# Z-FILTER TRIAL – SCOTT RIVER DAIRY

## A ROYALTIES FOR REGIONS PROJECT

## Under the

## REGIONAL ESTUARIES INITIATIVE

**Final Report prepared for the**

**Department of Water and Environmental Regulation, Western Australia**

**By**

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## Executive Summary

A trial of manure separation was conducted on a large 1,600 head rotary dairy located in the Scott and Blackwood Rivers catchment using a commercial dewatering/filtering equipment called the Z-Filter. The aim of manure separation is to provide options for dairy farmers to beneficially utilise nutrients and organic material in effluent, whilst simultaneously reducing the risk of causing environmental harm to waterways and groundwater. The trial was funded by the $20 million Regional Estuaries initiative of the Western Australian Government in partnership with the Department of Water and Environmental Regulation (DWER).

A well-designed and carefully executed sampling program provided compositional measurements of raw effluent produced at the dairy, as well as for treated water Filtrate and separated solids Filter Cake produced as two products of the Z-Filter. This was done during summer and winter, and with and without enhancing nutrient removal by using coagulation-flocculation chemicals. The results showed that the Z-Filter very effectively removed manure fibres, and this enabled the farmer to shandy the treated water Filtrate with onsite bore water to irrigate over a large irrigation area using an existing centre pivot irrigator. This then directly offsets synthetic fertiliser use by the nutrients present in the treated water Filtrate, with a direct anticipated savings benefit.

With the use of flocculant+lime coagulation-flocculation chemicals, nitrogen and phosphorus removal were greatly improved. These captured nutrients then end up in the separated Filter Cake to be available for reuse when land-applied by the farmer at an appropriate and convenient time. The farmer of the trial dairy anticipated significant benefits from organic matter in the Z-Filter Filter Cake, to be used instead of purchased compost to boost soil productivity in previously underperforming areas of the farm. Natural composting of a stockpile of Filter Cake was observed during the trial period. Further research should explore the agronomic performance of composted Filter Cake to better understand agronomic applications of this product in terms of pasture and other crop production benefits.

The trial's results were comparable to those achieved in a previous trial of the Z-Filter applied to effluent at a Western Australian piggery. The trial also provided robust scientific data for the Z-Filter applied to dairy effluent. Such data for dairy effluent was not previously available. Encouragingly, a moderate dosage of flocculant in combination with lime resulted in a medium to high proportion of nitrogen (48.8%) and phosphorus (79.9%) captured. Moreover, the trial showed that the use of flocculant and lime greatly increased the level of organic matter captured as Filter Cake (by ~4 fold), which the cost analysis showed may be more valuable than the captured nutrients.

The trial was not without operational challenges, many of which resulted from the makeshift integration of equipment into an existing operation. For example, to minimise costs, existing infrastructure onsite was utilised to achieve consistent and reliable results. However, such existing infrastructure was not always optimal for the use-purpose, with higher than usual energy consumption and maintenance requirements. The trial was however able to illuminate/elucidate/illustrate various design short-falls and to correct these during and progressively after the trial. The trial provided the dairy farmer significant first-hand operational experience, including "joys and pain-points". Following this operational experience and based on anticipated benefits, the farmer decided to purchase the Z-Filter to incorporate it into the routine effluent management systems of the dairy. This suggested that, from the farmer's perspective, the benefits outweighed the operational costs and challenges of the Z-Filter.

Overall, cost savings were significant, including from offsetting synthetic fertilisers and using composted Filter Cake instead of purchased compost. The estimated was $\$103,500.\text{annum}^{-1}$ value, with an estimated payback period for the Z-Filter infrastructure of 3.2 years. It is acknowledged that the relatively high purchase and installation cost of the Z-Filter (approximately $200,000) and operational requirements would not be cost-justified for all dairies, especially not for smaller dairies. However, future work could explore transportable systems to provide separation and collection services to multiple smaller dairies, or to help clean up legacy material in existing unlined effluent ponds.

Overall, many of the expected benefits of the trial were achieved, as follows:

1. the project replicated the nutrient capture performance measured in a previous Z-Filter study on pork effluent, in this trial achieved for dairy effluent. The trial provided robust scientific test data. The current study also found an economically profitable proposition for the Z-Filter applied to dairy effluent;
2. the project provided options and showed that, the farmer proposed operational use of filtrate could be achieved with nutrients being spread over a much larger application area than previously, thereby substantially decreasing impacts, and greatly reducing the risk of causing environmental harm if used in combination with appropriate wet weather storage. The data provided by the report was initially used by the farmer and his agronomist to adjust the use of synthetic fertilisers, to better match requirements of the pastures and to reduce the risk of nutrient run-off;
3. the project showed that the nutrient content (specifically nitrogen and phosphorus) in the Filtrate could be substantially reduced by the operation of the Z-Filter with flocculant and lime. Moreover, the removal of manure fibres by the Z-Filter may make the use of a single-pond system a viable option without causing frequent blockages of irrigation equipment, because manure fibres removed by the Z-Filter would then not need to be removed by an upfront solids sedimentation pond as in a two-pond system. This may save on storage size and capital costs by reducing rainwater catchment of the effluent pond surface area;
4. the Z-Filter and associated systems provided the farmer with choice and control as to where and when the nutrients are to be directed (Filtrate or Filter cake). This has been readily grasped by the farmer as evidenced by his intention to maximise capture of nutrients (and organic matter) in the Filter Cake during wetter periods and to do the reverse during dryer periods. This allows the farmer to maximise value and minimise environmental risks; and
5. the capacity to produce large quantities of organic matter-rich Filter Cake was a major anticipated cost and production benefit to the farmer, meaning that commercial compost would not have to be purchased and the composition of the Filter Cake could be known and trusted. This allows the farmer to aim for improved soil productivity. There would be need for future work to test and confirm the agronomic performance of the resulting composted products.

The trial provided a strong basis and justification for further consideration of manure separation approaches to provide options for dairy farms to value-add to effluent and reduce the environmental burden of milk production. Overall, the trial results suggested manure separation could greatly value-add and reduce the risk of dairy operations causing environmental harm.

# 1 Background, Objectives and Scope

The Department of Water and Environmental Regulation (DWER), Western Australia (WA) supports Western Australia's community, economy, and environment by managing and regulating WA's environment and water resources. DWER also lead the delivery of the Regional Estuaries Initiative (REI), a multi-million dollar investment over four years aiming to halt the decline in water quality of key estuarine ecosystems in the South West Regions of WA. DWER partnered with Department of Primary Industries and Regional Development to deliver the REI through collaborations with government agencies, catchment management and industry groups.

Augusta-Margaret River Clean Community Energy (AMRCCE) is a not-for-profit community organisation dedicated to reducing overall carbon emissions and supplying cost-effective renewable energy to the Augusta Margaret River region. AMRCCE identified dairy effluent as a potential renewable energy source in the region, which led to interest in technologies that capture and use the manure energy component in dairy effluent, with the co-benefit of keeping dairy effluent out of waterways.

In this report and project, dairy effluent refers to the manure-laden water that is produced when milking sheds and impervious yard surfaces adjacent to milking sheds are washed. The composition and large quantities of dairy effluent involved led to investigations of manure separation technologies. Through these investigations, AMRCCE identified the *Z-Filter* as a potentially viable and attractive, commercially available technology which may separate dilute dairy effluent in a single processing step, into a concentrated manure cake (termed Filter Cake) and treated water liquid component (termed Filtrate) for beneficial reuse. The Z-Filter is a technology originally developed in WA with significant business ownership retained in WA. The Z-Filter technology was deemed potentially attractive for dairy effluent, because of its modular and transportable nature. The Z-Filter technology had been previously tested on piggery effluent in a scientific study by Payne (2014)[1] in Western Australia, which showed a high proportion of nutrient and organic matter capture. However, no similar scientific test data were available for a Z-Filter applied to dairy effluent. Moreover, dairy operations and dairy effluent are distinct from piggery operations and piggery effluent, with technical implications for feasibility of a Z-Filter applied to dairy effluent. This highlighted a need for a similar scientific study to be conducted with a Z-Filter applied to dairy effluent.

With the recommendation from the REI Sustainable Agriculture Project Reference Group, DWER funded AMRCCE to conduct a Z-Filter trial at a dairy in the Scott and Blackwood Rivers catchments. AMRCCE subsequently sub-contracted the Centre for Agricultural Engineering, University of Southern Queensland (CAE USQ) to assist with the scientific design and delivery of the dairy Z-Filter trial. Objectives of the trial were to:

Objective 1 – Determine if the extents of manure solids and nutrient separation found in prior research on pork effluent could be replicated with dairy effluent from pasture-fed herds in the Scott and Blackwood River catchment.

Objective 2 – Determine if farmer proposed operational use of Filtrate could be achieved.

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[1] Payne, H. 2014. On-farm evaluation of pond-less piggery effluent treatment system using novel flocculation and filtration techniques. Report prepared for the Co-operative Research Centre for High Integrity Australian Pork. Project 4C-112. Available at http://porkcrc.com.au/wp-content/uploads/2015/01/4C-112-Final-Report-.pdf. Last accessed 25/07/2020.

Objective 3 – Compare Filtrate composition to nutrient requirement of the farmer for their crop.

Objective 4 – Establish the base-line value of the nutrients recovered in the Filtrate.

Objective 5 – Determine on-going needs to store effluent in holding ponds, based on measured Filtrate composition.

Objective 6 – Determine suitability of Filtrate for recycling in dairy washdown for reduced water use.

Objective 7 – Determine nutrient and organic material captured in Filter Cake to be available for conversion into other products (e.g. fertiliser or biogas energy).

The Table below summarises In-scope and Out-of-Scope items for the Z-Filter trial.

**Table 1** Summary of project scope for the dairy Z-Filter trial

| **In-scope** | **Out-of-Scope** |
|---|---|
| • Installation, commissioning, and operation of a commercial Z-Filter unit on effluent at a dairy in the Scott and Blackwood River region<br>• Sampling and analysis of composition to quantify nutrients and dry matter in:<br>o untreated raw dairy effluent<br>o treated dairy effluent from the Z-Filter<br>o separated manure cake from the Z-Filter<br>• Calculations to determine nutrients and dry matter capture from dairy effluent by the Z-Filter<br>• Operational observations regarding energy, chemicals and labour requirements of the Z-Filter treating dairy effluent<br>• A comparison and contrast of the existing waste management system (prior to the Z-Filter trial) with the system incorporating the Z-Filter trial<br>• To better understand the impact of the Z-Filter operation on reducing previous environmental risk, literature values for typical nutrient retention in effluent storage ponds was used to estimate effluent irrigated on-farm prior to the Z-Filter trial. | • Actual recycling of treated effluent for flushing onsite at the dairy where the trial was conducted<br>• Sampling and analysis of legacy material in the existing onsite effluent ponds, because the storage ponds and previous sprinkler/irrigation system were not analysed as they were no longer used by the farmer at the start of the trial<br>• Biogas energy production testing using manure or dairy effluent<br>• Agronomic testing of treated effluent and separated cake<br>• Effluent management plan for the dairy where the trial was conducted<br>• Operational testing on other manure separation technologies (i.e. not a Z-Filter, e.g. screw press)<br>• Operational testing of a Z-Filter on other effluent types (e.g. piggery effluent, meat processing effluent, milk processing effluent) |

Whilst biogas production and agronomic benefits did not form part of the testing in the current trial, a subsequent successful funding application under the National Landcare Program - Smart Farming Partnerships – Round 2, will see further research conducted on these aspects in the Scott and Blackwood River catchments over the period 2020-2024.

# 2 Trial Methodology

## 2.1 Dairy trial site details

The dairy where the trial occurred, was in Courtenay, WA. Table 2 below summarises key features of the dairy operation. The dairy is predominantly pasture-based, with grain-based supplement diets fed during milkings and cut silage carted to paddocks near the milking shed from the end of summer to the beginning of winter. Pasture areas were irrigated during summer months using 3 centre pivot irrigators and extracted bore water (no treatment) (Table 2). This irrigation system was said to be able to service an estimated area of 206 hectares (ha). Fertiliser was routinely supplied in mineral form to irrigated areas following recommendations from an agronomist and based on soil and pasture compositional testing.

**Table 2** Summary of trial dairy details

| | |
|---|---|
| Total farm area | 1050 ha (672 ha is arable) |
| Herd size during project period | 1600 head, milking year-round |
| Milking shed effluent production | 110 kL.day$^{-1}$ (40,150 m$^3$ effluent per annum) |
| Dairy configuration | Rotary dairy, capacity to milk about 350 cows.h$^{-1}$ |
| Water source | Bore water; availability is reasonably reliable; quality prior to filtering is poor to moderate, low pH and rich in iron; filtered at the milking shed prior to in-shed use and use for flood wash |
| Milk yield (annual) | Total milk sales 10.5 million L |
| Average time on dairy yard | 2 milkings (5.5 hrs total each, morning and afternoon), 4 groups in continuous flow, but 1 group at a time on the yard. Time taken from when 1st cow in the group enters the yard to when the last cow comes off the rotary is approximately 1h 20 min + some waiting time<br>Accordingly, average time on yard time ~ 45 min (am) + ~45 min (pm) ~90 min total |
| Yard catchment area for rainfall entering the effluent management system | 1,800 m$^2$ (including concrete milking yard, and concrete laneway entries to the yard (Figure 1) |
| Total area available for effluent irrigation | 206 ha, divided into 3 sections = 2x73 ha + 1x60 ha |

## 2.2 Existing effluent management system

Figure 1 presents photos of the dairy where the trial occurred. Effluent was being generated by cleaning of milking equipment, and washdown of the milking yards with a pipe and riser system fed by two overhead freshwater tanks (13.5 kL and 7 kL). The washdown for each of the two daily milkings consisted of an initial wetting of the concrete yards before cows arrived, a minimal subsequent wash midway through the milking, and a majority final wash (90% of total volume) at the end of each milking. The final wash-down was assisted by mechanical scraping of the yard surface with a tyre dragged behind a small tractor and by manual yard scrapers used by dairy staff. The washdown water consisted of the same filtered water as used in the milking shed. Table 2 presents the estimated total daily effluent volume.

The effluent drained by gravity into a long rectangular unmixed trafficable collection sump. From here the effluent was pumped into unlined effluent storage ponds (Figure 1), using a large chopper pump with automatic float switch. For several years, effluent in the storage ponds was irrigated daily and year-round by a travelling irrigation system, over a small ~8 hectares (ha) area near the milking shed. This area was used for growing a summer crop of sorghum and maize but was likely heavily overloaded with nutrients by the repeated application of effluent over such a small area. The extent of groundwater or surface water impacts from the unlined ponds and the small irrigation plot were unknown but likely significant.

**Figure 1** Aerial photo from Google Earth Pro for the milking shed complex of the Z-filter trial site. The existing effluent storage pond(s) are visible towards the right of the background image and in a close-up in the bottom left corner image

Figure 2 shows an estimated rainfall catchment area currently draining by gravity into the effluent collection system. This catchment area consisted of the concrete milking yard and concrete surfaces immediately adjacent to the milking yard at the end of laneways. All roofed areas of the milking shed drained away from the effluent collection system. This is preferred because it reduces the required effluent system size by excluding from the effluent system the stormwater off the roof. At other Australian dairies, rainwater off milking yards is also diverted away from the effluent system, but this would be impractical to implement at the current trial dairy because of the design of the milking yards.

Measure the distance or area of a geometric shape on the ground

Perimeter: 164.39 Meters

Area: 1,710.31 Square Meters

☑ Mouse Navigation

**Figure 2** Aerial photo from Google Earth Pro for the milking shed complex showing the estimated catchment area of stormwater entering the effluent management system

Before the Z-filter trial begun, manure solids accumulated in the trafficable effluent collection sump and was typically cleaned out approximately once every 1-2 weeks. The removed solids were stockpiled nearby until spreading was possible using existing solids spreading equipment owned by the farmer. The nature of the removed solids (moist and bulky) made spreading on-farm difficult.

## 2.3 Z-Filter – Description and function

The Z-Filter (Figure 3) is a mechanical solids separation device that functions similar to a belt filter press. Specifically, a Z-Filter uses a fabric to filter out and retain the solids component in the effluent. With the Z-Filter, the fabric filter element is referred to as a "sock", because it uniquely folds into a tube which is clamped along a plastic seam to seal in effluent on the inside.

**Figure 3** Close-up of the Z-Filter unit located at the dairy trial site

The Z-Filter operation starts with the sock partly open to receive effluent, after which the sock closes and travels in a diagonal downward incline where most of the Filtrate drains through the sock via gravity (i.e. in the free gravity drainage section). From here, the sock changes direction and travels upward in a serpentine path via a set of rollers that massage further Filtrate from the remaining solid material retained in the sock. The sock then passes through two adjustable compression rollers, which provide final mechanical dewatering of the manure Filter Cake to produce a stackable solids product. Lastly, the sock opens and travels past a set of scrapers to remove the Filter Cake dropping into a discharge chute; the sock then passes by some high pressure water sprays to wash off any adhering solids and prevent the sock from clogging up. The sock then returns to the start of the process, and the cycle repeats. Filter Cake discharged into the Z-Filter discharge chute is conveyed by a screw auger and dropped from the end of the chute. The Filtrate collects at the base of the Z-Filter and flows out of the Z-Filter by gravity.

With this sock-like operation, a Z-Filter is uniquely able to process dilute manure effluent into a stackable solids product in a single processing step, and is also very compact and modular. This starkly contrasts with other manure solids separation technologies that either require a pre-concentration step to increase solids content in the effluent prior to treatment (e.g. screw press) or have a comparatively large footprint and dead-weight (e.g. belt filter press).

## 2.4 Purpose of testing during the Z-Filter trial

Specific aims of testing during the trial were to:

1. quantify the extent of nutrient and manure solids captured by the Z-Filter, with and without assistance of flocculation chemicals, and for a winter and summer sample[2];

2. determine via the continuous operation of the Z-Filter, if there were any practical limitations of the operation that would prevent its regular use on a dairy farm, and whether these could be resolved; and

3. measure the composition of the Filter cake and the Filtrate to better understand beneficial reuse options for these on-farm.

For this, various samples of raw effluent, Filtrate and Filter Cake were collected and analysed, and the Z-Filter was operated for the trial period by AMRCCE staff and the dairy farmer to gain practical experience.

## 2.5 Infrastructure used during the trial

Because the trial was not originally intended as a permanent effluent management system, but rather a trial to develop options, existing infrastructure onsite was utilised wherever possible to optimise costs. Additional infrastructure implemented for the trial included the Z-Filter system, as well as ancillary equipment to ensure that representative and consistent samples could be collected for analysis of the system performance. Table 3 summarises the trial infrastructure, also indicating where existing infrastructure onsite had been repurposed for the trial. Figure 4 presents photos of the delivery and installation of the skid-mounted Z-filter equipment and ancillaries at the dairy trial site. Figure 5 presents photos of the trial infrastructure once installation had been completed and the tests were started.

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[2] winter and summer samples sought to distinguish between likely operational differences in effluent management with a Z-Filter during wetter periods as opposed to during dryer periods of the year.

**Table 3** Trial infrastructure

| **Item** | **Supplied/Installed by** |
|---|---|
| Z-Filter delivered in a skid mount, with plastic roof (Figure 3). This included:<br>• the Z-Filter unit itself;<br>• a pump to supply high-pressure sock-wash service water;<br>• a feed pump to supply effluent to the Z-Filter; and<br>• an extension conveyer to discharge Filter Cake produced by the Z-Filter onto a solids stockpile. | Z-Filter (part of lease) |
| Flocculant preparation, dosing, and mix-in equipment (Figure 4), able to use a single liquid-emulsion flocculant chemical | Z-Filter (part of lease) |
| Concreted laydown area for the Z-Filter and ancillary equipment | Farmer |
| Roofed and concreted area for storage of stockpile of Filter Cake produced by the Z-Filter | Farmer |
| Service water supply to Z-Filter | Farmer - Existing |
| Power (electricity) supply to Z-Filter | Farmer |
| Z-Filter Feed Tank - 10 kL plastic tank for storage and mixing of effluent prior to being sent to the Z-Filter | Farmer |
| Overhead mixer unit to mount through the roof of the Z-Filter Feed Tank, to keep the effluent homogeneously mixed before being sent to the Z-Filter | Z-Filter (part of lease) |
| Pump to transfer raw effluent from effluent collection sump to the Z-Filter Feed Tank (directly above) | Farmer - Existing |
| A means of mixing the effluent collection sump to keep manure suspended and to ensure that manure solids are effectively transferred to the Z-Filter Feed Tank | Farmer – Existing repurposed |
| A Filtrate pump well, into which the treated liquid component from the Z-Filter drained by gravity, and from which this liquid component was pumped onto a plastic storage tank (directly below) | Farmer |
| Filtrate Storage Tank – A 50 kL plastic tank for storage of the treated liquid component produced by the Z-Filter | Farmer |
| Pump to transfer the treated liquid component from the filtrate pump well to the Filtrate Storage Tank (directly above) | Farmer |
| Pump to transfer filtrate from Filtrate Storage Tank onto the existing onsite irrigation system | Farmer |
| Air compressor to supply pressurised air to the Z-Filter compression rollers | Farmer |
| Connecting pipework and connector fittings, including:<br>• from effluent collection sump to the Z-filter Feed Tank;<br>• from the filtrate pump well to the filtrate storage tank; and<br>• from the filtrate storage tank to the existing onsite irrigation system. | Farmer |
| Connecting pipework and connector fittings, including:<br>• from Z-Filter Feed Tank to the Z-filter, including a section of winding piping to extend the length of travel for effluent to react with any added flocculant chemical; and<br>• from the Z-filter to the filtrate pump well. | Z-Filter (part of lease) |

**Figure 4** Skid-mounted Z-filter unit and ancillaries upon delivery and during installation at the dairy trial site

**Figure 5** Completed Z-filter installation at the dairy trial site

Figure 6 provides a flow-diagram with an overview of the trial infrastructure.

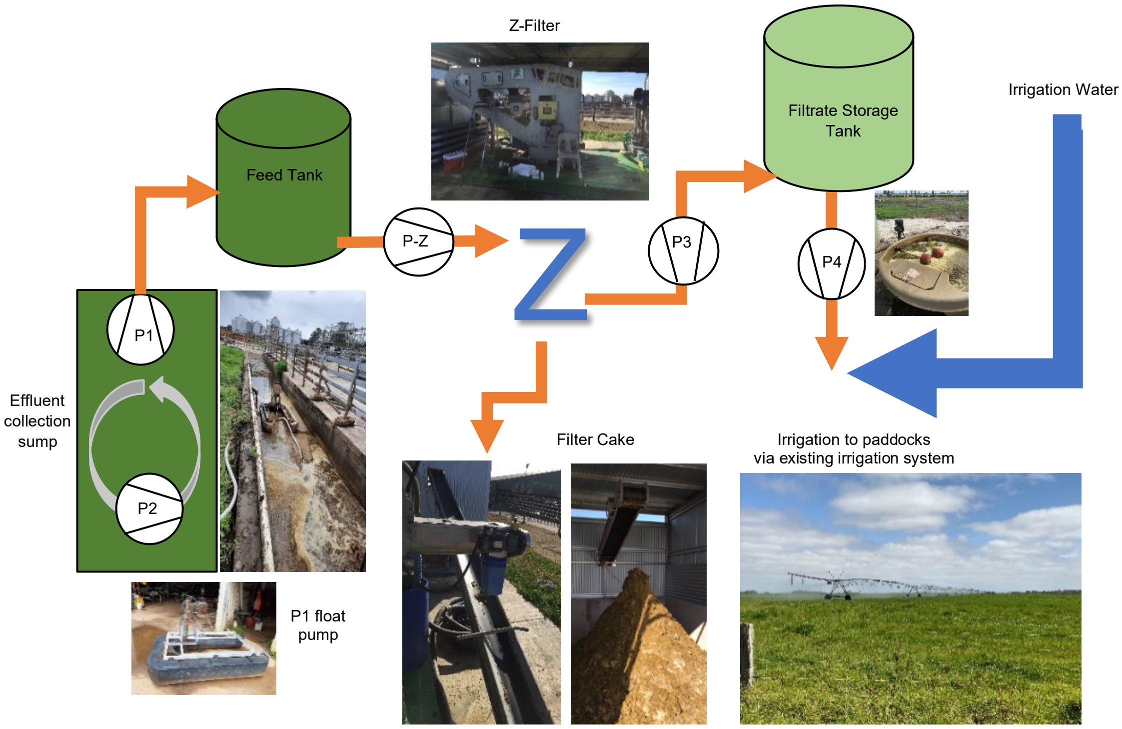

**Figure 6** Flowsheet overview of Z-filter trial infrastructure installed and operated at the dairy trial site. Orange arrows indicate the flow of effluent (untreated or treated) or separated Filter Cake. The large Z in the middle of the diagram signifies the Z-Filter unit. “P” in the diagram indicates a pump.

During the trial, effluent was collected as per usual in the rectangular collection sump, except that it was being mixed during the trial and thus no longer worked as a trafficable solids trap (see further below). Also, instead of the effluent being sent to the unlined effluent ponds and then onto the small irrigation area near the sheds, effluent was rather pumped from the collection sump to a Z-Filter Feed Tank. In this tank, the effluent was well-mixed using an overhead agitator to improve the homogeneity of the effluent for sampling and to smoothen the operation of the Z-Filter.

At the beginning of the trial, the farmer decided to discontinue use of the irrigation system and small irrigation paddock nearby the sheds, because of a high potential for environmental impacts and due to an inability to fully benefit from applied nutrients (See Section 4). Instead, the float pump that used to supply pond effluent to the irrigation system was reutilised to pump effluent from the rectangular effluent collection sump to the Z-Filter Feed Tank. This float pump (P1, Figure 6), operated based on a level switch with level sensors mounted on the inside of the Z-Filter Feed Tank. This ensured that the Feed Tank never completely emptied. In this way, the Z-Filter supply pump (P-Z, Figure 6) was protected from damage by preventing it running dry.

Effluent was pumped by P-Z, from the Feed Tank via an ultrasonic flowmeter that measured the flow rate of the raw effluent, via a dosing point where flocculant chemical could be added, via a high-shear inline impellor mixer designed to mix any flocculant chemical added with the effluent, via a section of pipe (winding stainless steel pipe of ~12 m plus 8 m of additional hose) to allow the flocculation of manure particles, and into the Z-Filter for processing.

The flowrate of flocculant chemical (when used) was adjusted by adjusting the rotation speed of the flocculant supply pump using a variable frequency drive. A separate ultrasonic flowmeter measured the flowrate of any flocculant chemical being added.

Filter Cake discharged from the Z-Filter discharge chute dropped onto a 9m conveyer, which transported the cake onto a stockpile in an adjacent solids storage shed. Periodically (~once per week), the farmer used existing farm equipment to collect the stockpiled Filter Cake to be composted/spread onto paddocks on the farm, also using existing solids spreading equipment.

Filtrate flowed by gravity into an external in-ground Filtrate pump well. From there, it was pumped by a submersible pump with a float switch (P3, Figure 6) into a 50 kL Filtrate storage tank. Finally, a transfer pump P4 (Figure 6) operating with a float switch, pumped the Filtrate from the Filtrate storage tank into:

1. summer - an existing onsite centre-pivot irrigation system, to be shandied with bore water and distributed across the existing irrigation paddocks (Figure 6); or
2. winter – an alternate irrigation system at an appropriate location elsewhere on the farm to be spread over an adequate irrigation area (See Section 4.2). In this case, the Filtrate was shandied with bore water.

## 2.6 Flocculation and coagulation chemicals used during the trial

Once the Z-Filter was successfully installed and commissioned, two separate commercial chemical suppliers were invited to attend site. These suppliers conducted testing onsite and offsite with various commercially available coagulation and flocculation chemicals to identify a suitable and effective chemical recipe for the dairy effluent of the trial farm (Figure 7).

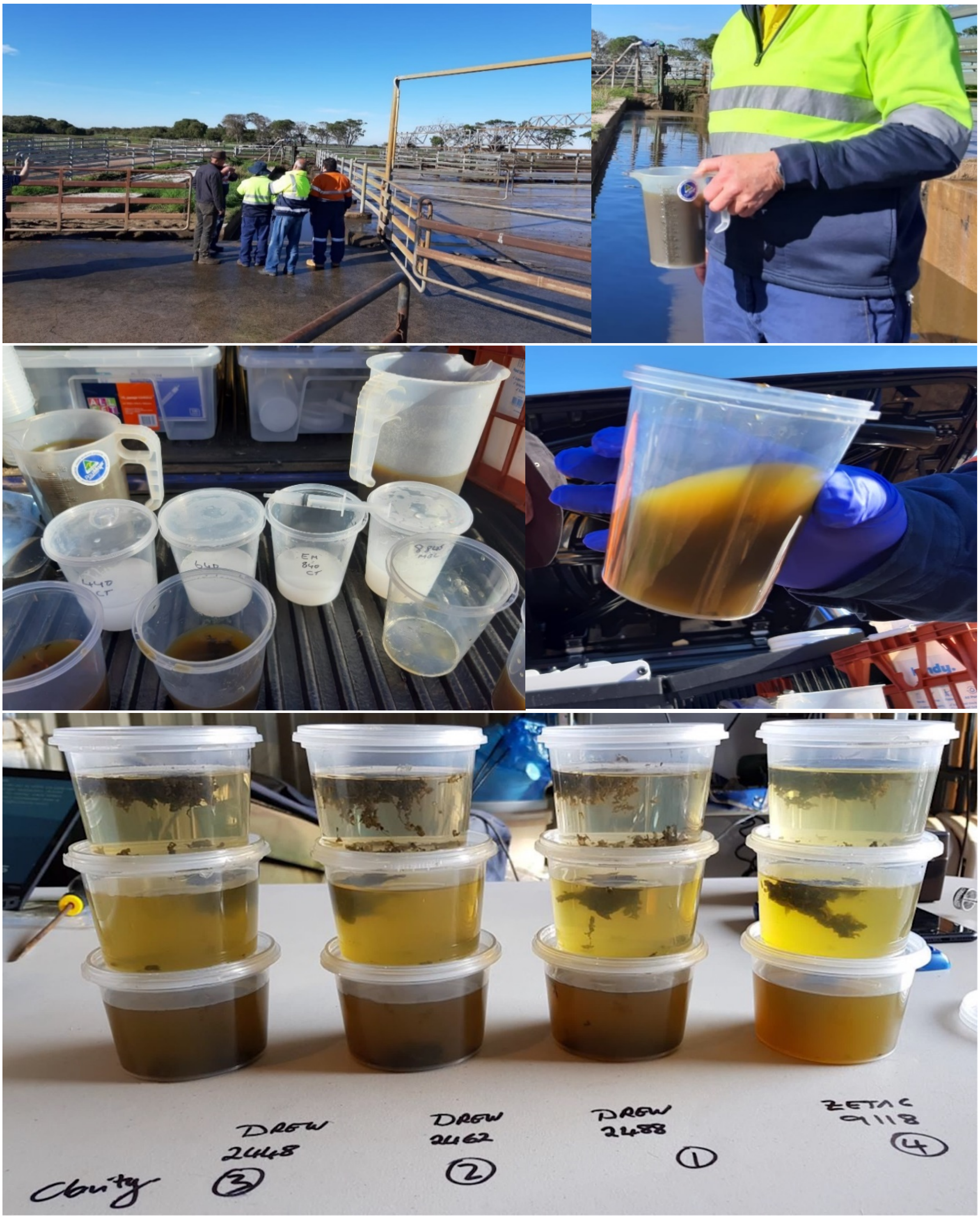

**Figure 7** Onsite and offsite testing performed by commercial chemical suppliers SNF and Solenis, to identify suitable chemical recipes to induce separation of manure solids and produce a clear Filtrate

From this chemical testing, a preferred flocculant chemical named Solenis DrewFloc$^{TM}$ 2488 was identified and purchased in 25L drums as a concentrated liquid emulsion. This flocculant was described by the manufacturer as a very high molecular weight high cationic charge polyacrylamide polymer. A Material Safety Data Sheet for this chemical is provided in Appendix A.

Flocculant mixing equipment used in the trial was supplied by the manufacturer/supplier of the Z-Filter as part of the lease arrangement of the equipment. This equipment was used to prepare a batch of flocculant for use, which consisted of 5 L of concentrated flocculant emulsion mixed with 1 kL fresh water, giving a 0.5% polymer solution. This involved adding the emulsion to a measuring funnel mounted on top of a t-piece, with a manual valve at its base slightly opened to slowly feed the emulsion into the t-piece. Fresh water was fed via the other port of the t-piece supplied from an adjacent 1 kL plastic storage drum. The outlet of the t-piece flowed through a centrifugal pump, which mixed the polymer and water together at high shear conditions and delivered the mixture into another adjacent 1 kL plastic storage drum. This latter storage drum had an overhead mixer unit to lightly mix the prepared polymer solution, before being switched off to not unnecessarily disturb the solution prior to use. A fresh batch of polymer solution was prepared for each sampling event that had chemical addition (See Table 4) and this batch of fresh solution was used within 1-2 days, in accordance with the supplier’s recommendations.

In some tests, a coagulant was also used in combination with the flocculant. The selected coagulant was industrial-grade Hydrated Lime (Hylime, Cockburn Cement) purchased from Bunnings in 20kg bags, and was used in the trial to:

(1) increase the cationic charge of the effluent to reduce the dispersive tendency of particulate organic matter in the effluent and thereby increase aggregation and growth of floccules. This would then reduce the need for flocculant (much more expensive) to increase the cationic charge of the effluent; and/or
(2) to increase the pH of the effluent, suggested to be favourable for improved performance of the type of flocculant that was used (SNF, personal communication, 2019).

The HyLime was added manually to batches of effluent held in the Z-Filter Feed Tank, and the amount added was based on measured pH of the effluent to be adjusted to around pH 9.2. This typically required approximately 1.5 L of HyLime per 8kL of effluent, and the adjusted pH was tracked and confirmed with a pre-calibrated pH probe (TPS, WP801-1211091, Waterproof WP-80 pH + Temperature) immersed in the Feed Tank contents whilst being mixed. DWER’s kind provision of funding to purchase this pH probe is gratefully acknowledged.

## 2.7 Test conditions and sampling during the trial

Table 4 below summarises test conditions used for sampling during the trial period.

**Table 4** Z-Filter operational settings/conditions and sampling details

| Operating conditions tested | Samples * | Sampling dates | Effluent flow rate ($L.min^{-1}$) | compression roller (bar) | Sock speed (Hz) | Flocculant# | Flowrate of prediluted flocculant as % of effluent flowrate | Lime ^ |
|---|---|---|---|---|---|---|---|---|
| No chemicals – Summer samples | 6 samples in total, collected across three days | 27/10/19<br>13/01/20-15/01/20 | 278 - 402 | Roller 1: 1.99-2.38<br>Roller 2: 1.82-1.95 | 7-7.5 | - | - | - |
| No chemicals – Winter samples<br>For broad comparison with summer sample, but NOT representing recommended winter operation | 2 samples in total collected across two days | 14/05/20<br>20/05/20 | 210 & 246 | Roller 1: 2.53 & 2.59<br>Roller 2: 1.97& 2.27 | 10 & 15 | - | - | - |
| Flocculant only **– Preliminary**<br>**To identify possible concentrations for winter flocculant trials** | 4 samples in total, each at a different flocculant concentration | 23/01/20, 30/01/20, 22/04/20 | 234 - 302 | Roller 1: 1.48-1.50<br>Roller 2: 1.20-1.30 | 9-16 | √ | 0.94%, 1.99%, 2.98% and 4.96% | - |
| Flocculant + Lime<br>– Winter sample<br>Represents recommended winter operation | 2 flocculant concentrations, 3 samples each collected across 4 days = 6 samples in total | 21/04/20, 22/04/20, 19/05/20, 20/05/20 | 197 - 244 | Roller 1: 1.36-1.56<br>Roller 2: 1.06-1.21 | 15-24 | √ | 3.00-3.02%<br>&<br>4.97-5.14% | √ |
| Lime only (no Flocculant)<br>– Winter sample | 1 sample | 02/09/20 | 314.3 | Roller 1: 2.4<br>Roller 2: 2.76 | 5 | - | - | √ |
| Total | 19 samples in total | | | | | | | |

* Separate sample bottles sent to two laboratories, providing additional replication to what is shown in the table, and enabling estimation of analytical uncertainty

# Flocculant = Solenis DrewFloc$^{TM}$ 2488

^ Lime = HyLime, which also adjusted pH of raw effluent to 9.1-9.3

The Z-Filter allowed some variation of its own operating conditions, including the flowrate of effluent to the Z-Filter, the speed at which the sock travelled through the Z-Filter, and the pressure applied by the compression rollers. However, these equipment settings were typically set based on visual inspection of the Filter Cake layer thickness, to try and achieve a thickness of 10-15 mm as suggested by the Z-Filter supplier to be optimal for producing a clear Filtrate. Depending on the solids content of the raw effluent, typical cake thicknesses achieved during the trial were 5mm to 15mm.

The addition of flocculant chemical influenced the conditions at which the Z-Filter could be operated, because flocculant made the Filter Cake "sticky" and less easy to dewater than when operating without flocculant. For this reason, when flocculant was used, the raw effluent feed rate to the Z-Filter typically had to be lower, the compression roller pressures had to be lower, and the sock speed had to be faster, otherwise the sock became clogged, built up contents inside and tripped equipment alarms.

### *2.7.1 Detailed sampling method for raw effluent and Filtrate*

The sampling of raw effluent and Filtrate is demonstrated in Figure 8.

**Figure 8** Photos illustrating the sampling method used for raw effluent and Z-Filter Filtrate, in the following order: (a) collection of raw effluent from sampling tap; (b) collection of Filtrate from discharge pipe at in-ground Filtrate pump well; (c) combining of grab samples in a large sealable bucket, stirred with a paint mixer prior to (d and e) sub-sampling into sample bottles provided by the analytical laboratories; and (f) measuring pH on the liquid samples in the sample bottles.

A sampling protocol was carefully designed to ensure that collected samples were representative and statistically represented the variability in the Z-Filter operation. This meant that every sample collected consisted of several grab samples which were aggregated and representatively sub-sampled. The retention time of liquid travelling through the Z-Filter was estimated at 40-45 seconds, which is short in comparison to the typical sampling period (30 minutes to 1 hour), so that aggregated samples collected in this way formed triplet sample sets (raw effluent+Filtrate+Filter Cake) that reliably represented the Z-Filter performance at respective operating conditions (Table 4). Prior to sampling, the Z-Filter Feed Tank was first filled with a fresh batch of raw effluent, which was then run through the Z-Filter, before the Z-Filter Feed Tank was again filled with a fresh batch of raw effluent and the Z-Filter operation and sampling begun. This was done to ensure that the Z-Filter was operating on “fresh” raw effluent, collected from the effluent collection sump.

The raw effluent grab sample (Figure 7a) was collected from a sampling tap on the pipe immediately following the Z-Filter pump (P-Z, Figure 8). The Filtrate sample (Figure 8b) was collected from the end of the pipe that discharged the Filtrate into the in-ground Filtrate pump well. Sufficient volumes of grab samples (~1-2L) were collected to be representative of the operational time point. These grab samples were combined in a large sealable bucket (20L), which was then stirred with a paint mixer (Figure 7c), prior to, and whilst collecting a representative subsample to near-completely fill the sample bottles with liquid-tight lids provided by the analytical laboratories (Figures 7d and e). Great care was taken to representatively sample the whole raw effluent or Filtrate, to minimise segregation of sinking or floating solids. pH was measured onsite without delay, with a pre-calibrated pH probe (TPS, WP801-1211091, Waterproof WP-80 pH + Temperature), and taking care not to cross-contaminate samples. To prevent cross-contamination, the pH probe was rinsed with deionised water and dried with a tissue prior to measurement of pH for a different sample.

### *2.7.2 Detailed sampling method for Filter Cake*

The sampling of Filter Cake is demonstrated in Figure 9. A Filter Cake grab sample was collected in a 20L plastic transporter crate placed on the raised rim of the conveyer belt directly under the end of the Z-Filter solids discharge chute (Figure 9a), during the time when corresponding raw effluent and Filtrate grab samples were collected. This sampling location was selected instead of sampling from the solids stockpile, so that:

1. the Filter Cake collected would be as fresh as possible (minimal opportunity for volatilisation losses); and
2. the Filter Cake would align with the raw effluent and Filtrate samples collected at the same operating conditions.

Several Filter Cake grab samples were aggregated in a larger bucket. In between collection of grab samples, the bucket was kept sealed with a tight lid, and kept in the shade. The aggregated sample was mixed/blended with a paint mixer (Figure 9b), and thoroughly mixed by hand by full inversion (Figure 9c, to minimise segregation of solids with varied size or density). A representative quarter was separated out by taking a full vertical cut (Figure 9d) and this quarter was again thoroughly mixed by hand via full inversion. Finally, a sub-sample was collected from the well-mixed quarter, again taking a full vertical cut (Figure 9e).

**Figure 9** Photos illustrating the sampling method used for Filter Cake, in the following order: (a) a Filter Cake grab sample was collected in a 20L plastic transporter crate placed on the raised rim of the conveyer belt; (b) several grab samples were aggregated in a larger bucket and mixed/blended with a paint mixer and (c) by hand by full inversion; (d) a representative quarter was separated out and again thoroughly mixed; and (e) a final sub-sample was collected to send to the analytical laboratory.

The aggregate samples collected in this way were placed without delay in a cooler box surrounded by ice bricks, to cool the samples and keep them cool until and during transport. In most cases, and wherever possible, the samples were couriered on the same day to the analytical laboratories in Perth. If this was not possible, the samples were kept cold in a refrigerator overnight and transported via courier the next day, again in a cooler box and on fresh ice bricks to keep the samples cool during transport.

## 2.8 Analyses

Most of the samples were sent separately to both a NATA accredited laboratory as well as a commercial analytical service at the University of Western Australia (UWA). This parallel analysis provided additional replication and a measure of analytical uncertainty for statistical data analysis. The results from the NATA accredited laboratory and the results from the UWA laboratory aligned reasonably well. This indicated that methods employed for sampling, and sample handling and analysis were robust and appropriate. Analytical methods are summarised in Table 5 below. Equation 1 was used to quantify the removal or capture extent of a particular analyte X by the Z-Filter (e.g. total phosphorus), calculated as a percentage change ($E_x$) in the concentration of the respective analyte in the raw effluent ($C_{x,\text{raweffluent}}$) and the Z-Filter Filtrate ($C_{x,\text{filtrate}}$):

$$E_{\mathrm{X}} = \frac{C_{\mathrm{X,raweffluent}} - C_{\mathrm{X,filtrate}}}{C_{\mathrm{X,raweffluent}}} \times 100 \tag{1}$$

The calculation approach in Equation 1 does not consider the moisture content in the Filter Cake, and therefore does not provide a comprehensive mass balance. However, it is commonly used in other studies, including that of Payne (2014)[3], and therefore allows cross-comparison of results obtained in the current project with that from other studies. A comprehensive mass balance was also performed in the current work, based on measured TS concentrations in the raw effluent ($C_{\mathrm{TS,raweffluent}}$), the Filtrate ($C_{\mathrm{TS,filtrate}}$) and the Filter Cake ($C_{\mathrm{TS,Cake}}$). Accordingly, the mass of Filter Cake produced over time ($M_{\mathrm{Cake}}$) was calculated using Equation 2:

$$\mathrm{M}_{\mathrm{Cake}} = \frac{\mathrm{M}_{\mathrm{raweffluent}} \times C_{\mathrm{TS,raweffluent}} - \mathrm{M}_{\mathrm{filtrate}} \times C_{TS,\mathrm{filtrate}}}{C_{TS,\mathrm{Cake}}} \tag{2}$$

where $M_{\mathrm{raweffluent}}$ and $M_{\mathrm{filtrate}}$ are the mass flowrates of raw effluent and filtrate, respectively. For the calculation, the specific gravity of raw effluent and Filtrate was assumed to be equal to unity, the volumetric flowrate of raw effluent was as measured and the Filtrate flow rate was resolved by mass balance, albeit being approximately equal to the raw effluent flow rate (i.e. $M_{\mathrm{raweffluent}} = M_{\mathrm{filtrate}}$). This assumption was deemed generally reasonable because of the high solids content of the Filter Cake and the low solids content of the raw effluent and Filtrate. Mass balance calculations on analytes (e.g. potassium, nitrogen and phosphorus) using $M_{\mathrm{cake}}$ determined by Equation 2, showed excellent mass balance closure (<10% differences) in line with expected analytical uncertainty.

Errors in calculated average values for replicate analyses were estimated using a two-tailed student t-test at a 95% confidence level and with appropriate degrees of freedom (n-1; where n is the number of replicates). Analytical uncertainty in individual measurements was accounted for by including all the measurement results from two labs in the calculation of averages. The NATA accredited lab also provided a duplicate analysis for a selected sample from each sample batch, and this gave a direct measure of measurement variability. When this variability was linearly propagated for calculated average values, it typically gave an estimate of error significantly smaller than that estimated via a student t-test.

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[3] Payne, H. 2014. On-farm evaluation of pond-less piggery effluent treatment system using novel flocculation and filtration techniques. Report prepared for the Co-operative Research Centre for High Integrity Australian Pork. Project 4C-112. Available at http://porkcrc.com.au/wp-content/uploads/2015/01/4C-112-Final-Report-.pdf. Last accessed 25/07/2020.

**Table 5** Analytical methods and analysis details

| Sample | Pre-treatment | Analyte | Method of Analysis |
|---|---|---|---|
| Raw effluent, Filtrate NATA lab | Pre-digested using hydrochloric and nitric acid, then diluted with water and analysed. | Total phosphorus (TP) | Determination of various metals by ICP-AES |
| | | Total aluminium (Al) | |
| | | Total calcium (Ca) | |
| | | Total copper (Cu) | |
| | | Total iron (Fe) | |
| | | Total potassium (K) | |
| | | Total magnesium (Mg) | |
| | | Total sulphur (S) | |
| | | Total zinc (Zn) | |
| | Samples are mixed well with a spatula and weighed into tubes. Most samples are analysed as received. | TKN | Colourimetrically based on APHA latest edition Norg C. |
| | | Total nitrogen (TN) | Total Nitrogen by high temperature catalytic combustion with chemiluminescence detection. |
| | | Total solids (TS) | Total Solids - determined gravimetrically. The samples are dried at 104 ± 10ºC. |
| | | Volatile suspended solids (VSS) | Method not stated, nor given by laboratory upon request.<br>Assume prefiltered with glass fibre filter and determined gravimetrically by drying at 104 ± 10ºC and loss on ignition in a muffle furnace at 550 ± 10ºC. |
| Filter Cake, NATA lab | Pre-digested using hydrochloric and nitric acid, then diluted with water and analysed.<br>Moisture content (and Total solids or TS by difference) determined by heating at 105ºC for a minimum of 12 hours. | Total phosphorus (TP) | Determination of various metals by ICP-AES.<br>Results expressed on a dry weight basis. |
| | | Total aluminium (Al) | |
| | | Total calcium (Ca) | |
| | | Total copper (Cu) | |
| | | Total iron (Fe) | |
| | | Total potassium (K) | |
| | | Total magnesium (Mg) | |
| | | Total sulphur (S) | |
| | | Total zinc (Zn) | |
| Raw effluent, Filtrate UWA lab | 4mL of effluent was digested with 2mL nitric acid and 0.5mL of $H_2O_2$, initially at room temperature for 1 hour before heating at 95ºC for 2 hours. Samples were then cooled and made to 20mL with MQ water. | Total elements, including TP, Total sodium, Al, Ca, Cu, Fe, K, Mg, S, Zn | Measured elements by Perkin Elmer Optima 5300DV, Norwalk Ct. against calibration standards using Y as an internal standard. |

| Sample | Pre-treatment | Analyte | Method of Analysis |
|---|---|---|---|
|  | All samples Diluted 6 x before digestion with potassium persulfate (0.5mL sample + 2.5mL MQ) and 20 x after dilution (0.5mL digest + 9.5mL MQ) to bring in to range for measurement on Lachat Flow injection Analyser.<br>MQ water = high purity water ( from MilliQ purification system 18.2Mohm.cm) | TN | Reference: from APHA Standard Methods for the Examination of Water and Wastewater (22nd Edition) ISBN: 978-087553-013-0<br>Digest: 4500-P J. Persulfate Method of Simultaneous Determination of Total Nitrogen and Total Phosphorus<br>Analysis: 4500-NO3 I. Cadmium Reduction Flow Injection Method |
|  | Samples were centrifuged and filtered through a 0.45µm PES Millipore® filter | Volatile fatty acids | HPLC. Standards were developed from pure versions of the target compounds with L-lactic acid (purity >98%), acetic acid (purity >99%), propionic acid (purity >99.5%), butyric acid (purity >99%), and succinic acid (purity >98%) being purchased from Sigma (Sigma-Aldrich Corporation, USA). The HPLC system was equipped with a Bio-Rad Aminex 87-H (300 x 7.8 mm, Bio-Rad) column and a UV-VIS detector set at 210 nm. Measurements were carried out using a mobile phase consisting of 5 mM sulphuric acid at a flow rate of 0.6 ml/min, while maintaining a column temperature of 50°C. |
|  | As received | TS and Volatile solids (VS) | Total solids (TS) and volatile solids (VS) were analysed according to Standard Methods (APHA, 1995). |
| Filter Cake<br>UWA lab | Solids (CN + multi-elements) were dried (@70°C) and ground in coffee grinder before analyses for total CN and other elements. | Total carbon (C) and Total nitrogen (N) | C and N analyses on dried solid material was measured by Elementar, Vario Macro combustion analyser, Hanau Germany (Dumas C N Method). |
|  | For total elements ~0.15g Dried material was accurately weighed and digested initially with 4 mL of nitric acid at 100°C for 30 mins. 0.5mL of perchloric acid was added before gradually raising the temperature to 180°C to dense white fumes of perchloric acid for 10 minutes. 3 mL of MQ water was added and reheated to dissolve the salts before making to 10mL final volume. | Total elements, including TP, Total sodium, Al, Ca, Cu, Fe, K, Mg, S, Zn | The resulting solution was measured for elements using Perkin Elmer Optima 5300DV, Norwalk Ct. against calibration standards using Y as an internal standard. |

## 2.9 Onsite operational observations and farmer feedback

On sampling days and periodically during normal operation of the Z-Filter between sampling days, onsite operational observations were made. These included:

1. observations about how well the contents of the effluent collection sump was being mixed to keep the effluent as homogeneous as possible and to prevent the settling and accumulation of manure solids;
2. electricity usage measurements, collected from an analogue meter which was installed on the main electricity supply board that provided power to the Z-Filter complex (including the Z-Filter and direct ancillary equipment such as pumps, mixers and the conveyer belt);
3. weather observations, including recording major raining events that could have contributed to systematic stormwater dilution of the collected effluent; and
4. observations about the indicative age of effluent in the collection sump, because in cases, effluent was neither being diverted to the existing onsite storage ponds nor was the Z-Filter operated for a period to try and accumulate enough effluent in the collection sump for use in a series of Z-Filter operational/sampling events.

In addition, during the trial, observational comments were sought from the farmer and farmer staff about the Z-Filter regarding things that were “working well” or “not working so well”.

# 3 Results and Discussion

Results are presented in this section together with the project objectives (section 1) that are addressed by particular results.

## 3.1 Objective 1 – Separation extents of manure total solids and nutrients

Results shown in Table 6 are for samples collected during summer and without any flocculation or coagulation chemicals added.

A typical low pH of the effluent was said to reflect typical low pH of the bore water. This was also associated with a moderate iron content (Table 6). During the earlier stages of the trial when bore water was directly supplied to the Z-Filter, the high-pressure water spray nozzles of the Z-Filter became blocked with iron scale (Figure 10), which had to be mechanically cleared. The farmer commented that iron scale was a common issue with blockages of the existing onsite irrigation systems. A decision was made to switch the water supply of the Z-Filter to the pre-filtered water from the milking shed, and once this was done, iron scale was not subsequently observed.

**Figure 10** Iron mineral scale collecting on the Z-Filter sock in the area where the sock is cleaned by a high-pressure water spray. The outer two spray nozzles in the left photo appear to be partially blocked.

The nutrient levels in raw effluent in Table 6 aligned well with nutrient levels estimated using the popular empirical estimation method of Nennich et al. (2005)[4] (also presented in Table 6). Specifically, the estimation method indicated that non-volatile nutrient levels (i.e. not nitrogen) in the raw effluent should have been approximately 59 mg.L$^{-1}$ for phosphorus and 164 mg.L$^{-1}$ for potassium.

Nitrogen estimated by the Nennich et al approach indicated that concentration in the raw effluent could have been as high as 371 mg.L$^{-1}$, and accordingly a comparison with the actual measured nitrogen concentration in the raw effluent (Table 6) indicated that as much as 45% of excreted nitrogen had already been lost by volatilisation. Phosphorus levels in the raw effluent were marginally lower in winter than in summer (Table 6). Nitrogen levels and potassium levels were similar in winter and summer, as were levels of other analytes. The only exception was calcium which was higher in the samples where lime was added in winter, because of the contribution of calcium from the dissolved lime.

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[4] Nennich, T.D., Harrison, J.H., VanWieringen, L.M., Meyer, D., Heinrichs, A.J., Weiss, W.P., St-Pierre, N.R., Kincaid, R.L., Davidson, D.L., Block, E. 2005. Prediction of manure and nutrient excretion from dairy cattle. *J Dairy Sci*, **88**(10), 3721-33.

**Table 6** Measured composition of raw effluent and Z-Filter filtrate samples collected under various conditions. Data presented are calculated average values and the range “(….)” of measured values.

| Analyte | Nennich et al. excretion rate estimates* | Summer operation, no chemicals | | Winter operation, flocculant + lime | | |
|---|---|---|---|---|---|---|
| | | Raw effluent | Filtrate | Raw effluent | Filtrate (3% Floc +Lime)* | Filtrate (5% Floc +Lime)* |
| pH | | 6.86 (6.57-7.04) | 6.82 (6.57-7.02) | -[#] | 9.11 (9.09 - 9.14) | 9.17 (9.09 - 9.28) |
| Total Nitrogen (mg·L$^{-1}$) | 371 | 203 (160-270) | 208 (160-270) | 234 (141-313) | 185 (113-241) | 117 (58-172) |
| Total Phosphorus (mg·L$^{-1}$) | 59 | 57 (39-70) | 53 (40-62) | 47 (30-66) | 20 (13-32) | 8.4 (4.4-15) |
| Total Potassium (mg·L$^{-1}$) | 164 | 160 (120-200) | 153 (130-180) | 168 (94-250) | 174 (126-230) | 132 (84-185) |
| Total Magnesium (mg·L$^{-1}$) | | 69 (45-92) | 64 (50-86) | 75 (50-100) | 59 (44-84) | 53 (35-67) |
| Total Iron (mg·L$^{-1}$) | | 8 (2.7-14.1) | 6.4 (2.6-11.6) | 9.6 (2.4-15.8) | 3.3 (1.4-7.3) | 1.3 (0.2-3.1) |
| Total Calcium (mg·L$^{-1}$) | | 92 (65-120) | 86 (64-103) | 203 (123-290) | 111 (76-170) | 81 (62-120) |
| Total Sodium (mg·L$^{-1}$) | | 128 (101-158) | 128 (98-164) | 130 (99-163) | 135 (120-152) | 116 (95-127) |
| Total Aluminium (mg·L$^{-1}$) | | 3 (1.4-5.7) | 2.9 (1-4.9) | 4.7 (1.8-8) | 1.5 (0.4-4.2) | 0.73 (0.02-1.61) |
| Total Sulphur (mg·L$^{-1}$) | | 22 (9-31) | 20 (11-30) | 27 (15-34) | 21.2 (15.3-26) | 13.9 (9.5-18.6) |
| Total Copper (mg·L$^{-1}$) | | 0.18 (0.07-0.32) | 0.14 (0.07-0.25) | 0.2 (0.1-0.27) | 0.08 (0.05-0.14) | 0.04 (0.01-0.07) |
| Total Zinc (mg·L$^{-1}$) | | 0.85 (0.4-1.4) | 1 (0.39-1.04) | 1.01 (0.42-1.5) | 0.39 (0.22-0.71) | 0.16 (0.03-0.37) |
| Electrical Conductivity (µS/cm) | | 2,326 (2,161-2,640) | 2,331 (2,149-2,607) | - | - | - |
| Total solids (% by wet mass) | | 0.52 (0.33-0.83) | 0.39 (0.29-0.53) | 0.7 (0.42-1.2) | 0.29 (0.18-0.42) | 0.2 (0.12-0.27) |
| Volatile solids (% by wet mass) | | 0.4 (0.23-0.67) | 0.27 (0.19-0.39) | 0.45 (0.27-0.9)^ | 0.11 (0.04-0.23)^ | 0.05 (0.02-0.09)^ |

*Nennich, T.D., Harrison, J.H., VanWieringen, L.M., Meyer, D., Heinrichs, A.J., Weiss, W.P., St-Pierre, N.R., Kincaid, R.L., Davidson, D.L., Block, E. 2005. Prediction of manure and nutrient excretion from dairy cattle. *J Dairy Sci*, **88**(10), 3721-33.

[#] Lime caused an increase in the raw effluent pH up to 9.19 (9.11-9.29)

^Volatile suspended solids

For the summer analyses without chemicals, the composition of Filtrate did not differ greatly from that of the Raw effluent, suggesting the Z-Filter was removing minimal proportions of macro and micro-nutrients. This is also shown in Table 7 by calculated percentage (%) changes in macro-nutrient concentrations between raw effluent and Z-Filter Filtrate. This was mainly because without using flocculation chemicals, most of the manure nutrients were not removed by the Z-Filter to the Filter Cake, but instead went through the Filter sock as fine suspended particulate matter in the Filtrate.

The only exceptions were total solids (TS) and volatile solids (VS), both of which were moderately removed by the Z-Filter (Table 7), resulting in lower average TS and VS concentrations in the Filtrate and a tighter concentration range for both (Table 6). This was likely due to the capture of coarse manure fibres, which would be very important to prevent blockages of the existing centre pivot irrigators (Section 3.2).

For the winter analyses using both flocculant and lime (Table 4), the Z-Filter was able to achieve moderate to high nutrient and solids removal extents (Table 7). The dose of flocculant was important, with an increase in dosage rate from 1% to 3% to 5% increasing nitrogen removal from approximately 19% to 37% to 55%, respectively, and phosphorus removal from approximately 8% to 20% to 36%, respectively. Lime was very important for phosphorus removal, but less important for nitrogen removal (Table 6). For example, with 5% flocculant dosage without and with lime addition, phosphorus removal extent was 36% (only duplicate results available) and 79.87(±12.55)% (Table 6), respectively. Lime by itself, without flocculant, achieved very poor phosphorus removal (1.1%) and negligible nitrogen removal. Albeit that only a single sample was collected in this case, and this sample was collected on a day that effluent was being extensively diluted with rainwater running off the milking shed yards. Overall, these results indicated that both flocculant and lime were necessary to successfully aggregate small manure particles so that they can be removed in the Filter Cake. Future research will further explore mechanisms for the action of flocculant and lime with solids separation from dairy effluent.

The removal of potassium was relatively minimal, both with and without the use of chemicals, and for both summer and winter analyses. This was expected because potassium is commonly a highly mobile macro-nutrient, prevalent in dissolved form in the aqueous phase. For this reason, a physical separation method such as a Z-Filter, would likely have minimal effect on potassium.

Table 7 also allows a comparison of nutrient and solids capture performance of the Z-Filter applied to dairy effluent in the current study, with that observed with the Z-Filter applied to piggery effluent in the study of Payne (2014)[5]. Overall, nitrogen, phosphorus and total solids removal appeared to be superior in the current study on dairy effluent. However, Payne was contacted to source original data from the piggery study to evaluate statistical variability.

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[5] Payne, H. 2014. On-farm evaluation of pond-less piggery effluent treatment system using novel flocculation and filtration techniques. Report prepared for the Co-operative Research Centre for High Integrity Australian Pork. Project 4C-112. Available at http://porkcrc.com.au/wp-content/uploads/2015/01/4C-112-Final-Report-.pdf. Last accessed 25/07/2020.

The findings from this further analysis showed that, within experimental variability, there was no significant difference in Z-Filter performance between the current trial on dairy effluent and the trial of Payne (2014) on piggery effluent (Table 7). **Accordingly, it was concluded that the extents of manure solids and nutrient separation found in prior research on pork effluent by Payne 2014 was able to be replicated with dairy effluent from pasture-fed herds in the Scott and Blackwood River catchment.**

**Table 7** Comparison of removal performance of the Z-Filter applied to raw dairy effluent (this study), and piggery effluent in the study of Payne (2014). Values listed from this study are calculated average(±95% confidence intervals).

| | **Calculated percentage (%) change in concentration between raw effluent and the Z-Filter Filtrate** | | |
|---|---|---|---|
| **Parameter** | **Dairy Effluent (this study)** | | **Piggery Effluent Payne (2014) Floc+Coagulant*** |
| | **Summer – No chemicals** | **Winter – 5% Floc+Lime** | |
| Total nitrogen | -3.65(±8.98) | 48.81(±6.12) | 35.1(±10.3) |
| Total phosphorus | 3(±2.98) | 79.87(±12.55) | 65.1(±20.3) |
| Total potassium | 0.8(±2.54) | 8.65(±1.29) | 10.1 |
| Total sulphur | 2.73(±6.25) | 43.41(±4.31) | NR* |
| Total solids | 22.63(±8.99) | 72.43(±7.22) | 58.3(±11.5) |
| Volatile solids | 28.64(±10.02) | NM* | 72.8(±19.2) |
| Volatile suspended solids | NM | 90.7(±12.7) | NM |

“NR” means not reported; “NM” means not measured; *95% confidence intervals here were calculated using the original raw data sourced from the study of Payne (2014)

Table 8 below provides a composition measurement results for the Filter Cake. The Filter Cake was stackable (Figure 11) with a moderate to high solids content (11-24%). Ability to compost was also supported by a near-ideal carbon-to-nitrogen (C/N) ratio with Filter Cake produced by the Z-Filter without using chemicals (i.e. 25-30). Indeed, measurements using a temperature probe showed that this Filter Cake was reaching temperatures of 50+°C inside a stockpile in the onsite shed, indicating that natural composting was already occurring. However, the increased nitrogen capture when using chemicals shifted the C/N ratio of the Filter Cake to decrease and fall outside the optimum range for composting, meaning that additional carbon may be required to compost Filter Cake produced with chemicals during winter. During the trial, the farmer was already making enquiries about where to source additional carbon-rich material from, to facilitate the co-composting of the Filter Cake.

**Table 8** Measured chemical composition of Filter Cake - average (range)

| **Parameter** | **Filter Cake Summer – No chemicals** | **Filter Cake Winter – 5% Floc+Lime** |
|---|---|---|
| Total Nitrogen (mg·kg$^{-1}$ DM*)) | 13,000 (11,000-15,000) | 25,411 (18,438-32,169) |
| Total Phosphorus (mg·kg$^{-1}$ DM) | 1,127 (770-1,600) | 9,330 (4,796-16,000) |
| Total Potassium (mg·kg$^{-1}$ DM) | 1,136 (800-1,400) | 1,426 (1,195-1,600) |
| Total Carbon (mg·kg$^{-1}$ DM) | 440,895 (425,400-456,390)# | 458,788 (440,213-469,000) |
| Total Magnesium (mg·kg$^{-1}$ DM) | 1,233 (1,000-1,400) | 4,599 (3,300-6,422) |
| Total Iron (mg·kg$^{-1}$ DM) | 1,256 (470-2,800) | 2,914 (2,328-3,500) |
| Total Calcium (mg·kg$^{-1}$ DM) | 4,611 (3,300-6,600) | 25,455 (13,740-44,000) |
| Total Sodium (mg·kg$^{-1}$ DM) | 1,033 (900-1,100) | 894 (755-1,016) |
| Total Aluminium (mg·kg$^{-1}$ DM) | 533 (340-1,100) | 1,559 (1,100-2,088) |
| Total Sulphur (mg·kg$^{-1}$ DM) | 1,689 (1,300-2,400) | 3,172 (2,341-4,200) |
| Total Copper (mg·kg$^{-1}$ DM) | 8.33 (4-13) | 39 (25-48) |
| Total Zinc (mg·kg$^{-1}$ DM) | 70.67 (57-92) | 200 (130-240) |
| Total solids (% by wet mass) | 18.2 (11-24) | 16 (15-17) |
| Volatile solids (% by wet mass) | 14.98 (10-18.52) | - |
| Carbon to Nitrogen mass ratio (-) | 30.3 (29.3-31.29)# | 18 (14-25) |

*DM means dry matter

#Only analysed in duplicate

**Figure 11** Stockpile of Filter Cake produced by the Z-Filter. The appearance and colour of the Filter Cake is light brown when not using chemicals and dark brown when using chemicals (flocculant+lime).

## 3.2 Objectives 2, 3, 4 and 7 – Farmer proposed operational use of Filtrate and Filter Cake, and benefits

The project provided options for dairy farmers to have choice and control over the beneficial reuse of nutrients and organic matter in dairy effluent. Specifically, reuse of nutrients and organic matter needs to be both economical as well as practical and the benefits need to outweigh the opportunity costs of operating more sophisticated manure separation devices such as a Z-Filter.

The trial provided options for the farmer which included:

1. to use or not use chemicals to control the capture of nutrients in the Filter Cake;
2. using the Z-Filter without chemicals would remove manure fibre but would retain most of the nutrients in the Filtrate, and the Filtrate can then be land-applied over the full existing irrigation area using the existing irrigation infrastructure. This allows the direct offset of synthetic fertiliser use; or
3. using the Z-Filter with chemicals would remove manure fibre and nutrients into the Filter Cake, allowing more efficient storage of manure nutrients and organic matter prior to being land-applied when conditions permit, and over areas potentially far afield where the nutrients and organic matter in the Filter Cake would most value-add.

### 3.2.1 Reuse of Filtrate

Prior to the trial, dairy effluent was stored in built-up unlined holding ponds with a significant risk of nutrients leaching into groundwater. Moreover, beneficial reuse options were limited, with overapplication of nutrients occurring over a small area nearby the milking shed (Section 4). Manure separation, such as via a Z-Filter, provides the farmer with options to choose whether to keep nutrients and organic matter in the Filtrate or whether to capture these in the Filter Cake, depending on the farmer proposed reuse approach.

At the trial dairy during dry weather, the existing centre pivots could be used onsite, with the farmer using irrigation water to shandy Filtrate before being applied to the existing centre-pivot irrigation areas. Prior to the trial, these same centre pivots were being used to irrigate bore water without Filtrate. This approach provided the farmer value by diluting and spreading manure nutrients left in the Filtrate over a much larger area (Section 4) and additional value from the additional irrigation water provided by the Filtrate.

The use of chemicals (flocculant+lime) with the Z-Filter can further reduce environmental risks associated with storage and the application of Filtrate, by reducing nitrogen and phosphorus loads in the Filtrate (Section 3.1). Figure 12 below illustrates the typical differences in physical appearance between Filtrate produced by the Z-Filter with or without chemicals.

**Figure 12** Typical appearance of Z-Filter Filtrate (a) with and (b) without the use of flocculant and lime

### 3.2.1 Reuse of Filter Cake

Prior to the trial, manure solids were accumulating in the trafficable effluent collection sump which then had to be cleaned out approximately every week. The solids collected in this way was typically watery, bulky, and dilute and difficult to dry prior to being able to be spread onsite. In contrast, the Filter Cake produced by the Z-Filter was stackable with a much higher solids content (11-24%) (Section 3.1). Ability to naturally compost, and thereby prepare the material for beneficial reuse, is influenced by carbon-to-nitrogen ratio, as described above (Section 3.1).

The farmer emphasised the perceived benefits of the Filter Cake. Specifically, due to concern over a progressive decline in the agronomic performance of paddocks, the farmer had been purchasing ~300 $m^3$ or tonnes of compost to apply to pastures onsite and rebuild soil health. The farmer said he would have bought more compost if he could have afforded it, because he had areas on the farm that were previously not available to the herd because of the depletion in soil health.

The Z-Filter without chemicals could routinely produce ~281 tonnes per annum of Filter Cake, at seemingly ideal composting conditions (Section 3.1). With chemicals (flocculant and lime) Filter Cake production increases to ~1,300 tonnes per annum. The farmer commented that they knew what was in the Filter Cake compost, whereas they did not know the detailed composition of the commercial compost, and therefore the Filter Cake was preferred.

The commercial implications of these farmer proposed operational uses of Filtrate and Filter Cake are discussed further below in Section 3.6. Section 4 compares the existing effluent management system (prior to the trial), with an effluent management system integrating the Z-Filter.

## 3.3 Objective 5 – On-going need for effluent storage

The Australian national approach to dairy effluent systems design, typically recommends storage of effluent when the soil water deficit is inadequate (i.e. rainfall exceeds evapotranspiration). This is because under such conditions the risk of nutrient run-off can be significant. Typically, these aspects are covered in an Effluent Management Plan prepared by an Accredited Designer, which also addresses site-specific opportunities and constraints.

Some tools commonly used for design of effluent storage systems use a daily soil water balance whilst others lump the final water balance on a monthly basis. With a monthly water balance, entire months are lumped based on prevailing soil water deficit, either as months during which effluent can be land-applied and do not need to be stored or as months during which effluent must be stored. With a daily balance, storage pond design sizes may be smaller than with a monthly balance, because the system may be designed relying on some “dry days“ during wetter months for which land-application of effluent would be appropriate. Effluent that is land-applied on such days would then not need to be included in the required effluent storage volume. However, reliance on individual days of effluent application increases the management responsibility on the farmer and may not be realistic for a farm scenario.

The inclusion of a Z-Filter provides options, because a single-pond system may become suitable for storage of effluent prior to effluent irrigation. This is because the Z-Filter removes the coarse solids (e.g. manure fibres) that would have otherwise caused blockages in many irrigation systems. The use of a single pond system could reduce effluent storage size as compared to a two-pond system that has an upfront sedimentation pond to remove coarse solids, because a single pond system may have a smaller rainwater catchment area. This could save on construction costs of the storage system.

Wet weather storage could also provide capacity to store effluent when the Z filter is offline for maintenance or system failure.

## 3.4 Objective 6 – Suitability of Filtrate for recycling as flush water

It may be possible to reuse Filtrate from a Z-Filter for flood wash purposes. However, whilst not the experience in South Western Australia, observations elsewhere in Australia have shown that recycling of treated effluent for flood washing can make yard surfaces slippery if a post-rinse of fresh water is not provided to remove any surface residue. Also, it is important to note that some Flocculant tended to make its way through into the Filtrate, and slipperiness of the flocculant is an important hazard stated on its Material Safety Data.

A reasonable proportion of effluent produced at the trial dairy originated from the pipe-and-riser flood washing system. This was estimated at approximately 40kL per day (or 39% of total daily effluent volume) from emptying of the 13.5 kL and 7 kL flood wash tanks during each milking. There would also be a trade-off between the cost of chemicals (flocculant+lime) vs. the quality of the Filtrate required for the flood wash and the additional cost of water for post-rinsing.

The benefits of recycling Z-Filter Filtrate for flood wash are:

1. reducing overall effluent volumes to handle; and
2. reducing water use at the dairy.

However, with the trial dairy site, the farmer valued the additional irrigation water provided by the Filtrate (an estimated 4% of the overall irrigation water volume), and flood wash represented a much smaller proportion of the overall water use in the milking shed of the trial dairy as compared to other dairies. For this reason, the farmer considered the use of recycled effluent for flood wash to be a questionable proposition.

## 3.5 Operational observations for the Z-Filter

AMRCCE staff and the Z-Filter supplier installed the equipment and operated it until such a time it was running consistently. Subsequently, the dairy farmer and/or farm staff operated the Z-Filter for a significant proportion of the trial period, with intermittent assistance from AMRCCE staff to service the equipment as needed. This operational experience, gave a realistic perspective on the Z-Filter operations, including of potential operational challenges and regular operator requirements.

Indeed, the trial period was not without significant operational challenges, but importantly, several of these challenges originated from the fact that Z-Filter system was installed as a trial system, not as a normal part of the on-going operational effluent management system. As a result, existing on-farm infrastructure were repurposed for the trial wherever possible to save on installation costs, and these were not always well suited for the trial application. Impacts of this are described in this section.

### *3.5.1 Effluent heterogeneity and the Z-Filter operation*

There was an existing effluent transfer pump (Figure 13), which prior to the trial was typically used to pump effluent from the trafficable effluent collection sump to the existing unlined effluent storage ponds. During the Z-Filter trial, this same pump was repurposed to continuously mix the contents of the effluent collection sump to provide a consistent raw effluent feed to the Z-Filter. This meant that this large pump was operating for much longer time periods than usual, consuming unnecessarily electricity for largely sub-optimal mixing of the effluent collection sump.

**Figure 13** Large existing effluent transfer pump, which was repurposed for recirculation mixing of the Z-Filter.

Whilst great care was taken on sampling days to ensure that mixing of the sump was consistent and reasonable, it was not practical to always ensure this same consistency on non-sampling days. A consequence was that the Z-Filter operational settings could not be optimised for routine operating conditions, because the solids concentration in the raw effluent changed too drastically during non-sampling days. On one operational day, a very large change in solids concentration in the effluent, caused the Z-Filter sock to overfill with solids, jumping off its roller tracks, opening up and dumping a lot of Filtrate Cake into the Z-Filter chamber, nearly filling up the Z-Filter chamber (Figure 14) by the time operators noticed the issue and turned the equipment off. This also meant that a large quantity of manure fibre ended up in the onsite irrigation systems, causing blockages that took a significant amount of maintenance to be rectified.

**Figure 14** Once during the trial period, the sock became overfilled with manure fibre and dismounted off its runs, opening and emptying manure cake into the Z-Filter internals. This happened unnoticed and led to a substantial amount of manure fibre entering the Filtrate and blocking the onsite irrigation systems.

Much of the piping installed onsite for the trial, were often joined with temporary fittings not suited for long-term operation, meaning that some unnecessary pipe leaks and pipe failures were occurring during the trial period.

As a result of the learnings during the trial, the farmer has now installed a lower energy more efficient mixing system on the effluent sump, which is likely to prevent similar events occurring in the future. The trafficable effluent collection sump now no longer requires regular cleaning as before, and this further reduces the overall maintenance and operations burden of the whole effluent system onsite.

### *3.5.2 Routine maintenance of the Z-Filter*

Semi-regular monitoring and daily cleaning of the Z-Filter can avoid damage or reduction of life span to the sock. The Z-Filter is expected to require approximately two hours of daily operator intervention, to hose down the equipment internals and ensure the equipment is operating correctly over the long term. This is important because the sock costs approximately $3,000 each, and with proper maintenance, the manufacturer advised an expected life span of 1,500 hours with appropriate operator care (i.e. ~one year of operation). Also, it is expected that additional labour due to the Z-Filter would be offset by reduced maintenance requirements and cost of the effluent application system; the removal of manure fibres by the Z-Filter means that the irrigation system is no longer blocked with such fibres, and a sedimentation pond is not required to remove solids prior to application of effluent.

### *3.5.3 Lack of automation of flocculant make-up system*

The flocculant preparation system (Section 2.6) was highly manual and considered tedious for routine operation. For example, at the trialled flocculant dosage rate of 5% of the effluent flow rate (Table 4), approximately 5 batches per day of pre-diluted flocculant solution would be required, each of which would have to be manually prepared by farm staff. This was important because with this level of additional labour, the farmer would be unlikely routinely use flocculant, especially considering its additional cost (See Section 3.6). As a result, the farmer (not surprisingly) chose to operate the Z-Filter without flocculant during the trial period. Automation of the flocculant preparation system would likely be required if flocculant is to be used as a routine part of future effluent management at the dairy.

## 3.6 Economic cost-benefit of the Z-Filter operation

### 3.6.1. Costs

The purchase and operational requirements of a Z-Filter would unlikely be cost-justified for all dairies, especially not for smaller dairies.

The **purchase and installation costs** were an estimated **$200,000** in total. For a nominal amortization period of 10 years, this would amount to an annualised cost of $20,000 per annum.

Important **operational costs** for the operation of a Z-Filter include:

- **flocculant** (emulsion purchased at $8.4.kg$^{-1}$), which if used only during winter months at a dosage rate of 5% of the effluent flow rate, can amount to a cost of **~$27,202.annum$^{-1}$** (based on 4 months per year of use)
- **lime**, which if used during winter months at the typical dosage applied in the tests (Table 4), can amount to a cost of **~$700.annum$^{-1}$**;
- **filter sock** replacement, at a nominal 300 L.min$^{-1}$ effluent flowrate), at **$4,500 per annum** (1.5 half sock replacements per annum);
- incremental increase in **electricity consumption** of 4kWe for the Z-Filter unit, and an additional 18kWe for ancillary mixers, pumps, the air compressor and the solids conveyer belt. This includes the electricity requirements of the new mixing system installed in the effluent collection pit. At 300 L.min$^{-1}$ effluent flow (2,231 hours per annum of Z-Filter operation), and an electricity cost of 16.84 c.kWh$^{-1}$ (current pending rate), this incremental electricity use amounts to **~$8,300.annum$^{-1}$**.

By summing these costs together, the total annualised cost of purchasing, installing and operating the Z-Filter amounts to **~$60,700.annum$^{-1}$**, which is equivalent:

- **0.6 cents per L of milk**; or
- **$25.8 per kg of phosphorus** in the effluent**.**

Flocculant is clearly the greatest cost of operating the Z-Filter. The farmer may choose not to use flocculant, which would greatly reduce costs.

### 3.6.2. Benefits

Important savings/benefits from operation of a Z-Filter include nutrients in the dairy effluent that, because of the Z-filter operation, can now be beneficially reused on-farm. For this, the farmer provided the following indicative costs for the synthetic fertilisers that they commonly use:

- Super potash 3:2 at $424 per tonne, translating into $4.40.kg$^{-1}$ P and $1.20.kg$^{-1}$ K; and
- Urea at $500 per tonne, translating into $1.26.kg$^{-1}$ N.

At these costs, the value of nutrients in 110 kL.d$^{-1}$ of raw effluent was estimated at:

- $10,100.annum$^{-1}$ (at 200 mg.L$^{-1}$ N, Table 6);
- $10,600.annum$^{-1}$ (at 60 mg.L$^{-1}$ P, Table 6); and
- $8,100.annum$^{-1}$ (at 168 mg.L$^{-1}$ K, Table 6);

equalling a total nutrient benefit of $28,800.annum$^{-1}$ .

In addition, the Filter Cake will be used instead of commercial compost to boost soil productivity on-farm, and this was considered here, because the farmer was incurring real costs for the purchase of compost. An actual cost of 304 tonnes was provided, which amounted to $109,400. Some of this cost however was for a trace element boost, which may also need to be purchased separately and added to the Filter Cake. As such, only the cost of the **compost and freight** were considered as **avoidable by the farmer instead using the Filter Cake** that is produced by the Z-Filter, and this amounted to an actual value of **$74,727 ex GST**. This could be considered a realistic minimum saving with considerable additional value to be gained as the farmer needs a larger volume and will be able to produce a greater volume.

The total value of operating the Z-Filter (including nutrients and compost displacement) is then **~$103,500.annum$^{-1}$**. This value expressed in similar units to that in Section 3.6.1, is 1 cents per L of milk produced or $46.4 per kg of phosphorus in the effluent.

Clearly, the analysis shows that most of the value is in the organic matter in separated Filter Cake with additional benefit from the nutrient value in the Filtrate; albeit that future research will need to explore the extent of agronomic benefit to pasture growth derived from utilising composted Filter Cake as a soil improver.

### 3.6.3 Cost-Benefit Analysis

The above costs and benefits give an estimated **payback period** for the purchase and operation (including revenue and costs) of a Z-Filter of approximately **3.2 years.** This is highly favourable.

Following significant operational experience with the Z-Filter, and in light of these anticipated cost benefits, the dairy farmer decided to purchase the Z-Filter to form part of the on-going effluent management system at the farm.

# 4 Effluent system comparison – Before Trial vs. During Trial

The original project scope included the provision of a separate waste management system report to the farmer of the trial site. For this AMRCCE had arranged during the trial period, for a process engineering consultant to provide (on an in-kind basis) the waste management report, including recommendations about how effluent systems on-farm could be retrofitted to increase system life and to reduce labour. The Farmer declined this offer on several occasions, as it was his intention to have a Dairy Effluent Management Plan prepared via DairyCare as a potential candidate for the REI grant of $60,000. For this reason, this section of the report instead provides a comparison of the effluent management systems at the farm before the trial (pre-existing baseline) and during the trial, to outline performance and potential impacts. This can then be used to inform the preparation of a Dairy Effluent Management Plan for the site.

## 4.1 The old (legacy) system

As an overview recap from the details in Section 2.2, the old effluent management system at the trial dairy included the following:

1. Daily throughout the year, effluent was produced by the milking operations, collected in a central collection sump and pumped to onsite unlined holding ponds;
2. Daily throughout the year (including in winter) effluent in the unlined holding ponds was irrigated over an 8 ha area used to grow maize or sorghum, using a float pump on the pond liquid surface;
3. The effluent collection sump used to operate as a trafficable solids trap with a weeping wall, albeit that the openings in the weeping wall typically blocked;
4. Periodically, the accumulated solids in the solids trap were removed by scraping and then dried and put out onto pastures. The pasture site tended to be nearby because the solids were not in an easily transportable form; and
5. Periodically, the settled solids (sludge) in the unlined ponds were removed, although rarely fully dried because of the high water table and therefore typically required carting of large quantities of water, so sludge tended to be spread in close proximity.

The generally recommended approach for nutrient budgeting is to use site-specific nutrient composition measurements on solids, sludge and irrigated effluent. However, at the trial farm, such measurements would be unreliable because of the regular significant interactions between the high water table and effluent in the unlined effluent pond, and effluent was applied year-round over the 8 ha area near the milking sheds. Moreover, the old irrigation was completely taken out of service by the farmer at the outset of the trial, so that direct sampling and measurements of irrigation effluent could no longer be performed.

For this reason, a more conservative approach was used in this work, whereby the measured composition of raw effluent (Table 6) was instead used together with common nutrient partitioning reported in Birchall et al. (2008)[6] to determine nutrients ending up in effluent and nutrients ending up in sludge. Accordingly, 40% of the phosphorus and 90% of the potassium in the raw effluent was partitioned to the irrigated effluent applied over the 8 ha area.

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[6] Birchall S, Dillon C, Wrigley R. Effluent and manure management database for the Australian dairy industry. Dairy Australia; 2008.

A comparison of the results for raw effluent in Table 6 with empirical estimates by industry-standard approaches (Section 3.1) showed a large proportion of nitrogen deposited at the milking sheds was lost by volatilisation and did not enter the effluent stream. For comparison, estimated nitrogen loss by volatilisation was ~45% from Table 6 as compared to 50% given in Table 1, Chapter 2 of Birchall et al. (2008). For this reason, measured nitrogen in raw effluent was used directly for calculations without additional losses, to provide conservative results.

Nutrient losses from unlined effluent ponds to groundwater may be an additional and important adverse environmental impact. Moreover, nutrients in solids and sludge could have caused additional nutrient impacts if not spread at an appropriate time of the year or if not spread over an adequate application area. Accordingly, Table 9 gives estimates of nutrient loadings for the existing (baseline) effluent management system, calculated for a nominal 110 kL.d$^{-1}$ of raw effluent flow.

**Table 9** Estimated nutrient loadings for existing effluent management system

| Parameter | Total Nitrogen | Total Phosphorus | Total Potassium |
|---|---|---|---|
| Nominal concentrations in the raw effluent (mg·L$^{-1}$) | 200 | 60 | 168 |
| Total nutrient loading in raw effluent (kg·annum$^{-1}$) | 8,030 | 2,400 | 6,740 |
| Nutrient loading in irrigated effluent (kg·annum$^{-1}$)[#] | 4,820 | 960 | 6,070 |
| Sludge nutrient loading (kg·annum$^{-1}$)* | 3,210 | 1,440 | 670 |
| Nutrient loading for effluent applied over 8 ha of application (kg.ha$^{-1}$.annum$^{-1}$)[&] | 600 | 120 | 760 |

[#] Based on 40% of phosphorus, 90% of potassium and 60% of nitrogen in the raw effluent partitioning to the final irrigated effluent applied over the 8 ha area.

*Based on 60% of phosphorus, 10% of potassium and 40% of nitrogen in the raw effluent partitioning to the sludge deposited in the unlined holding ponds.

These nutrient loadings in Table 9 for effluent applied over the 8 ha area, are well above what is typically removed by maize and sorghum as per Birchall et al. (2008), and therefore poses a high nutrient run-off and leaching risk.

### 4.2 New System (as at the Project end)

The following summarises the new effluent management system that the farmer was operating during and at the end of the trial period:

1. On a daily basis throughout the year, raw effluent runs from the dairy/yard into the effluent collection sump, which is now being well-mixed by a newly installed mixing system to keep all manure particulate matter suspended, then;
2. from here, the raw effluent is pumped to the Z-Filter with an insignificant volume of particulate matter now remaining in the collection sump on an on-going basis, so that the sump no longer has to be cleaned by the farmer, then;
3. on a daily basis throughout the year, the effluent is separated by the Z-Filter into Filter cake and Filtrate; and
4. with the Filter cake being used to create compost which is land applied as needed to boost soil productivity on the farm; and
5. during the drier months of the year (with an appropriate soil moisture deficit), the Filtrate is shandied with bore water and irrigated onto 73 ha pasture (which will be expanded to 146 ha at a later stage) through the existing centre pivot irrigators (Figure 15); and/or will be directly applied to an appropriate irrigation area using another irrigation system. Figure 16 shows a photo of an alternate irrigation system used for Filtrate at the trial farm.

Flocculant could be used to increase the production of composted Filter Cake, and to limit the nutrient content in the Filtrate, to better balance nutrient requirements of pasture growth onsite. This is demonstrated in Figure 17 and Figure 18.

**IMPORTANT: (1) The small irrigation paddock 8 ha formerly used in the old system (Section 4.1) has been completely taken out of service and will no longer receive effluent; (2) the amount of nutrients routinely applied to land onsite will be reduced because of the use of nutrients in Filtrate, in accordance with guidance from the farmer's agronomist.**

**Figure 15** Photo of existing centre pivot irrigation system

**Figure 16** Photo of alternate irrigation system used for Filtrate at the trial site

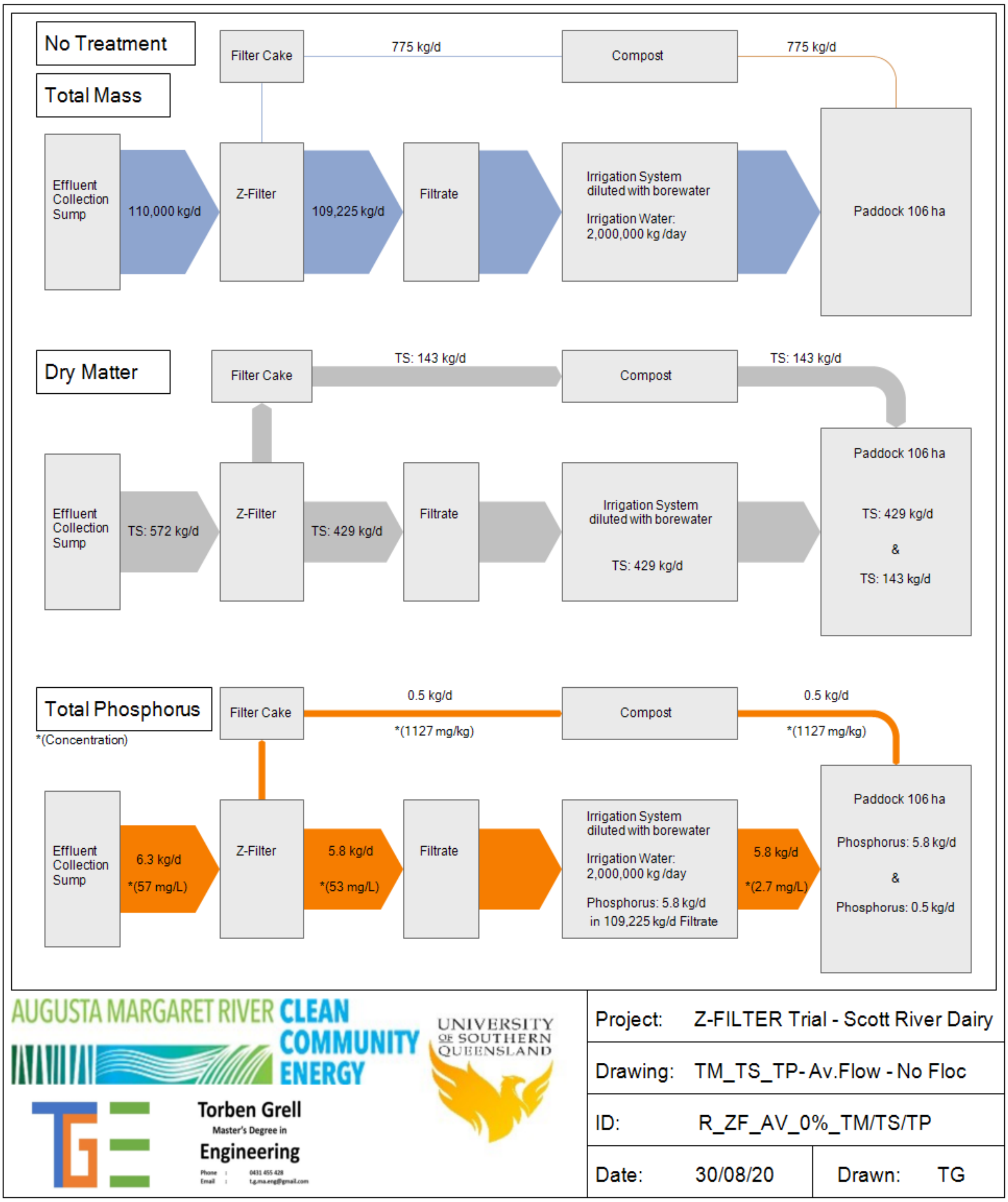

**Figure 17** Farmer proposed use of Z-Filter Filtrate and Filter Cake, when not using flocculant and lime. When no flocculant or lime is used, there are more nutrients in the Filtrate and less in the Filter Cake. Amounts given in the diagram above with units of kg/d is a mass flux. Concentrations of total phosphorus as measured in the trial, are also indicated with an "*". Note that concentration in the Filter Cake is given in mg/kg dry matter.

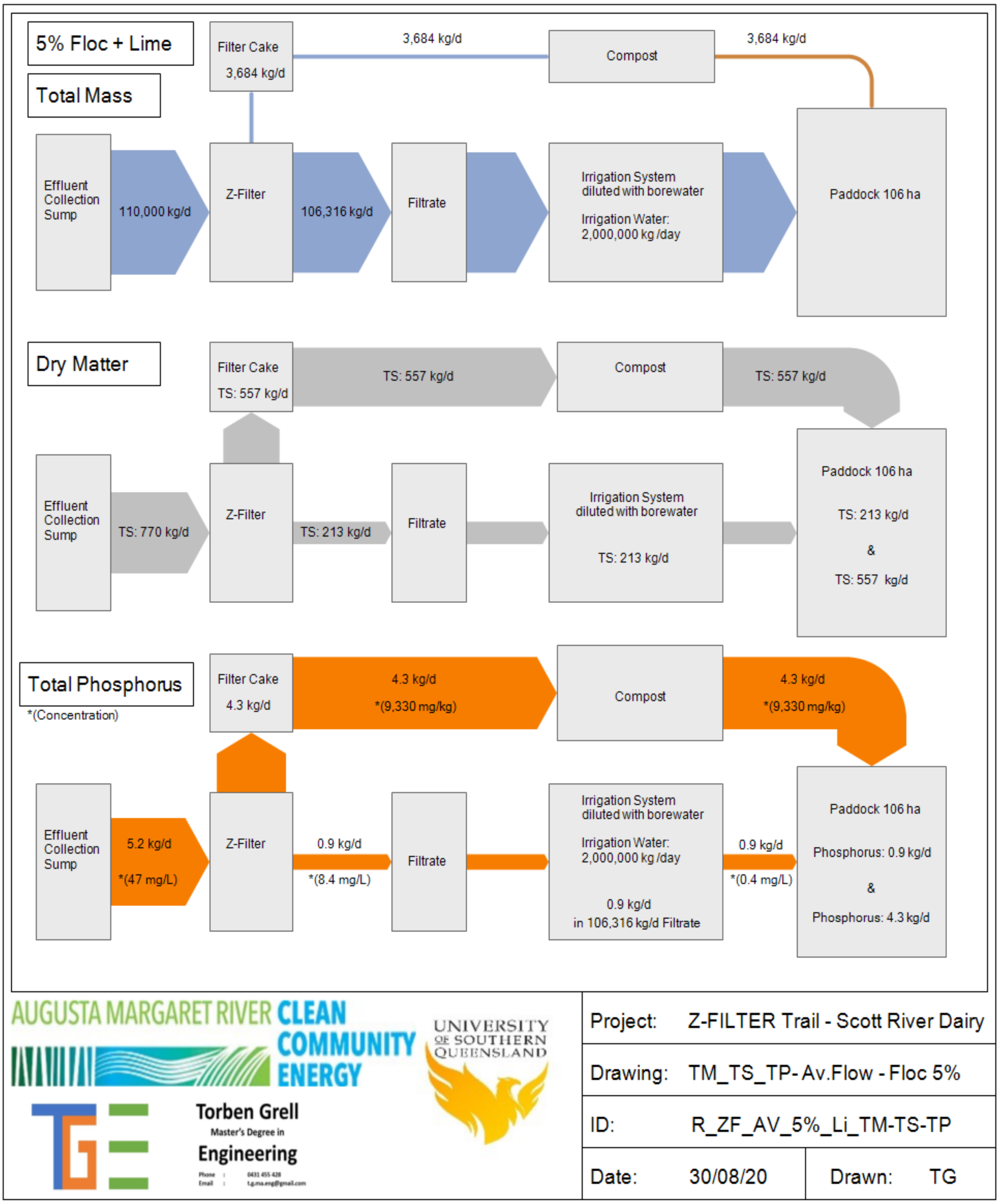

**Figure 18** Farmer proposed use of Z-Filter Filtrate and Filter Cake, when using 5% flocculant and lime. When flocculant + lime is used, there are less nutrients in the Filtrate and more nutrients in the Filter Cake. Amounts given in the diagram above with units of kg/d is a mass flux. Concentrations of total phosphorus as measured in the trial, are also indicated with an "*". Note that concentration in the Filter Cake is given in mg/kg dry matter.

The Z-Filter removes manure fibres that could have otherwise blocked irrigation systems, and thus allows the nutrients in Filtrate to be spread over a much larger area of the farm. Table 10 presents estimated nutrient loadings for the new effluent management system. Whilst potassium as a macro-nutrient was not removed to a notable extent by the Z-Filter operation, the potassium loadings in Table 10 are below industry guideline limits to minimise the risk of metabolic diseases in grazing cattle (i.e. <100 kg per ha per year).

The nutrient content was measured for two separate samples collected on different days (15-01-2020; 30-01-2020) from the outlet of the Filtrate Storage Tank, representing the composition of Filtrate that would either be shandied with bore water and then sent to the Centre Pivot irrigation system, or instead be sent directly to another irrigation system onsite. The results are also presented in Table 10. As expected, the nutrient levels in the outlet of the Filtrate Storage Tank were similar to that of the Filtrate samples without using flocculant or lime, as analysed and given in Table 6.

**Table 10** Measured concentrations in Filtrate Tank outlet and estimated nutrient loadings for new effluent management system

| Parameter | Total Nitrogen | Total Phosphorus | Total Potassium | Total Sulphur |
|---|---|---|---|---|
| Concentrations measured in outlet of Filtrate Storage Tank ($mg \cdot L^{-1}$)[#] | 160-220 | 44-55 | 150-170 | 21 |
| Nutrient loading for Filtrate applied over 73 ha area ($kg.ha^{-1}.annum^{-1}$)[&] | 121 | 30 | 94 | 12 |

[#] Measured range of values for two samples, one of which was analysed by two separate laboratories, collected from outlet of the Filtrate Storage Tank.

[&] Based on the maximum measured concentration in the table, 110 $kL.d^{-1}$ of Filtrate Flow and 73 ha of irrigation area.

## 5 Conclusions and recommendations

The trial presented in this report was the first to provide robust scientific data and practical experience with a Z-Filter applied to dairy effluent. The real operational experience and scientific data helped to evaluate the technology and, more generally, manure separation concepts for dairies in the Scott and Blackwood Rivers catchments.

During the trial, the dairy farmer of the trial site was also able to gain significant first-hand operational experience with the Z-Filter and provided realistic reflections on its “joys and pain-points”. Significantly, following this operational experience, the farmer decided to purchase the Z-Filter to incorporate it into the routine effluent management systems of the dairy. This suggests that, from the farmer’s perspective, the benefits of having options to beneficially reuse fertiliser nutrients and organic matter outweighed operational challenges of the Z-Filter.

The trial clearly showed that nutrient and organic matter capture by the Z-Filter is sensitive/highly responsive to the use of an appropriate flocculant in combination with lime. The use of lime together with a flocculant was distinct from the previous piggery trial of the Z-Filter, which instead used a flocculant in combination with a chemical coagulant. Lime is of more general interest, being a common ingredient used for soil amendment. With the cost of flocculant being substantial, it would be worthwhile for future work to explore whether lime can provide phosphorus removal with minimal use of flocculant.

For example, the farmer mostly operated the Z-Filter without flocculant dosing during the trial period, because the system was much more cumbersome to operate with flocculant.

With the Z-Filter having a mobile and modular design, it may be possible to explore a Z-Filter as a transportable system to provide a separation and collection service to multiple smaller dairies (with due consideration of biosecurity requirements), especially in regions with significant risk of nutrient and organic matter run-off and leaching from effluent. The current trial results provide a strong basis and justification for further exploration of such modular concepts.

There are several large unlined holding ponds at dairies in the Scott and Blackwood Rivers catchments, and elsewhere in Western Australia. With these legacy systems, organic material and nutrients in stored effluent and sludge may continue leaching and/or overflowing into ground and surface waters. Whilst being outside the scope of the current trial, a Z-Filter could be explored as a means to clean up the legacy material in such holding ponds.

The farmer of the dairy where the trial occurred anticipated significant benefits from organic matter in the Z-Filter Filter Cake, for boosting of soil productivity in previously underperforming areas on-farm. The issue of depleted soil health is expected to be common to many dairies in the region so likely other dairies would similarly benefit from compost. The natural composting observed with the Filter Cake was encouraging and suggested that the Filter Cake could be amenable to conversion into a valuable compost product. However, further research should explore the agronomic performance of Filter Cake compost products to better understand and future-proof agronomic applications of such products to pasture and other crop production.

Overall, the trial results suggested manure separation could greatly value-add to the beneficial reuse of effluent nutrients and organic matter by providing farmers with options, including to simultaneously reduce negative impacts of dairy operations on the environment.

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## Appendix A - Material Safety Data Sheet for Solenis DrewFloc$^{TM}$ 2488

## Conforms to EU Regulation 1907/2006/EC as amended.

## SECTION 1: Identification of the substance/mixture and of the company/undertaking

### 1.1 Product identifier

Trade name : Drewfloc™ 2488
polymer
™ Trademark, Solenis or its subsidiaries or affiliates,
registered in various countries

### 1.2 Relevant identified uses of the substance or mixture and uses advised against

Use of the Substance/Mixture : Flocculant

| **1.3 Details of the supplier of the safety data sheet** | **1.4 Emergency telephone number** |
|---|---|
| Solenis<br>Fascinatio Boulevard 522<br>2909 VA CAPELLE A/D IJSSEL<br>Netherlands<br>EHSProductSafetyTeam@solenis.com | +1-302-502-0991 , or contact your local emergency telephone number at 112<br>**Product Information**<br>Contact your local Solenis representative |

## SECTION 2: Hazards identification

### 2.1 Classification of the substance or mixture

**Classification (REGULATION (EC) No 1272/2008)**

| Eye irritation, Category 2 | H319: Causes serious eye irritation. |
|---|---|

### 2.2 Label elements

**Labelling (REGULATION (EC) No 1272/2008)**

Hazard pictograms :

Signal word : Warning

Hazard statements : H319 Causes serious eye irritation.

Precautionary statements :

**Prevention:**

P264 Wash skin thoroughly after handling.
P280 Wear eye protection/ face protection.

**Response:**

P305 + P351 + P338 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.

P337 + P313 If eye irritation persists: Get medical advice/ attention.

### 2.3 Other hazards

This substance/mixture contains no components considered to be either persistent, bioaccumulative and toxic (PBT), or very persistent and very bioaccumulative (vPvB) at levels of 0.1% or higher.

## SECTION 3: Composition/information on ingredients

### 3.2 Mixtures

**Hazardous components**

| Chemical name | CAS-No.<br>EC-No.<br>Registration number | Classification | Concentration (% w/w) |
|---|---|---|---|
| Alkanes, C16-20-iso- | Not Assigned<br>700-992-1<br>01-2119452551-44-xxxx | Asp. Tox. 1; H304 | >= 25 - < 40 |
| Ethoxylated alcohols (C12-18) | 68213-23-0 | Eye Dam. 1; H318<br>Aquatic Acute 1; H400<br>Aquatic Chronic 3; H412 | >= 2,5 - < 3 |

For explanation of abbreviations see section 16.

## SECTION 4: First aid measures

### 4.1 Description of first aid measures

General advice : Move out of dangerous area.
Show this safety data sheet to the doctor in attendance.
Do not leave the victim unattended.

If inhaled : If breathed in, move person into fresh air.
If unconscious, place in recovery position and seek medical advice.
If symptoms persist, call a physician.

In case of skin contact : First aid is not normally required. However, it is recommended that exposed areas be cleaned by washing with soap and water.

In case of eye contact : Immediately flush eye(s) with plenty of water.
Remove contact lenses.

| | | |
|---|---|---|
| | | Protect unharmed eye. |
| If swallowed | : | Do not give milk or alcoholic beverages.<br>Never give anything by mouth to an unconscious person.<br>If symptoms persist, call a physician. |

### 4.2 Most important symptoms and effects, both acute and delayed

| | | |
|---|---|---|
| Symptoms | : | Signs and symptoms of exposure to this material through breathing, swallowing, and/or passage of the material through the skin may include:<br>stomach or intestinal upset (nausea, vomiting, diarrhea)<br>irritation (nose, throat, airways) |
| Risks | : | Causes serious eye irritation. |

### 4.3 Indication of any immediate medical attention and special treatment needed

| | | |
|---|---|---|
| Treatment | : | No hazards which require special first aid measures. |

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## SECTION 5: Firefighting measures

### 5.1 Extinguishing media

| | | |
|---|---|---|
| Suitable extinguishing media | : | Use extinguishing measures that are appropriate to local circumstances and the surrounding environment.<br>Water spray<br>Foam<br>Carbon dioxide (CO2)<br>Dry chemical |
| Unsuitable extinguishing media | : | High volume water jet |

### 5.2 Special hazards arising from the substance or mixture

| | | |
|---|---|---|
| Specific hazards during firefighting | : | If product is heated above its flash point it will produce vapors sufficient to support combustion. Vapors are heavier than air and may travel along the ground and be ignited by heat, pilot lights, other flames and ignition sources at locations near the point of release.<br>Do not allow run-off from fire fighting to enter drains or water courses. |
| Hazardous combustion products | : | Carbon monoxide<br>Carbon dioxide (CO2)<br>Nitrogen oxides (NOx) |

### 5.3 Advice for firefighters

| | | |
|---|---|---|
| Special protective equipment for firefighters | : | In the event of fire, wear self-contained breathing apparatus. |

| | | |
|---|---|---|
| Specific extinguishing methods | : | Product is compatible with standard fire-fighting agents. |
| Further information | : | Fire residues and contaminated fire extinguishing water must be disposed of in accordance with local regulations. |

## SECTION 6: Accidental release measures

### 6.1 Personal precautions, protective equipment and emergency procedures

| | | |
|---|---|---|
| Personal precautions | : | Persons not wearing protective equipment should be excluded from area of spill until clean-up has been completed.<br>Comply with all applicable federal, state, and local regulations. |

### 6.2 Environmental precautions

| | | |
|---|---|---|
| Environmental precautions | : | Prevent product from entering drains.<br>Prevent further leakage or spillage if safe to do so.<br>If the product contaminates rivers and lakes or drains inform respective authorities. |

### 6.3 Methods and material for containment and cleaning up

| | | |
|---|---|---|
| Methods for cleaning up | : | Soak up with inert absorbent material (e.g. sand, silica gel, acid binder, universal binder, sawdust).<br>Keep in suitable, closed containers for disposal. |

### 6.4 Reference to other sections

For further information see Section 8 and Section 13 of the safety data sheet.

## SECTION 7: Handling and storage

### 7.1 Precautions for safe handling

| | | |
|---|---|---|
| Advice on safe handling | : | Do not breathe vapours/dust.<br>Do not smoke.<br>Container hazardous when empty.<br>Avoid contact with skin and eyes.<br>Smoking, eating and drinking should be prohibited in the application area.<br>For personal protection see section 8.<br>Dispose of rinse water in accordance with local and national regulations. |
| Advice on protection against fire and explosion | : | Normal measures for preventive fire protection. |
| Hygiene measures | : | Wash hands before breaks and at the end of workday. When using do not eat or drink. When using do not smoke. |

### 7.2 Conditions for safe storage, including any incompatibilities

| | | |
|---|---|---|
| Requirements for storage areas and containers | : | Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage. Electrical installations / working materials must comply with the technological safety standards. |
| Other data | : | No decomposition if stored and applied as directed. |

### 7.3 Specific end use(s)

| | | |
|---|---|---|
| Specific use(s) | : | No data available |

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## SECTION 8: Exposure controls/personal protection

### 8.1 Control parameters

Contains no substances with occupational exposure limit values.

**Derived No Effect Level (DNEL) according to Regulation (EC) No. 1907/2006:**

| Substance name | End Use | Exposure routes | Potential health effects | Value |
|---|---|---|---|---|
| Alkanes, C16-20-iso- | Workers | Inhalation | Systemic, long-term | 29,4 mg/m3 |
| Remarks: | Repeated dose toxicity | | | |
| | Workers | Dermal | Systemic, long-term | 8,34 mg/kg |
| Remarks: | Repeated dose toxicity | | | |
| | General population | Inhalation | Systemic, long-term | 7,25 mg/m3 |
| Remarks: | Repeated dose toxicity | | | |
| | General population | Dermal | Systemic, long-term | 4,17 mg/kg |
| Remarks: | Repeated dose toxicity | | | |
| | General population | Oral | Systemic, long-term | 4,17 mg/kg |
| Remarks: | Repeated dose toxicity | | | |

### 8.2 Exposure controls

**Engineering measures**

Provide sufficient mechanical (general and/or local exhaust) ventilation to maintain exposure below exposure guidelines (if applicable) or below levels that cause known, suspected or apparent adverse effects.

**Personal protective equipment**

| | | |
|---|---|---|
| Eye protection | : | Wear chemical splash goggles when there is the potential for exposure of the eyes to liquid, vapor or mist. |
| Hand protection | | |
| Material | : | butyl-rubber |
| Material | : | nitrile rubber |
| Remarks | : | The suitability for a specific workplace should be discussed with the producers of the protective gloves. |

Skin and body protection : Wear as appropriate:
Impervious clothing
Safety shoes
Choose body protection according to the amount and concentration of the dangerous substance at the work place.

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## SECTION 9: Physical and chemical properties

### 9.1 Information on basic physical and chemical properties

Appearance : liquid

Colour : white

Odour : ester-like

Odour Threshold : No data available

pH : ca. 3,7 (20 °C)
Concentration: 10 g/l

Melting point/freezing point : No data available

Boiling point/boiling range : ca. 103 °C

Flash point : 94 °C
Calculated Flash Point

Evaporation rate : No data available

Flammability (solid, gas) : No data available

Upper explosion limit : No data available

Lower explosion limit : No data available

Vapour pressure : < 35 hPa (20 °C)

Relative vapour density : No data available

Relative density : No data available

Density : ca. 1,03 g/cm3 (20 °C)

Solubility(ies)
Water solubility : soluble

Solubility in other solvents : No data available

Partition coefficient: n-octanol/water : No data available

Decomposition temperature : No data available

Viscosity
Viscosity, dynamic : No data available

Viscosity, kinematic : > 20,5 mm2/s (40 °C)

Oxidizing properties : No data available

### 9.2 Other information

Self-ignition : No data available

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## SECTION 10: Stability and reactivity

### 10.1 Reactivity

No decomposition if stored and applied as directed.

### 10.2 Chemical stability

Stable under recommended storage conditions.

### 10.3 Possibility of hazardous reactions

Hazardous reactions : Product will not undergo hazardous polymerization.

### 10.4 Conditions to avoid

Conditions to avoid : Keep away from heat, flame, sparks and other ignition sources.
Heat, flames and sparks.

### 10.5 Incompatible materials

Materials to avoid : Acids
Strong oxidizing agents

### 10.6 Hazardous decomposition products

Hazardous decomposition products : Carbon monoxide
Carbon dioxide (CO2)
Nitrogen oxides (NOx)

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## SECTION 11: Toxicological information

### 11.1 Information on toxicological effects

**Acute toxicity**

Not classified based on available information.

**Components:**

**Alkanes, C16-20-iso-:**

Acute oral toxicity : LD50 (Rat, male and female): > 10.000 mg/kg
Method: OECD Test Guideline 401

Acute dermal toxicity : LD50 (Rat, male and female): > 2.000 mg/kg
Method: OECD Test Guideline 402
GLP: yes
Assessment: Not classified as acutely toxic by dermal absorption under GHS.

**Ethoxylated alcohols (C12-18):**

Acute oral toxicity : LD 50 (Rat): > 2.000 mg/kg

Acute inhalation toxicity : Remarks: No data available

Acute dermal toxicity : LD50 (Rabbit): > 2.000 mg/kg

**Skin corrosion/irritation**

Not classified based on available information.

**Product:**

Remarks: May cause skin irritation in susceptible persons.

**Components:**

**Alkanes, C16-20-iso-:**

Species: Rabbit
Method: OECD Test Guideline 404
Result: Slightly irritating to skin
GLP: yes

**Ethoxylated alcohols (C12-18):**

Result: Not irritating to skin

**Serious eye damage/eye irritation**

Causes serious eye irritation.

**Product:**

Remarks: **Vapours may cause irritation to the eyes, respiratory system and the skin. Causes serious eye irritation.**

**Components:**

**Alkanes, C16-20-iso-:**

Species: Rabbit
Method: OECD Test Guideline 405
Result: Not irritating to eyes

GLP: no

**Ethoxylated alcohols (C12-18):**

Result: Corrosive

**Respiratory or skin sensitisation**

**Skin sensitisation**

Not classified based on available information.

**Respiratory sensitisation**

Not classified based on available information.

**<u>Components:</u>**

**Alkanes, C16-20-iso-:**

Test Type: Maximisation Test
Species: Guinea pig
Method: OECD Test Guideline 406

**Germ cell mutagenicity**

Not classified based on available information.

**<u>Components:</u>**

**Alkanes, C16-20-iso-:**

Genotoxicity in vitro : Test Type: Ames test
Species: Salmonella typhimurium
Metabolic activation: with and without metabolic activation
Method: OECD Test Guideline 471
Result: negative
GLP: yes

: Test Type: In vitro mammalian cell gene mutation test
Species: mouse lymphoma cells
Metabolic activation: with and without metabolic activation
Method: OECD Test Guideline 476
Result: negative
GLP: yes

: Test Type: Chromosome aberration test in vitro
Species: Human lymphocytes
Metabolic activation: with and without metabolic activation
Method: OECD Test Guideline 473
Result: negative
GLP: yes

**Carcinogenicity**

Not classified based on available information.

**Reproductive toxicity**

Not classified based on available information.

**STOT - single exposure**

Not classified based on available information.

**STOT - repeated exposure**

Not classified based on available information.

**Aspiration toxicity**

Not classified based on available information.

**Components:**

**Alkanes, C16-20-iso-:**

May be fatal if swallowed and enters airways.

**Further information**

**Product:**

Remarks: No data available

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## SECTION 12: Ecological information

### 12.1 Toxicity

**Product:**

| | | |
|---|---|---|
| Toxicity to fish | : | LC50 (Fish): > 1 - 10 mg/l<br>Exposure time: 96 h<br>Method: OECD Test Guideline 203<br>Remarks: Information refers to the main component. |
| Toxicity to daphnia and other aquatic invertebrates | : | EC50 (Daphnia magna (Water flea)): > 10 mg/l<br>Exposure time: 48 h<br>Method: OECD Test Guideline 202<br>Remarks: Information refers to the main component. |

**Components:**

**Alkanes, C16-20-iso-:**

| | | |
|---|---|---|
| Toxicity to fish | : | LC50 (Danio rerio (zebra fish)): > 0,026 mg/l<br>Exposure time: 96 h<br>Test Type: semi-static test<br>Method: Directive 67/548/EEC, Annex V, C.1.<br>Remarks: No toxicity at the limit of solubility |
| Toxicity to daphnia and other aquatic invertebrates | : | EC50 (Daphnia magna (Water flea)): > 0,077 mg/l<br>Exposure time: 48 h<br>Test Type: static test<br>Method: Directive 67/548/EEC, Annex V, C.2.<br>Remarks: No toxicity at the limit of solubility |

Toxicity to algae : ErC50 (Desmodesmus subspicatus (Scenedesmus subspicatus)): > 0,021 mg/l
Exposure time: 72 h
Test Type: static test
Method: Directive 67/548/EEC, Annex V, C.3.
GLP: yes
Remarks: No toxicity at the limit of solubility

NOEC (Desmodesmus subspicatus (Scenedesmus subspicatus)): > 0,021 mg/l
Exposure time: 72 h
Test Type: static test
Method: Directive 67/548/EEC, Annex V, C.3.
GLP: yes
Remarks: No toxicity at the limit of solubility

Toxicity to microorganisms : EC 50 (Pseudomonas putida): > 2,0 mg/l
Exposure time: 5,25 h
Test Type: Static
GLP: yes

Toxicity to daphnia and other aquatic invertebrates (Chronic toxicity) : NOEC: 100 mg/l
Exposure time: 21 d
Species: Daphnia magna (Water flea)
Test Type: semi-static test
Analytical monitoring: yes
Method: OECD Test Guideline 211
GLP: yes

**Ethoxylated alcohols (C12-18):**

Toxicity to fish : LC50 (Danio rerio (zebra fish)): 0,876 mg/l
Exposure time: 96 h
Test Type: semi-static test
Method: Directive 67/548/EEC, Annex V, C.1.
Remarks: Information given is based on data obtained from similar substances.

Toxicity to daphnia and other aquatic invertebrates : EC50 (Water flea (Daphnia magna)): 0,999 mg/l
Exposure time: 48 h
Test Type: static test

Toxicity to algae : EC50 (Pseudokirchneriella subcapitata (green algae)): 0,41 mg/l
End point: Growth inhibition
Exposure time: 72 h
Test Type: static test
Method: OECD Test Guideline 201
Remarks: Information given is based on data obtained from similar substances.

Toxicity to fish (Chronic : NOEC: 0,16 mg/l

| | | |
|---|---|---|
| toxicity) | | Exposure time: 10 d<br>Species: Lepomis macrochirus (Bluegill sunfish)<br>Test Type: flow-through test |
| Toxicity to daphnia and other aquatic invertebrates (Chronic toxicity) | : | NOEC: 0,77 mg/l<br>End point: Reproduction Test<br>Exposure time: 21 d<br>Species: Water flea (Daphnia magna)<br>Test Type: flow-through test<br>Remarks: Information given is based on data obtained from similar substances. |

### 12.2 Persistence and degradability

**Components:**

**Alkanes, C16-20-iso-:**

| | | |
|---|---|---|
| Biodegradability | : | Test Type: aerobic<br>Inoculum: activated sludge<br>Result: Not readily biodegradable.<br>Biodegradation: 32 %<br>Related to: Theoretical oxygen demand<br>Exposure time: 28 d<br>Remarks: Inherently biodegradable. |

**Ethoxylated alcohols (C12-18):**

| | | |
|---|---|---|
| Biodegradability | : | Result: Readily biodegradable.<br>Biodegradation: 95 %<br>Exposure time: 28 d<br>Method: OECD Test Guideline 301F |

### 12.3 Bioaccumulative potential

**Product:**

| | | |
|---|---|---|
| Bioaccumulation | : | Remarks: The bioaccumulation potential cannot be determined. |

**Components:**

**Alkanes, C16-20-iso-:**

| | | |
|---|---|---|
| Partition coefficient: n-octanol/water | : | log Pow: 9,5 - 10,1 (26 °C)<br>Method: OECD Test Guideline 117 |

### 12.4 Mobility in soil

No data available

### 12.5 Results of PBT and vPvB assessment

**Product:**

| | | |
|---|---|---|
| Assessment | : | This substance/mixture contains no components considered |

to be either persistent, bioaccumulative and toxic (PBT), or very persistent and very bioaccumulative (vPvB) at levels of 0.1% or higher..

### 12.6 Other adverse effects

**Product:**

| | |
|---|---|
| Additional ecological information | : An environmental hazard cannot be excluded in the event of unprofessional handling or disposal. |

## SECTION 13: Disposal considerations

### 13.1 Waste treatment methods

| | |
|---|---|
| Product | : The product should not be allowed to enter drains, water courses or the soil.<br>Do not contaminate ponds, waterways or ditches with chemical or used container.<br>Send to a licensed waste management company. |
| Contaminated packaging | : Empty remaining contents.<br>Dispose of as unused product.<br>Empty containers should be taken to an approved waste handling site for recycling or disposal.<br>Do not re-use empty containers. |

## SECTION 14: Transport information

### 14.1 UN number

**ADR:** Not dangerous goods

**RID:** Not dangerous goods

**INTERNATIONAL MARITIME DANGEROUS GOODS:** Not dangerous goods

**INTERNATIONAL AIR TRANSPORT ASSOCIATION - CARGO:** Not dangerous goods

**INTERNATIONAL AIR TRANSPORT ASSOCIATION - PASSENGER:** Not dangerous goods

### 14.2 UN proper shipping name

**ADR:** Not dangerous goods
**RID:** Not dangerous goods
**INTERNATIONAL MARITIME DANGEROUS GOODS:** Not dangerous goods
**INTERNATIONAL AIR TRANSPORT ASSOCIATION - CARGO:** Not dangerous goods
**INTERNATIONAL AIR TRANSPORT ASSOCIATION - PASSENGER:** Not dangerous goods

### 14.3 Transport hazard class(es)

**ADR:** Not dangerous goods
**RID:** Not dangerous goods
**INTERNATIONAL MARITIME DANGEROUS GOODS:** Not dangerous goods
**INTERNATIONAL AIR TRANSPORT ASSOCIATION - CARGO:** Not dangerous goods
**INTERNATIONAL AIR TRANSPORT ASSOCIATION - PASSENGER:** Not dangerous goods

### 14.4 Packing group

**ADR:** Not dangerous goods
**RID:** Not dangerous goods
**INTERNATIONAL MARITIME DANGEROUS GOODS:** Not dangerous goods
**INTERNATIONAL AIR TRANSPORT ASSOCIATION - CARGO:** Not dangerous goods
**INTERNATIONAL AIR TRANSPORT ASSOCIATION - PASSENGER:** Not dangerous goods

### 14.5 Environmental hazards

**ADR:** Not applicable
**RID:** Not applicable
**INTERNATIONAL MARITIME DANGEROUS GOODS:** Not applicable
**INTERNATIONAL AIR TRANSPORT ASSOCIATION - CARGO:** Not applicable
**INTERNATIONAL AIR TRANSPORT ASSOCIATION - PASSENGER:** Not applicable
`

### 14.6 Special precautions for user

Not applicable

### 14.7 Transport in bulk according to Annex II of Marpol and the IBC Code

Not applicable for product as supplied.

Dangerous goods descriptions (if indicated above) may not reflect quantity, end-use or region-specific exceptions that can be applied. Consult shipping documents for descriptions that are specific to the shipment.

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## SECTION 15: Regulatory information

### 15.1 Safety, health and environmental regulations/legislation specific for the substance or mixture

REACH - Restrictions on the manufacture, placing on the market and use of certain dangerous substances, preparations and articles (Annex XVII) : Not applicable

REACH - Candidate List of Substances of Very High Concern for Authorisation (Article 59). : Not applicable

REACH - List of substances subject to authorisation (Annex XIV) : Not applicable

Regulation (EC) No 1005/2009 on substances that : Not applicable deplete the ozone layer

| | |
|---|---|
| Regulation (EC) No 850/2004 on persistent organic pollutants | : Not applicable |
| Regulation (EC) No 649/2012 of the European Parliament and the Council concerning the export and import of dangerous chemicals | : Not applicable |

Seveso III: Directive 2012/18/EU of the European Parliament and of the Council on the control of major-accident hazards involving dangerous substances.
Not applicable

**The components of this product are reported in the following inventories:**

| | |
|---|---|
| DSL | : This product contains one or more components that are not on the Canadian DSL and have annual quantity limits. |
| AICS | : On the inventory, or in compliance with the inventory |
| ENCS | : Not in compliance with the inventory |
| KECI | : On the inventory, or in compliance with the inventory |
| PICCS | : Not in compliance with the inventory |
| IECSC | : On the inventory, or in compliance with the inventory |
| TCSI | : On the inventory, or in compliance with the inventory |
| TSCA | : Not On TSCA Inventory |

### 15.2 Chemical safety assessment

No data available

## SECTION 16: Other information

**Further information**

Revision Date: 06.09.2018

| Classification of the mixture: | | Classification procedure: |
|---|---|---|
| Eye Irrit. 2 | H319 | Calculation method |

**Full text of H-Statements**

| | |
|---|---|
| H304 | : May be fatal if swallowed and enters airways. |
| H318 | : Causes serious eye damage. |
| H400 | : Very toxic to aquatic life. |
| H412 | : Harmful to aquatic life with long lasting effects. |

**Full text of other abbreviations**

| | | |
|---|---|---|
| Aquatic Acute | : | Acute aquatic toxicity |
| Aquatic Chronic | : | Chronic aquatic toxicity |
| Asp. Tox. | : | Aspiration hazard |
| Eye Dam. | : | Serious eye damage |

ADN - European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways; ADR - European Agreement concerning the International Carriage of Dangerous Goods by Road; AICS - Australian Inventory of Chemical Substances; ASTM - American Society for the Testing of Materials; bw - Body weight; CLP - Classification Labelling Packaging Regulation; Regulation (EC) No 1272/2008; CMR - Carcinogen, Mutagen or Reproductive Toxicant; DIN - Standard of the German Institute for Standardisation; DSL - Domestic Substances List (Canada); ECHA - European Chemicals Agency; EC-Number - European Community number; ECx - Concentration associated with x% response; ELx - Loading rate associated with x% response; EmS - Emergency Schedule; ENCS - Existing and New Chemical Substances (Japan); ErCx - Concentration associated with x% growth rate response; GHS - Globally Harmonized System; GLP - Good Laboratory Practice; IARC - International Agency for Research on Cancer; IATA - International Air Transport Association; IBC - International Code for the Construction and Equipment of Ships carrying Dangerous Chemicals in Bulk; IC50 - Half maximal inhibitory concentration; ICAO - International Civil Aviation Organization; IECSC - Inventory of Existing Chemical Substances in China; IMDG - International Maritime Dangerous Goods; IMO - International Maritime Organization; ISHL - Industrial Safety and Health Law (Japan); ISO - International Organisation for Standardization; KECI - Korea Existing Chemicals Inventory; LC50 - Lethal Concentration to 50 % of a test population; LD50 - Lethal Dose to 50% of a test population (Median Lethal Dose); MARPOL - International Convention for the Prevention of Pollution from Ships; n.o.s. - Not Otherwise Specified; NO(A)EC - No Observed (Adverse) Effect Concentration; NO(A)EL - No Observed (Adverse) Effect Level; NOELR - No Observable Effect Loading Rate; NZIoC - New Zealand Inventory of Chemicals; OECD - Organization for Economic Co-operation and Development; OPPTS - Office of Chemical Safety and Pollution Prevention; PBT - Persistent, Bioaccumulative and Toxic substance; PICCS - Philippines Inventory of Chemicals and Chemical Substances; (Q)SAR - (Quantitative) Structure Activity Relationship; REACH - Regulation (EC) No 1907/2006 of the European Parliament and of the Council concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals; RID - Regulations concerning the International Carriage of Dangerous Goods by Rail; SADT - Self-Accelerating Decomposition Temperature; SDS - Safety Data Sheet; TCSI - Taiwan Chemical Substance Inventory; TRGS - Technical Rule for Hazardous Substances; TSCA - Toxic Substances Control Act (United States); UN - United Nations; vPvB - Very Persistent and Very Bioaccumulative

**Further information**

| | | |
|---|---|---|
| Other information | : | The information accumulated herein is believed to be accurate but is not warranted to be whether originating with the company or not. Recipients are advised to confirm in advance of need that the information is current, applicable, and suitable to their circumstances. This MSDS has been prepared by the Solenis Environmental Health and Safety Department. |

Sources of key data used to compile the Safety Data Sheet
Key literature references and sources of data

SOLENIS Internal data
SOLENIS internal data including own and sponsored test reports
The UNECE administers regional agreements implementing harmonised classification for labelling (GHS) and transport.

GB / EN