC and Tywi Farm Nutrient Partnership members to provide a talk.

NRW were part of the BBC news article - River pollution solution trialled on dairy farm in Wales - BBC News

An update on the project has featured in one of the WLMF Sub Group on Agricultural Pollution newsletters.

9. Looking Forward

- Please provide a summary of planned actions for next quarter.

NRW will continue working with the Tywi Farm Partnership members to help deliver the project and explore other opportunities with any future projects going forward.

Working with ARC on what permits/licences will be required for the treatment of slurry after the trial period.

I confirm, to the best of my knowledge that all the details in this form are correct and that I have adhered to all relevant terms and conditions of the Collaboration Agreement.

Name Marc Williams
Position Held Specialist Advisor: Agriculture, NRW
Date 16/11/2022

Dwr Cymru/Welsh Water

SMARTExpertise 2014 – 2020
Research Development & Innovation (RD&I)
Partner Progress Report

Partner Name
Welsh Water
Project Title
Tywi Nutrient Farm Partnership
Lead University
Coleg Sir Gar
Period
April 2021 – September 2022

10. Project Activity

- Provide a summary of the activity undertaken this period

- How does this meet with the project objectives and work packages?

- What benefits have you seen from this work? Does this include collaboration with any of the other partners (if so, who have you worked with, has this led to any further unforeseen benefits?)

Work on signing the NDA and Collaboration Agreement successfully concluded.
Sampling of the stream initiated.
Catchment scientists toured the site and met with the NRW at site

11. Publicity

- Have there been any good news stories arising from the project activity to date?

- Please provide details of any project related publicity / marketing materials or papers published by the university/company to date.

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I confirm, to the best of my knowledge that all the details in this form are correct and that I have adhered to all relevant terms and conditions of the Collaboration Agreement.

Name Paul Gaskin
Position Held Research and Innovation Scientist
Date 25/11/2022

Aquatreat

Undeb Ewropeaidd / European Union — Llywodraeth Cymru / Welsh Government
Cronfa Datblygu Rhanbarthol Ewrop
European Regional Development Fund

SMARTExpertise 2014 – 2020
Research Development & Innovation (RD&I)
Partner Progress Report

Partner Name
Aquatreat
Project Title
Tywi Nutrient Farm Partnership
Lead University
Coleg Sir Gar
Period
April 2021 – November 2022

1. Project Activity

- Provide a summary of the activity undertaken this period

- How does this meet with the project objectives and work packages?

- What benefits have you seen from this work? Does this include collaboration with any of the other partners (if so, who have you worked with, has this led to any further unforeseen benefits?)

Project Objection was:
1. Evaluating the best chemical treatment via Jar testing
2. Train Staff on Jar testing
3. Optimising chemical dosing
4. Training staff on how to optimise the dosing
5. Continual evaluation of chemicals throughout the Project as different aspects changed
6. Creating a visual display for Dairy Tech
7. Advice on supporting Equipment to enhance the chemical optimisation

I believe all objectives have been completed. As a business we work with Abattoirs, Dairies and food factories. This project gave us an understanding of what is needed at the front end of the food chain and is good to understand Natural Resources Wales plans moving forward as we can take this back to our industrial partners and plan for the future.

We have worked in conjunction with GEA on a Few projects to help them with their chemical needs.

2. Publicity
- Have there been any good news stories arising from the project activity to date?
- Please provide details of any project related publicity / marketing materials or papers published by the university/company to date.

Visits

Defra Civil servants Visit form London

WG Civil Servants visit form Cardiff

Visits

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Welsh Government 6 AM members of the Economy and Rural Affairs Committee

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3. Looking Forward

- Please provide a summary of planned actions for next quarter.

Continuous improvement as above objectives

I confirm, to the best of my knowledge that all the details in this form are correct and that I have adhered to all relevant terms and conditions of the Collaboration Agreement.

Name
Craig Quinnell
Position Held
Director
Date
08/11/22

Power and Water

SMARTExpertise 2014 – 2020
Research Development & Innovation (RD&I)
Partner Progress Report

Partner Name
Power & Water
Project Title
Tywi Nutrient Farm Partnership
Lead University
Coleg Sir Gar
Period
April 2021 – September 2022

1. Project Activity

- Provide a summary of the activity undertaken this period
- How does this meet with the project objectives and work packages?
- What benefits have you seen from this work? Does this include collaboration with any of the other partners (if so, who have you worked with, has this led to any further unforeseen benefits?)

Following on from earlier investigations into the use of electrocoagulation on agricultural wastes the investigations undertaken in this study were made to see if Electrochemical Advanced Oxidation Process (EAOP) could provide a suitable solution to on-farm water treatment, as part of slurry and other waste managements, to ultimately provide water that could be reused or discharge to water course.

Advanced oxidation processes (AOP) are the treatment of water and wastewater to remove contaminants, using an oxidation process with reactions involving hydroxyl radicals [•OH]. Electrochemical AOP (EAOP) generates these radicals through the electrolysis of water. Anodes with specialized coatings, usually containing transition metals, are used to carry out the electrolysis.

EAOP electrodes that can be used to produce free radicals can be grouped into two broad categories:

- Active – Reaction occurs on the surface of the anode – can promote the formation of stable oxidants.
- Non-active – generates highly oxidant species (H_2O_2), O_3, [•OH] and reactions can occur away from the surface of the electrode

For this investigation an anode from each group was investigated.

Method.
Water samples were collected by the CSG team and brought to Power & Water's laboratory. The samples were assessed to prepare a baseline composition and then were treated with EAOP using our bench top Soneco® reactor. Tests were done at a range of doses and using two different anode materials, one in the Active range and one in the non-Active range. The pH was adjusted for some of the tests to examine its influence and for some tests a coagulation process was applied first to see if any additional material could be removed to improve the EAOP.

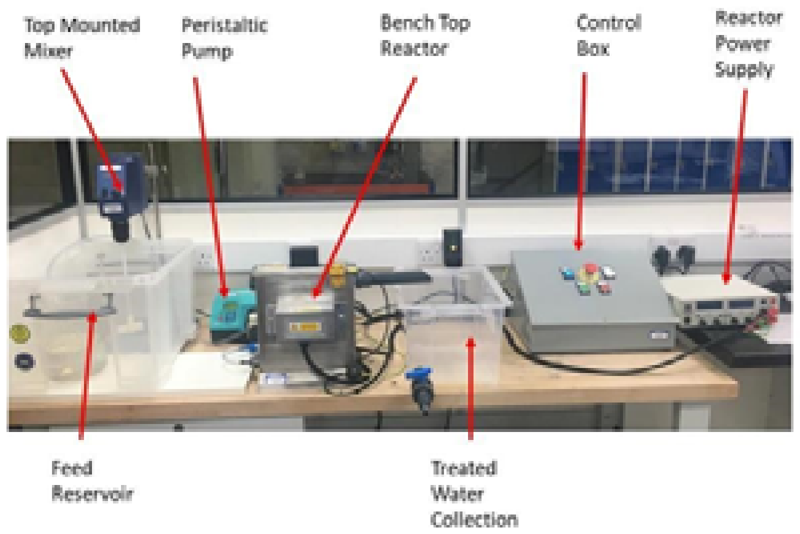

Fig 1 Bench top reactor setup

examine its influence and for some tests a coagulation process was applied first to see if any additional material could be removed to improve the EAOP.

Fig 1 Bench top reactor setup

Samples of the treated water were collected and the composition assessed.

Samples received had high concentrations of Ammonia and COD and it was necessary to undertake dilutions to be within the range of the determinand test kits. There was also still a lot of solid material in them. Variations in the samples were noted each time, and also there were differences reported with the on-farm processes in operation each time.

The laboratory results showed no consistent removal shown for the Ammonia or COD removal results with the active MMO. It is felt that some of the reduction shown at some doses can be attributed to errors introduced due to the significant dilution required to achieve measurements with the test kits in use.

There is some removal observed with the non-active MMO for ammonia, but this should be considered with caution, due to the dilution issues and the fact that there were a limited number of samples tested.

The non-active MMO was demonstrated a greater COD removal than the active MMO, but it did not improve with extra power.

In conclusion, removal for both COD and ammonia was limited. If the ammonia removal were extrapolated the energy required is expected to be prohibitive and considerably in excess of other existing solutions. However, Soneco® may be better considered as an option for polishing or disinfection process downstream when the majority of the contaminants had been removed. Testing for this would still be required and should be considered as a future work opportunity.

Power and Water- WP6.1, WP6.2, WP6.3, WP6.4 and WP6.5 will be led by Power & Water and supported by the Research Coordinator and the two Research Assistants.

WP6.1 - There is literature available regarding the use of EAOP for Ammonia and COD reduction, but it appears limited for agricultural wastes. Power & Water engaged with Strathclyde University to develop our knowledge on the subject, which lead us to an understanding about the influence of pH and active and non-active anodes and guided our laboratory investigation plan.

WP6.2, WP6.3 - Lab work was done as described above.

WP6.4, WP6.5 - Lab investigations did not identify a suitable solution at this time, for treatment at the proposed stage of treatment. Results suggested that the process may be better as a polishing process once the high contamination levels were removed.

Whilst we did not achieve the contaminant reduction that would be required at the proposed treatment stage, we were able to demonstrate some removal and along with other work we have been carrying out into EAOP and disinfection, suggest future work on final stage treatment (polishing) before discharge or reuse.

2. Publicity

- Have there been any good news stories arising from the project activity to date?
- Please provide details of any project related publicity / marketing materials or papers published by the university/company to date.

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3. Looking Forward

I confirm, to the best of my knowledge that all the details in this form are correct and that I have adhered to all relevant terms and conditions of the Collaboration Agreement.

Name Mike Rattenbury
Position Held Director
Date 13th December 2022

Netafim

SMARTExpertise 2014 – 2020
Research Development & Innovation (RD&I)
Partner Progress Report

Partner Name
Netafim
Project Title
Tywi Nutrient Farm Partnership
Lead University
Coleg Sir Gar
Period
April 2021 – September 2022

1. Project Activity

- Provide a summary of the activity undertaken this period

- How does this meet with the project objectives and work packages?

- What benefits have you seen from this work? Does this include collaboration with any of the other partners (if so, who have you worked with, has this led to any further unforeseen benefits?)

Work Undertaken:

1. Above ground testing. A series of tests run with CSG team to verify that the liquid post treatment caused no blockage of the driplines. In these tests we looked at the impact on different flow rate drippers. The results of this work guided the next stage of the development.
2. Install subsurface driplines in designated field. In doing this we designed a configuration that allowed testing of two flow rates of dripline and two spacings between driplines with a view to optimising grass growth and minimising the cost of the system to deploy.
3. With the driplines installed we could then install the pump and additional filtration along with control system to operate the drip system.
4. The system was then operated through the summer of 2022. Grass was irrigated periodically. Sensors were used to ensure no over irrigation. The grass growth was compared to unirrigated growth and samples were taken for quality analysis.

Project Objectives and Work Packages
Our primary objective was to take the Netafim subsurface drip irrigation technique used in other parts of the world with a mixture of slurry and water and apply it to the Welsh farmland where additional water is not necessary or always available. Due to the slurry processing and management tools assembled at Gelli Aur and incredible support and dedication of the team on site we have achieved this and can demonstrate a fully costed proposal to prospective customers. The Netafim Subsurface Drip irrigation compliments other techniques developed and demonstrated at Gelli Aur.
As part of our initial proposals, we anticipated being able to bring 3rd part advanced nutrient monitoring into this project to further automate and provide management data but unfortunately, we did not achieve, as the technology still today is not field ready. We will

continue to work with the manufacturer on this and once its ready will share the results with the Gelli Aur team and other collaborators on the project. Whilst this is unfortunate, we have invested no time or costs within this project on this aspect.

Project Benefits
Working with a consortium of the calibre that was assembled has been a privilege but more importantly has fast tracked a solution to be market ready. The Gelli Aur team have focussed attention on Welsh agriculture which without their intervention the solutions now available would not yet be field ready. The project offers the Welsh livestock producers a range of solutions but also a pathway to develop and build a unique investment plan to develop their on-farm slurry management. The solutions developed are applicable to livestock producers globally and we have shared our experience with colleagues and customers across northern Europe and Scandinavia.

2. Publicity

- Have there been any good news stories arising from the project activity to date?
- Please provide details of any project related publicity / marketing materials or papers published by the university/company to date.

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Netafim Global Internal News

Article presenting the open day and the project. Reach is Netafim 6000 global employees

3. Looking Forward

- Please provide a summary of planned actions for next quarter.

During this project we have developed and demonstrated how with Netafim subsurface drip irrigation, Welsh dairy farmers can maximise their benefit from cattle slurry, utilising all of the nutrient content to improve growth of feedstocks and reduce use of man-made fertilisers. This system allows application of slurry to be optimised around the weather and crop need and likewise reduce the risk of pollution. But more than that it removes the need for heavy machinery to move the slurry. The Gelli Aur open day was great success and obviously sowed the seeds of development for a number of farmers that attended.
As part of our commercialisation we are developing resources that farmers can access to understand in more detail our offering and the opportunities it brings. We are also in contact with the Gelli Aur team on how we may continue the demonstration after completion of this project.

I confirm, to the best of my knowledge that all the details in this form are correct and that I have adhered to all relevant terms and conditions of the Collaboration Agreement.

Name Julian Gruzelier
Position Held Chief Technical Officer
Date 25/11/2022

N2-Applied

Undeb Ewropeaidd / European Union
Llywodraeth Cymru / Welsh Government
Cronfa Datblygu Rhanbarthol Ewrop
European Regional Development Fund

SMARTExpertise 2014 – 2020
Research Development & Innovation (RD&I)
Partner Progress Report

Partner Name
N2 Applied
Project Title
Tywi Nutrient Farm Partnership
Lead University
Coleg Sir Gar
Period
April 2021 – September 2022

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WP 6.14 Desktop information study: A series of potential setups and implementations of the N2 technology into the existing process stream at Gelli Aur were explored and suggested. This was a conceptual study and the options for implantation and exploration were provided as part of the interim report delivered in February 2022. This study informed future decision making for implementing the technology on-site.

WP 6.15 Lab analysis of samples: Sampling and analysis was taken on two separate occasions in August 2021 and February 2022 to inform the interim report and estimation study. This was useful for predicting output potential of the N2 unit after installation, and planning future crop applications.

WP 6.16 Processing of slurry through trial unit: This WP was modified from the original plan as the small scale trial unit which was intended to be used was decommissioned early in the project. Instead, the full-scale plasma unit was installed at the farm earlier than planned to complete the processing originally determined to be in this WP. Initial processing of a small volume has been completed and will be sampled and analysed.

WP 6.17 Installation of plasma unit: This WP was due for delivery in month 18 of the project but was delivered early to align with WP 6.16 instead. The plasma unit was installed in September 2022 and will be operational for the next quarter. Further work can now begin to use NEO on site for larger crop trials and to feed into the existing project infrastructure.

WP 6.18 Decommissioning of plasma unit: Decommissioning of the plasma unit will be carried out before the end of the project if required, or the unit will remain in place if further funding is achieved, therefore making cost savings.

Additional benefits: In addition to the main WPs carried out, it was also possible to conduct 3x small scale plot trials using NEO on grassland and harvested for silage across the 2022 growing season. Though not in the original project plan, and using NEO sourced from another farm, these trials complimented N2 Applied's ongoing trials portfolio and gave valuable insight into the management of NEO inputs on the farm in the future, and for optimising future, larger scale trials work at the farm.

2. Publicity

- Have there been any good news stories arising from the project activity to date?
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N2 Applied press releases:
06/10/22 – Newsletter and press release covering the installation of the plasma unit at Gelli Aur Farm.

N2 Applied shows:
Attended Down to Earth and DairyTech shows in support of Coleg Sir Gar.
Attended and presented at Open Day at Gelli Aur 15/09/22.

3. Looking Forward

- Please provide a summary of planned actions for next quarter.

With the installation of the full-scale pilot unit at Gelli Aur Farm we now have the opportunity to develop the solution practically and carry out studies on-site based around the previous desktop studies carried out.

- There will be the opportunity to take and analyse samples of treated slurry from the farm itself and to validate the estimation report carried out in WP 6.15 and to satisfy WP 6.16.
- There is the potential to treat slurry and feed it into the existing infrastructure and dewatering technology, and to optimise the processes by exploring inputting NEO into different parts of the process.
- There is an expanded potential to collaborate with other project partners to optimise the processing and compliment their technologies, so satisfying WP 6.17. Netafim in particular we have already had a meeting with to discuss collaboration.

I confirm, to the best of my knowledge that all the details in this form are correct and that I have adhered to all relevant terms and conditions of the Collaboration Agreement.

Name Nick Humphries
Position Held Chief Agronomist
Date 08/11/22

Desktop study for performance potential of N2 Applied plasma unit for: Tywi Farm Nutrient Partnership

This report has been created to demonstrate the expected effects of implementation of a N2 Applied mk4.5 plasma unit at the Gelli Aur Farm site as part of the Tywi Farm Nutrient Partnership. Here set out, is a brief description of the N2 plasma technology, analysis and assessment of the various substrates available from the slurry and existing treatment processes in the project, a treatment estimation based on chemical analysis of these substrates, and a plan for the practical implementation of the N2 unit on-farm.

The N2 Applied plasma technology N2 Applied have developed is a novel plasma technology which fixes nitrogen (N) from the air and absorbs it into livestock slurry, increasing the fertiliser N content, reducing ammonia (NH3) loss, and preventing methane (CH_4) formation from the slurry. The technology operates solely on electricity which it uses to ionise a flow of air, splitting the nitrogen and oxygen molecules within, and generating a reactive nitrogen gas. The gas is then absorbed directly in the liquid phase of the livestock manure. Consequently, the manure is enriched with nitrate (NO_3) and its pH is lowered. This stabilises the ammonium in the manure, preventing its loss as NH_3, whilst also providing conditions which inhibit the formation of CH_4. The resultant substrate is then called a Nitrogen Enriched Organic (NEO) fertiliser. A diagram demonstrating a simplified version of the N2 plasma process is shown in Figure 1.

Various research projects and field trials have been conducted and have shown up to 95% reduction of NH_3 loss in storage, up to 91% of NH3 reduction on field application, and >99% control of CH_4 emissions in storage. The preservation of this NH_3-N and CH_4-C in the slurry allows for the return of these nutrients to soils. Additionally, the addition of renewably produced NO_3-N from the plasma process means a virtuous cycle can be created locally on-farm, supporting soil organic processes and crop growth, and reducing the carbon footprint of agriculture. This carbon footprint reduction comes from the offset of Haber-Bosch produced nitrogen fertiliser, a reduction in indirect nitrous oxide emissions from ammonia loss, and direct elimination of CH_4 emissions from slurry storage.

As part of this project with Coleg Sir Gar at Gelli Aur Farm, N2 Applied seek to further validate the results previously gathered and to demonstrate the implementation and impact on a working Welsh dairy farm. Additionally, incorporating the N2 technology into the existing project infrastructure and working with the other partners and solutions involved presents a fantastic opportunity to expand our knowledge. Both of the chemical processes involved in the treatment of various substrates and in the practical implementation of the N2 technology alongside other complementary technologies on a working dairy farm.

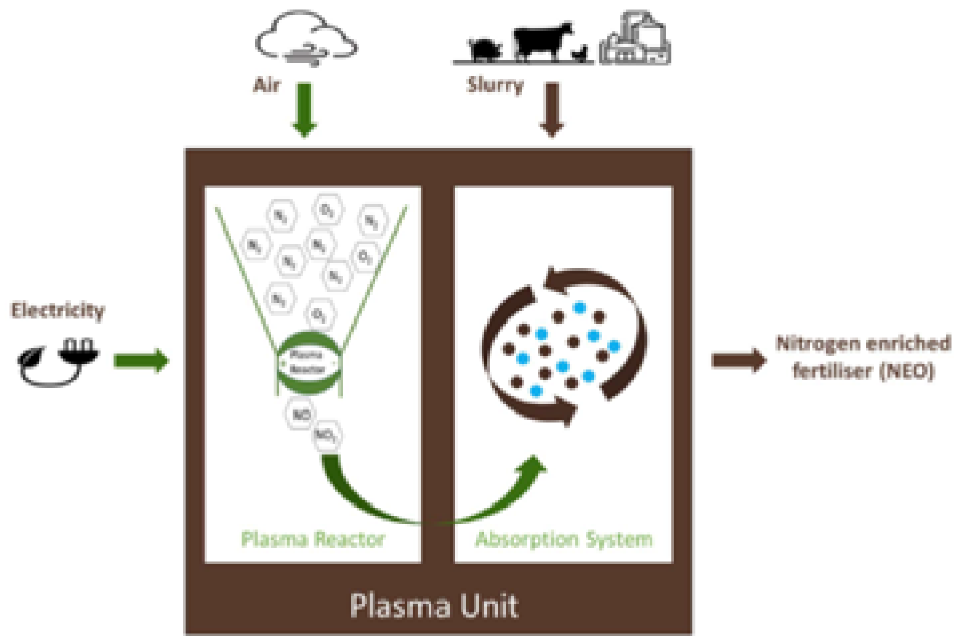


Figure 1: A Simplified Diagram Showing the Two-stage Process of the N2 Plasma Unit. In the first stage, air is passed through an electric plasma arc to generate NOx gas. In the second stage, this gas is then absorbed into the slurry to provide the treatment effect resulting in NEO fertiliser

Chemical analysis of Gelli Aur substrates. During a site visit on 10th August 2021 one sample each was taken from several points in the existing treatment setup at the farm, including separated slurry, diluted slurry from the storage tower, slurry which had undergone chemical separation, and surface sludge from the Dissolved Air Flotation (DAF) process. A diagram demonstrating the layout of the existing treatment setup is shown in Figure 2.

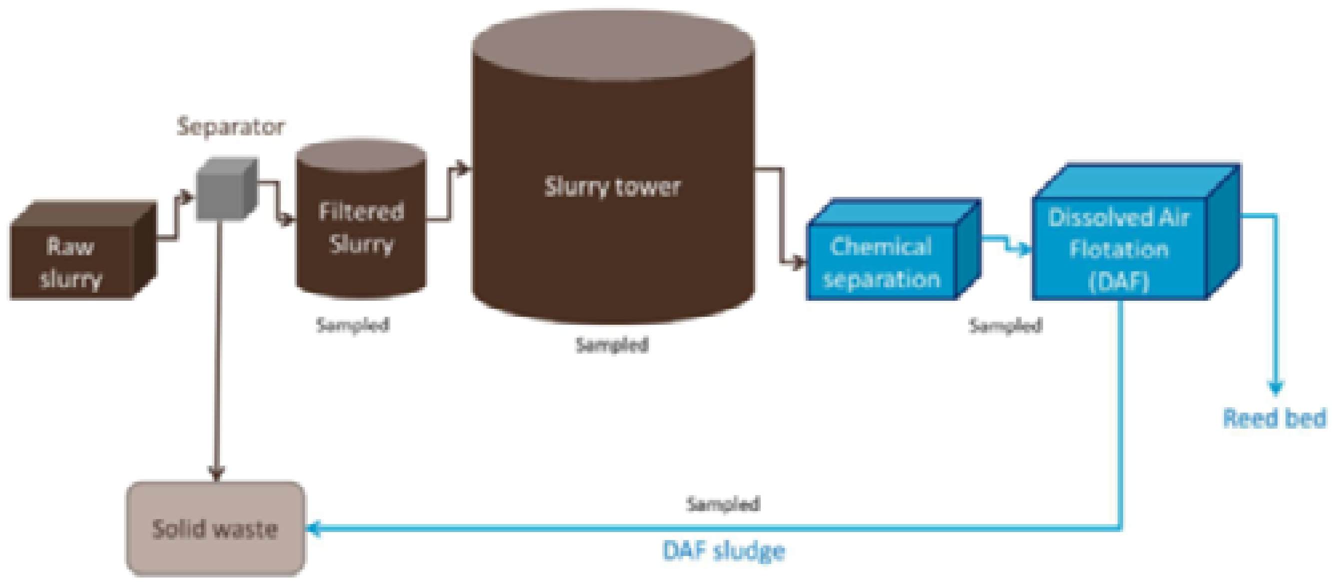


Figure 2 - Gelli Aur Farm Existing Treatment Setup. Points Sampled for Analysis are Indicated

Collected samples were sent to NRM laboratories for chemical analysis with the results included in Table 1. The results show interesting effects during progress through the treatment system. The raw slurry loses approximately 25% dry matter, but all soluble nutrients remain roughly at the same levels. Of particular interest to the N2 system is the total N and ammonium N which show minimal change from raw to separated but are relatively low compared to other dairy slurries which have been analysed by N2 Applied. The P and K are at similar levels to other slurries, with moderate P content to satisfy crop requirement upon land application, and high K content.

Between separation and storage in the tower the slurry is diluted with rain/wash water, and this is evident in the lowering of all chemical and physical factors by around a factor of 4 in the tower from separation, though nutrient levels remain proportional. After chemical separation most of the P is stripped from the solution, as are several other nutrients, and half of the total N is lost, but ammonium-N levels remain fairly stable by comparison. K also remains at a relatively stable level. Post-DAF sludge shows a proportionally high level of many of the remaining nutrients, indicating they are removed from the resultant water from the DAF, but these levels may be concentrated up. However, these samples were taken as an indication of the best place for implementation of the N2 treatment, and no conclusions about the performance of the existing system can be drawn.

Table 1: Chemical analysis of samples taken at different points in the Gelli Aur treatment process. Analysis provided by NRM laboratories

Laboratory Reference		SLUR111978	SLUR111979	SLUR111980	SLUR111982	SLUR111981
Sample Reference		CSG Raw	CSG Sep	CSG Tower	CSG Pre-DAF	CSG DAF Sludge
Determinand	Unit	Liquid Waste	Liquid Waste	Liquid Waste	Liquid Waste	Liquid Waste
Oven Dry Solids	%	5.63	4.21	1.07	0.380	0.370
TKN	% w/w	0.20	0.19	0.04	0.02	0.02
Nitrate N	mg/kg	<10	<10	<10	<10	<10
Ammonium N	mg/kg	941	1005	249	186	123
Total P	mg/kg	354	340	101	<5	<5
Total K	mg/kg	2760	2744	702	629	423
Total Mg	mg/kg	440	423	103	83.4	61.5
Total Cu	mg/kg	1.96	1.85	0.62	<0.2	<0.2
Total Zn	mg/kg	14.4	9.70	3.08	<0.5	<0.5
Total S	mg/kg	304	278	65.4	20.8	19.6
Total Ca	mg/kg	973	859	312	225	178
Nitrite N	mg/kg	<1	<1	<1	<1	<1
Total Na	mg/kg	279	271	105	99.8	266
pH 1:6 [Fresh]		7.52	7.57	7.18	7.34	7.04

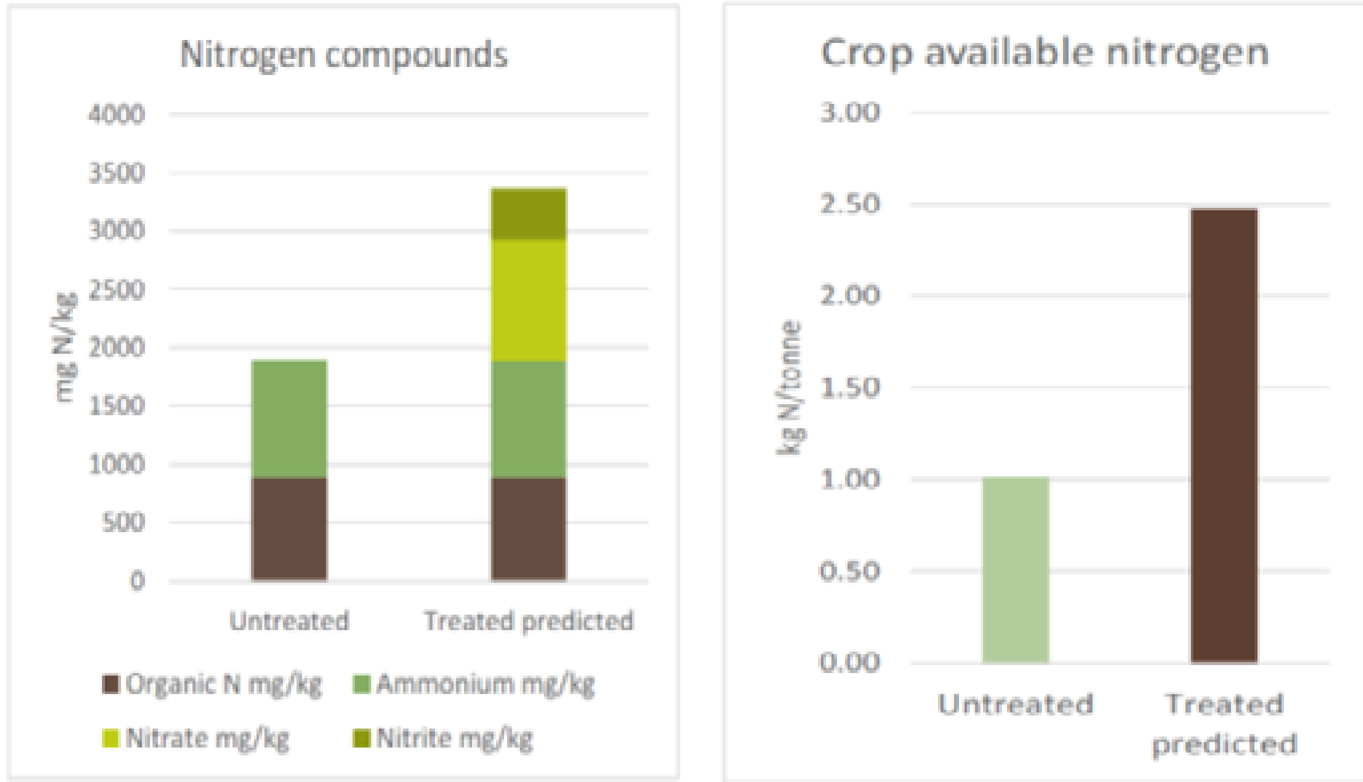
N2 estimated treatment effects

Using the analysis of the separated slurry it is possible to conduct a treatment estimation of the effects of the N2 unit and the resultant NEO fertiliser. The N2 plasma treatment process adds crop available N to the slurry in the form of nitrate and nitrite, whilst also eliminating methane loss and lowering the pH. The lower pH prevents ammonia loss, meaning more of the ammonium-N is retained in the digestate both in storage and on field application. Usually around 50% of the ammonium-N can be lost before reaching the crop. The estimated increase in total and crop available N is detailed in Table 2 and Figure 3 below. These are based on an average of empirical data from our database of previously treated samples.

Table 2: Predicted Changes in Total and Crop Available Nitrogen in Gelli Aur Farm Slurry After N2 Treatment

	From Analysis	Estimated After Treatment	Increase in N
Total N	1.90kg N/tonne	3.37kg N/tonne	+77%
Plant Available N	1.01kg N/tonne	2.47kg N/tonne	+145%

Figure 3: Graphs Displaying Expected Treatment Effects on Nitrogen Content of Slurry From Gelli Aur Farm



As can be observed the proportion of available N in the slurry would be greatly increased upon treatment through additional nitrate and nitrate. The organic N content of the digestate will remain unchanged, and all other nutrients such as P, K, Mg, S etc. will also remain at the same concentrations. This means that the soil conditioning effects of the slurry are still present, but with a higher N dose per unit volume application, and no ammonia loss.

N2 unit implementation

Based on the analysis results there are several different options for implementation of the N2 unit on-farm for treatment of the different substrates. These are detailed below. As part of this project, we will seek to further explore and test these ideas.

Separated slurry

Based on the analysis results presented in Table 1, the most optimal substrate for treatment with the N2 Applied plasma system appears to be slurry directly after mechanical separation. At this point there is a high level of ammonium content in the slurry to allow for absorption and enrichment with nitrate, and to provide the maximum benefits in terms of ammonia and methane reduction. The N2 unit also requires separation of the solids before treatment, so this stage is the simplest to implement. However, treating the slurry at this stage, though providing a good option for the N2 system in isolation, may not allow for full integration with the other technologies. This is due to part of the following process requiring the pH to be raised. Raising the pH would likely undo the treatment process of the N2 unit, favouring the formation of ammonia gas and possibly leading to loss of the added nitrate. NEO could therefore not be fed into the beginning of the existing treatment process but could find use as a side stream of production for direct field application. This layout is demonstrated in Figure 4 below.

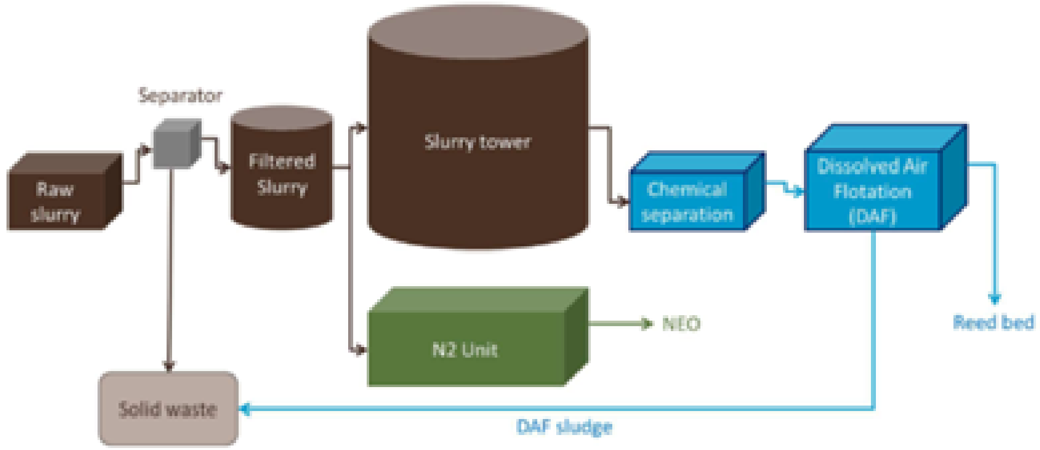


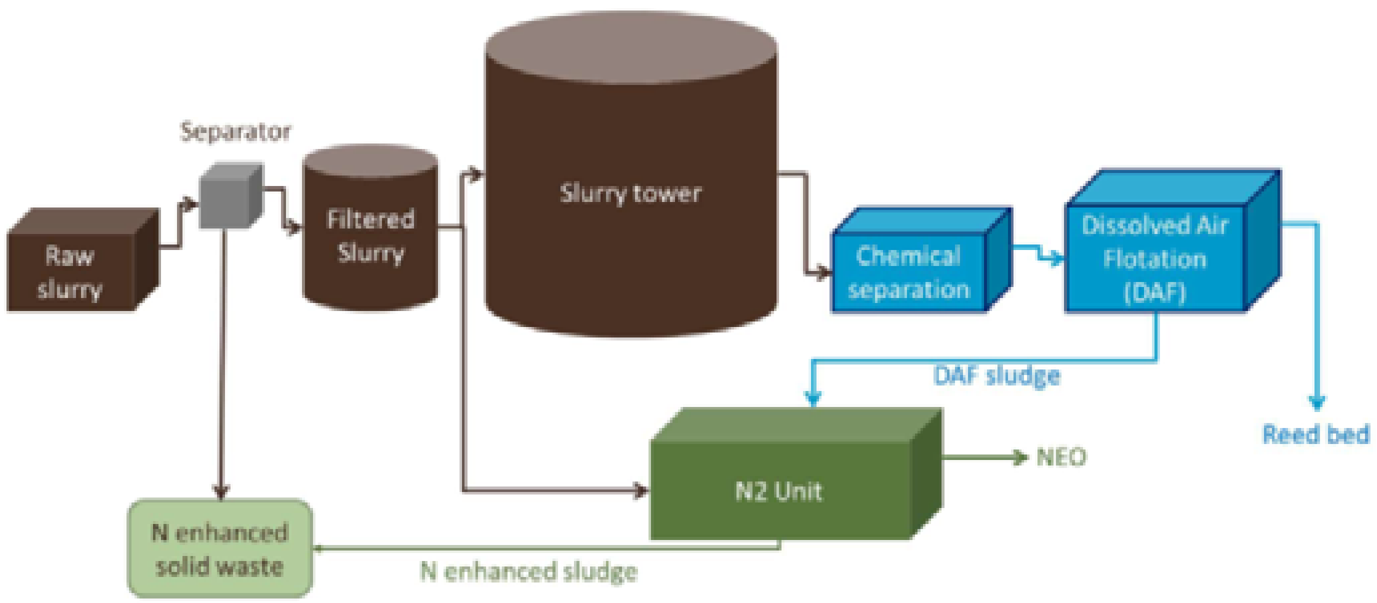
Figure 4: Implementing the N2 Unit as a Side Stream of Production to Generate NEO Fertiliser for Direct Field Application.

DAF sludge

An alternative treatment option could be to treat the DAF sludge. This contains some ammonium to allow for absorption capacity but is lower than slurry and so would likely treat very quickly. The N2 unit should be able to handle very high volumes of this liquid sludge. The current use of this sludge is to be applied to the separated solids from the slurry to enhance its fertiliser value. This route could still be utilised and enhanced by the N2 treatment, increasing the N content of the solids with additional nitrate, and making it a more valuable fertiliser product.

In terms of practical implementation, if the DAF sludge could be stored in small volumes of >1m3 it might allow for periodic treatment of the sludge as a side stream alongside treatment of the separated slurry. This could allow for upgrade of part of the slurry stream as NEO fertiliser whilst allowing the rest to be treated as dischargeable water, as well as enhancing the value of the solids. This would also increase the output volume of both systems, as there would be two separate streams of production each running at full capacity if needed. This setup would mitigate any high influxes of slurry or washing water/rainwater or could allow for expansion of the number of cows that the combined system could handle. A demonstration of this setup is shown below in Figure 5.

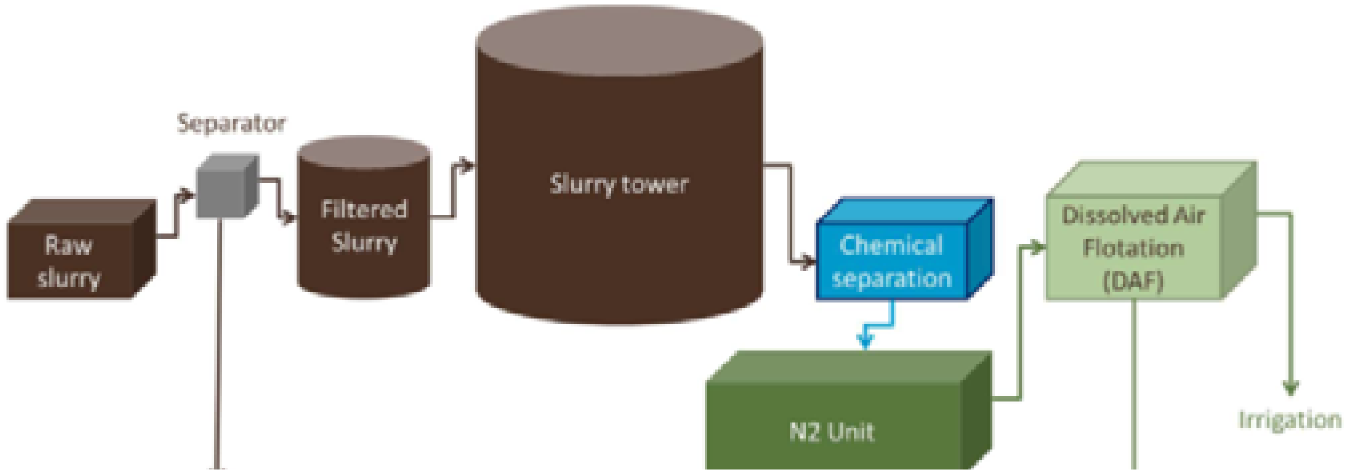
Figure 5: NEO as a Side Stream of Production and Used to Treat the DAF Sludge for Application to the Separated Solids



Pre-DAF

Another alternative implementation of the N2 unit could be to treat liquid post-chemical separation and before entering the DAF. There is a low ammonium content present in the pre-DAF liquid that should offer some treatment capacity. If the dilution effect from the slurry tower was removed and the ammonium content remains high this could provide a good medium for nitrate absorption. The uncertainty here is whether the nitrate is then separated out with the DAF sludge or, more likely, that it remains in solution. This could cause a problem with achieving discharge standard for the water, as nitrate which remains in solution is considered a pollutant if it finds its way into waterways. However, a water with nitrate content could provide an excellent option for fertigation if utilised alongside the Netafim irrigation as part of this project. The implementation has the most questions associated with it and will require further investigation. A demonstration of this setup is detailed in Figure 6 below.

Figure 6: N2 unit implemented to treat liquid post-chemical separation and pre-DAF



Conclusion

I hope this report provides some interesting information and insight into the N2 Applied technology and its potential and planned implementation as part of the Tywi Farm Nutrient Partnership project at Gelli Aur Farm. As further work is carried out and more information is gathered we look forward to providing updated results and moving forward with the practical implementation on the farm site.

Abbreviations

AHDB – Agriculture and Horticulture Development Board
AMD – Acrylamide Monomers
ATM - Atmospheres
ATV – All Terrain Vehicle
BOD – Biological Oxygen Demand
BDD – Boron Doped Diamond
COD – Chemical Oxygen Demand
CSG – Coleg Sir Gâr
DAF – Dissolved Air Flotation
DC/WW – Dŵr Cymru/Welsh Water
Defra – Department for the Environment, Food and Rural Affairs
DM – Dry Matter
DOC – Dissolved Organic Carbon
EC – Electro-Conductivity
EM - Electro-Magnetic
EU – European Union
GHG – Greenhouse Gas Emissions
GPS – Global Positioning System
GWP – Global Warming Potential
IoT – Internet of Things
IPCC - Intergovernmental Panel on Climate Change
LCA – Life Cycle Assessment
LESS – Low Emission Slurry Spreading
MMO – Mixed Metal Oxide
NEO – Nitrogen Enriched Organic Fertiliser
NFU - National Farmers Union
NIR – Near Infra-Red
NRW – Natural Resources Wales
NTU - Nephelometric Turbidity Units
OM – Organic Matter
OP – Ortho Phosphate
PAC – Polyaluminium Chloride
PAM – Polyacrylamide
PBT – Pitched Blade Turbine
ppm – parts per million
SCA – Soil Carbon Assessment
SG – Specific Gravity
SOC – Soil Organic Carbon
ST. DEV – Standard Deviation
TFNP – Tywi Farm Nutrient Partnership
TK – Total Potassium
TKN - Total Kjeldahl Nitrogen
TN – Total Nitrogen
TON – Total Oxidised Nitrogen
TP – Total Phosphorus
%TS – Percentage Total Solids
TSS – Total Suspended Solids
UV – Ultra Violet
WHO – World Health Organisation

References

1. Müller, C., Laughlin, R.J., Christie, P. and Watson, C.J., (2011) Effects of repeated fertilizer and cattle slurry applications over 38 years on N dynamics in a temperate grassland soil.
2. Haile, A. and Ayalew, T., (2018) Comparative study on the effect of bio-slurry and inor¬ganic N-fertilizer on growth and yield of kale (Brassica oleracea L.).
3. https://gov.wales/sites/default/files/publications/2021-03/water-resources-con¬trol-of-agricultural-pollution-wales-regulations-2021-guidance-for-farmers-and-land¬managers.pdf
4. https://projectblue.blob.core.windows.net/media/Default/Market%20Intelligence/dairy/Files/Supply%20and%20demand/Farm%20data/UK%20and%20EU%20cow%20num-bers/Average%20herd%20size%20by%20country%20(UK).xls
5. Møller, H.B., (2001) Separation of slurry in a decanting centrifuge and a screw press as influenced by slurry characteristics.
6. Natural Resources Wales. A review of the economic value of angling in Welsh rivers (2018).
7. Radford et al,. (2007)
8. Miriam Otoo and Johannes Paul (2017) Resource Recovery from Waste for Agriculture, Landscaping and Aquaculture.
9. Hongmei Cui et al,. Application progress of enhanced coagulation in water treatment (2020).
10. Bruno G. Pollet. Effect of ultrasound in liquids.
11. K.H. Gayer et al,. The solubility of aluminium hydroxide in acidic and basic media at 25oC.
12. Ning Wei et al,. Coagulation behaviour of polyaluminium chloride: effect of pH and coagulant dosage.
13. Driscoll CT and Schecher WD (1990); The chemistry of aluminium in the environment.
14. Witters HE et al (1996); Physiochemical changes of aluminium in mixing zones: mortality and physiological disturbances in brown trout.
15. P.K. Holt, G.W. Barton, C.A. Mitchell,. The future for electrocoagulation as a localised water treatment technology, Chemosphere (2005).
16. Kawamura (2000) - Integrated Design and Operation of Water Treatment Facilities.
17. https://www.watermarkprojects.co.uk/dissolved-air-flotation/
18. Sher, F., Malik, A. and Liu, H., (2013). Industrial polymer effluent treatment by chemical coagulation and flocculation.
19. Ye, C., Wang, D., Shi, B., Yu, J., Qu, J., Edwards, M. and Tang, H., (2007). Alkalinity effect of coagulation with polyaluminum chlorides: Role of electrostatic patch. Colloids and Surfaces A: Physicochemical and Engineering Aspects.

20. Yan, M., Wang, D., Yu, J., Ni, J., Edwards, M. and Qu, J., (2008). Enhanced coagulation with polyaluminum chlorides: role of pH/alkalinity and speciation.
21. Minnesota Pollution Control Agency (2006). Phosphorus Removal and Treatment Technologies.
22. https://www.naturalresources.wales How to comply with your environmental permit.
23. The Urban Waste Water Treatment Directive Regulations (UWWTR)
24. https://polyseed.com/wp-content/uploads/2020/06/BODforwebsite.pdf
25. WHO (1998), Aluminium in Drinking Water - guidelines.
26. WRc (1997) Treatment technology for aluminium, boron and uranium. Document prepared for WHO by the Water Research Centre, Medmenham, and reviewed by S. Clark, US EPA; A. van Dijk-Looijaard, KIWA, Netherlands; and D. Green, Health Canada.
27. WHO Guidelines for Drinking Water Quality – Fourth Edition (2011).
28. Health Canada (2020), Guidance on Natural Organic Matter in Drinking Water.
29. https://www.legislation.gov.uk/wsi/2018/647/made The Water Supply (Water Quality) regulations (2018).
30. https://www.merckmillipore.com/Web-PL-Site/pl_PL/-/PLN/ShowDocument-File?ProductSKU=MDA_CHEM 800830&DocumentType=MSD&DocumentId=800830_SDS_IN_EN.PDF&DocumentUID=1715275&Language=EN&Country=IN&Origin=PDP .
31. Anne-Gw´ena¨elle Guezennec, Caroline Michel, Kathy Bru, Sol`ene Touz´e, Nicolas Desroche, In`es Mnif, Mikael Motelica-Heino,. Transfer and degradation of polyacrylamide-based flocculants in hydrosystems: a review.
32. A. Nyyssölä, J. Ahlgren (2019) Microbial degradation of polyacrylamide and deamination product polyacrylate.
33. Boya Xiong, Rebeca D. Loss, D Shields, T Pawlik, R Hochreiter, A.L Zydney and M Kumar (2018).
Polyacrylamide degradation and its implications in environmental systems.
34. Feng Yu, Ruimin Fu, Yun Xie and Wuling Chen. Isolation and characterisation of polyacrylamide degrading bacteria from dewatered sludge.
35. C. Seybold (1994). Polyacrylamide review: soil conditioning and environmental fate.
36. Jennifer L. Kerr, John S. Lumsden, Spencer K. Russell, Edyta J. Jasinska, Greg G. Goss (2014).
Effects of anionic polyacrylamide products on gill histopathology in juvenile rainbow trout (Oncorhynchus mykiss).
37. R. Shanker, C Ramakrishna and P Seth. Microbial degradation of acrylamide monomer (1990).
38. L. Brown, K. Bancroft and M. Rhead. Laboratory studies on the adsorption of acrylamide monomer by sludge, sediments, clays, peat and synthetic resins (1980).
39. S.S. Lande, S.J. Bosch and P.H. Howard (1979). Degradation and leaching of acrylamide in soil.
40. R.M. LoPachin. The changing view of acrylamide neurotoxicity (2004).
41. https://www.haywardgordon.com Mastering Mixing Fundamentals.
42. H. Landry, C. Laguë and M. Roberge (2004). Physical and rheological properties of manure slurry.

43. Patrick T. Spicer, Wolfgang Keller and Sotiris E. Pratsinis (1996). The effect of impeller type on floc size and structure during shear-induced flocculation.
44. Sophie Balemans et al (2020) The impact of local hydrodynamics on high rate activated sludge flocculation in laboratory and full-scale reactors.
45. http://www.pellermix.com .
46. Perazzolo F, Mattachini G, Tambone F, Misselbrook T and Provolo G., (2015) Effect of mechanical separation on emissions during storage of two anaerobically codigested animal slurries.
47. Petersen J, and Sorensen P (2008). Loss of nitrogen and carbon during storage of the fibrous fraction of separated pig slurry and influence on nitrogen availability.
48. Fangueiro D, Senbayran M, Trindade H and Chadwick D. (2008) Cattle slurry treatment by screw press separation and chemically enhanced settling: effect on greenhouse gas emissions after land spreading and grass yield.
49. Amon B, Kryvoruchko V, Amon T, and Zechmeister-Boltenstern S. (2006) Methane, nitrous oxide and ammonia emissions during storage and after application of dairy cattle slurry and influence of slurry treatment.
50. Beudert, B.; Döhler, H.; Aldag, R. (1989). Ammonia losses from diluted cattle manure with water in a model test.
51. Ten Hoeve, Marieke, Gómez Muñoz, Beatriz, Jensen, Lars Stoumann, Bruun, Sander (2016).
Environmental impacts of combining pig slurry acidification and separation under different regulatory regimes - a life cycle assessment.
52. S. G. Sommer, M. Hjorth, J. J. Leahy, K. Zhu, W. Christel, C. G. Sørensen (2015) Pig slurry characteristics, nutrient balance and biogas production as affected by separation and acidification.
53. Adam J.H, (2019) Co-digestion of cattle slurry and food waste.
54. Fangueiro D, Hjorth M, and Gioelli F. (2015) Acidification of animal slurry – a review.
55. Regueiro I, Coutinho J, Fangueiro D, Pociask M. (2016). Animal slurry acidification affects particle size distribution and improves separation efficiency.
56. G. Cocolo et al (2014). Assessment of different solid-liquid separation techniques for livestock slurry.
57. Fangueiro D. (2010). Nitrogen mineralization and CO2 and N2O emissions in a sandy soil amended with original or acidified pig slurries or with the relative fractions.
58. Triin Saue, Kalvi Tamm (2010). Main environmental considerations of slurry acidification. Report from WP5, Activity 2.
59. Z. Al-Qodah, M. Al-Shannag, K. Bani-Melhem, E. Assirey, M. A. Yahya and A. Al-Shawabkeh (2018). Free radical-assisted electrocoagulation processes for wastewater treatment.
60. M. Shestakova and M. Sillanpää 2017. Electrode materials used for electrochemical oxidation of organic compounds in wastewater.
61. Bahman Kholdebarin and J. J. Oertli (1977) Effect of pH and Ammonia on the Rate of Nitrification of Surface Water.
62. Natural Resources Wales - Wales Bathing Water Quality Report (2020).

63. https://www.thescottishfarmer.co.uk/machinery/18187102.slurry-spreading-end-splash-plate-sight .
64. https://archive.ipcc.ch/ipccreports/sres/land_use/index.php?idp=84 .
65. https://www.teagasc.ie/publications/2020/low-emission-slurry-spreading-less.ph.
66. Samuel Mohammed Chekabab et al., The ecological habitat and transmission of Escherichia coli O157:H7 (2013).
67. M. Vital, F. Hammes and T. Egli (2008). Escherichia coli O157 can grow in natural freshwater at low carbon concentrations.
68. Maria del Mar Lleò et al., (2005). Survival of enterococcal species in aquatic environments.
69. Climate Policy Watcher - The Influence of Temperature on the Nitrification Rate.
70. H. E. Wild, Jr., C. N. Sawyer and T. C. McMahon (1971). Factors Affecting Nitrification Kinetics.
71. AHDB Nutrient Management Guide (RB209).
72. Awual and Jyo, (2011). Assessing of phosphorus removal by polymeric anion exchangers.
73. WHO, Water Quality and Health – Review of Turbidity (2017).

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