Water Auditing: The first step to effective effluent management on dairy farms in South West Western Australia

An approach of Zero Waste Discharge on a dairy farm in Boyanup, Western Australia

Submitted to the School of Engineering and Information Technology, Murdoch University in partial fulfilment of the requirements for the degree of Bachelor of Engineering (Honours)

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I hereby declare that this project is my own work and that it has not been submitted previously for a degree. I have correctly referenced and acknowledged where others contributed any work.

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ABSTRACT

This project investigates the possibility of achieving zero waste discharge on a dairy farm in south west Western Australia. The current best practices for dairy farm effluent treatment were assessed in a literature review and a water audit and a nutrient balance were conducted on a specific farm in Boyanup, W. A. with 500 cattle.

The finding was 52 L/cow per milking of water were used, which is higher than the industry benchmark. Nutrients were leaking into groundwater table at six meters depth at low concentrations.

Four different options were assessed in a techno-economic options assessment:

i) no action to be taken;
ii) installing a pond for effluent storage;
iii) installing a tank for effluent storage, and
iv) recycling effluent after primary treatment for dairy yard wash combined with construction of a roof on the yard for additional rainwater catchment and reduction of heat stress on cows.

The paper concludes that a hybrid option incorporating effluent recycling for yard wash by installation of flood wash tanks, construction of a pond for storage during wet seasons, and the erection of a roof on the yard for additional rainwater catchment and reduction of heat stress on cows. This final recommendation was designed to achieve zero waste discharge and showed further benefits such as an increase in milk production and a reduction of labour.

The installation cost for the proposed overall system was estimated at $170,000 with a payback period of 6.2 years.

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GLOSSARY

TABLE 1 - GLOSSARY

Acronym	**Expansion**
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
COP	Code Of Practice For Dairy Shed Effluent (WA)
ETC	Environmental Technology Centre
MAFRL	Marine and Freshwater Research Laboratory
MBBR	Moving Bed Biofilm Reactor
MBR	Membrane Bioreactor
NH_3	Ammonia
NO_3^-	Nitrate
K	Potassium
PO_4^{3-}	Phosphate
PRIs	Phosphate Retention Indices
SAT	Soil-Aquifer Treatment
SBR	Sequencing Batch Reactor
SWWA	South West of Western Australia
TN	Total Nitrogen
TP	Total Phosphorous
TST	Trafficable Solids Trap
WA	Western Australia
ZWD	Zero Waste Discharge

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1 INTRODUCTION

1.1 CONTEXT

Dairy farm effluent and the nutrients it carries can have a significant environmental impact on waterways. Over the past 50 years, the dairy industry has experienced a reduction in the number of farms whilst the number of cattle per farm has increased, leading to centralisation and intensification of potential environmental pollution (Agriculture and Resource Management Council of Australia and New Zealand; Australian and New Zealand Environment and Conservation Council 1999).

A common problem these industries face is the increased environmental stress from their effluent production. Effluent from cowshed wash down is rich in manure, and consequently nutrients often filter directly to farm paddocks and creeks, exceeding the nutrient assimilation rate of soils and thereby contributing to eutrophication in nearby waterways (GeoCatch 2017).

During the 1990s, significant blue green algae outbreaks were observed in Australian catchments, and in 1994 surveys showed that dairy effluent was a contributor to their occurrence, together with required land clearing resulting in less nutrient uptake by plants (Neville, et al. 2008). Tasmania was the first in 1997 to react with publishing a Code of Practice for Effluent. Western Australia later published a Code in 2012 (S. Birchall 2016). The Code of Practice should be followed by farms in regards to their effluent discharge. No effluent is supposed to leave the site/farm at which it is produced, and sufficient buffer distances are to be respected (Western Dairy; Dairy Australia; GeoCatch 2016). The Department of Water currently runs a project in the south west Western Australia (SWWA) to enable implementation of the Code by dairy farms, with supporting funds from the Western Australia (WA) Royalties for Regions program (Department of Water; Royalties for Regions; 2016).

1.2 OBJECTIVES

This project is aimed at using water auditing in combination with a nutrient balance, and the assessment of current effluent treatment technologies at dairy farms in the SWWA to support the analysis of options for reduction of nutrient discharge on one dairy farm to zero waste discharge (ZWD).

Major goals of the project were to detect large water consumption areas on the farm, achieve 10% closure in the audit, and determine if nutrient leakage occurs after effluent application on paddocks. Options were suggested and designed to achieve ZWD on the site. Storage during wet periods, reduction of water usage, recycling of effluent to lower hierarchy streams, and improved treatment were potential strategies. A techno-economic assessment of these options led to a site-specific recommendation. The conclusion of this paper includes a statement regarding the transferability of the chosen design across the dairy industry, between farms at different locations.

1.3 METHODOLOGY

This report was structured into four different parts:

1. Literature review to assess current best practice.
2. Water audit on site.
3. Nutrient balance on site.
4. Techno-economic options assessment to achieve ZWD.

1.3.1 PART 1 - LITRATURE REVIEW

Before performing an analysis at the farm a literature review was done to assess the current best practice of dairy farm water use and effluent treatment. Several site visits were undertaken in cooperation with the Geographe Catchment Council for assessment of industry standards in WA.

1.3.2 PART 2 - WATER AUDIT

The second part was a water audit, performed on a site in Boyanup, WA, in order to determine the amount of intervention required to reduce water loss and control effluent/nutrient management. Inflows and outflows were determined, with appropriate flow rates shown on a flow diagram. Existing meters were read hourly, indicating the level of water usage. Inflows to the dairy were estimated by tank level drop. Where possible, meters were installed on sinks; where not possible, the flow rate was determined by the bucket and stopwatch method with the use of each outflow being timed over the period of one day. The aim was a closure with an error of less than 10%. Usage of water per milking process and per day was determined using the above measurements. Major water outlets were identified and recorded. Raw options were suggested for the reduction of water use and the reuse of water for lower hierarchy streams. Conservation measures were established as follows:

1. Source elimination
2. Source reduction
3. Reuse water directly without treatment
4. Recycle water after treatment
5. Use freshwater when no other source is available

Conclusions drawn at this stage were later combined with results from part 3 in an options assessment (method 4).

1.3.3 PART 3 - NUTRIENT BALANCE

A nutrient balance was conducted on site with samples taken at five different locations and compared to benchmarks from the literature review.

The first sample consisted of the raw inflow to the effluent treatment process, and this is expected to have the highest nutrient levels. The second sample, taken after the T-piece and therefore after primary treatment, should show less nutrient levels. These levels may drop even further at the third sampling location, where the effluent was irrigated. If treatment occurred within the sump after the solids trap, nutrient levels would decrease at this point. The third sample was the water sample taken on the soil surface during irrigation. It was compared to the fourth sample, taken 200 mm below ground level. A hole was dug in the paddock and a catchment container (pan lysimeter) installed. This sample was located beneath plant roots to indicate how much nutrients the pasture root zone takes up. The fifth sample was taken with the same method at a depth of 550 mm below soil surface. This sample displayed further nutrient uptake of soil, and conclusions were drawn from here on how much nutrient leakage might occur. Raw options were suggested for the reduction of nutrients by effluent application area extension, as well as the recycling of water and storage opportunities for wet periods of the year.

Conclusions drawn at this stage were later combined with results from part 2 in an options assessment (part 4).

1.3.4 PART 4 - TECHNO-ECONOMIC OPTIONS ASSESSMENT

The fourth part was a techno-economic options assessment, combining the findings from water audit and nutrient balance parts.

To determine which option was most viable, a multi criteria analysis (MCA) was performed. Criteria found to be of the highest importance to the project's objectives was chosen, including:

- Achievement of ZWD
- Installation cost
- Running/maintenance cost
- Labour requirement
- Risk

In order to achieve a non-bias weighting for the criteria listed above, different stakeholder groups ranked the criteria from 1-5, with 5 being the most important. The stakeholders included:

Michael Twomey	(farmer on site of this project)
Breanne Brown	(regulator, Geographe Catchment Council)
Sam Taylor	(technical specialist at AgVivo)
Goen Ho	(water auditing specialist, Murdoch University)
Laura Senge	(auditor)
Chenoa Lange	(community)

These scores were then averaged to conclude the final weighting value.

After the weights of the criteria had been determined, each option received a rank in each criterion (place 1 being the best performing option for that criterion). The weights were then multiplied by the scores of the criteria and summed up to produce an overall score. The option with the lowest total score was deemed most viable (Appendix 2).

2 LITERATURE REVIEW

This literature review covers an assessment of current best practices and standards for dairy farm effluent treatment in the south west region of Western Australia.

2.1 WATER AUDITING

The water audit reveals where efficient water use can be improved and where water usage can be reduced. This reduces the total volume of effluent requiring treatment for nutrient removal or recycling, and in turn can result in reduced capital and operating costs. The Agriculture and Resource Management Council of Australia and New Zealand and the Australian and New Zealand Environment and Conservation Council points out the significance of management for water use reduction. Efficient cow flow and animal waiting results in lower stress levels for cows, feed fomulation and time spent on milking. Additionally it can reduce the water usage significantly.

Comparing different sources indicates a benchmark daily washdown requirement to be around 50 L/cow/day (DEC manual 2006); (Flemmer and Flemmer 2007). However, this figure originates from before intensification, when the average herd size was still as low as

139 cows per farm (Vanderholm 1984); (Dairy statistics 2002). A study from 2000 indicated rotaries using 26 L/day/cow and the herringbone 19 L/day/cow (Rogers and Alexander 2000).

In general, a reduction of water use by about 50% in dairies has been observed from 1996 to 2005 (Olejniczak 1996) (McDonald 2005), whilst from 2005 to 2008 only a small reduction was noticed (Mc Donald 2008).

The water audit will show the balance between water input and water output during the dairy shed operation with appropriate flow directions and units (Li 2016). At dairy sheds, typical inputs are bores, dams, rivers, creeks or scheme water and the 'operations' observed in the audit should include at least the flows in Table 2 (Wrigley 1994).

TABLE 2 – RELATIVE WATER USE BY DAIRY SHED OPERATIONS

Outlet	**Expected volume**
Yard Wash	Highest Volume
Pit Or Platform Wash	Medium To High Volume
Cup Sprays	Only In Rotaries, Medium Volume
Platform Sprays	Only In Rotaries, Medium To Low Volume
Teat Wash	Negligible Volume
Milking Machine Wash	Medium Volume
Vat Wash	Medium Volume
Plate Cooler	Usually Recycled
Cow Cooling	Rarely Used In Practice, Low Volume

Water quality is measured as needed. Opportunities for improvement are pointed out. They may include reduction of water use, water reuse or recycling and fit-for purpose or water resource substitution. Financial evaluations shall be included and a water management strategy proposed. It will be aimed for a closure of less than 10% (Li 2016).

2.2 NUTRIENT BALANCE

Per the Effluent Management Guidelines for Dairy Sheds in Australia, in general, nutrient reuse as fertiliser with the organic components and nutrients through land application is the most efficient and suitable method. When utilised, groundwater protection, land contamination, soil structure, salinity and eutrophication of surface waters need to be considered on a regional basis (Agriculture and Resource Management Council of Australia and New Zealand; Australian and New Zealand Environment and Conservation Council 1999).

To avoid pollution, a suitable area is required to reapply the effluent.

The Guidelines point out several factors determining the size of that area:

- Likelihood of water logging, surface runoff and soil erosion;
- Groundwater depth, quality;
- Climatic conditions (rainfall, wind speed, evapotranspiration;
- The kind of crop grown;
- Management practices;
- Soil properties;
- Quality and quantity of effluent;
- Operational life, phosphorous sorption capacity (Agriculture and Resource Management Council of Australia and New Zealand; Australian and New Zealand Environment and Conservation Council 1999).

Houlbrooke suggests as a rule of thumb 8ha/100cows without feed pad, and limits for N of 150 or 200 kg/ha/yr (Houlbrooke 2008).

Continual testing and knowledge of the soil properties around the application area is essential, as excess nutrient application can damage soils. Loam or clay soils are generally preferred over sandy soils or heavy clay soils. For solid application, the area should not be prone to erosion or water logging and should be suitable for improving pasture or dry land cropping. To determine application rates and avoid excess nutrient loads, properties of the effluent (salinity, BOD, pH and nutrient content) need to be considered. Limiting factors are generally hydraulic loading, nutrient loading (N and P) and salt loading (K)

(Agriculture and Resource Management Council of Australia and New Zealand; Australian and New Zealand Environment and Conservation Council 1999). The DoW agrees (as stated in their water quality and protection note 33) that application rates should be matched to seasonal evapotranspiration rates, plant needs and soil moisture reserves. However, water cycles may need to be varied depending on weather conditions and plant root growth (Government of Western Australia; Department of Water 2010).

Generally, when nutrients are mentioned, nitrogen comes to mind. However, as pointed out by Gerritse, for prevention of long term environmental impact, the input of P should be controlled more acutely than N. If possible Phosphate Retention Indices (PRIs) of the entire application area shall be taken to determine suitability. As an example, in soil with a PRI of 20, PO_4^{3-} leaching would be around 1.2 m in 50 years, whilst at a PRI of 1, the same leaching occurs in just 2 years. The sole influencing factor is the phosphorous fixing, whilst soil water content does not affect the travel velocity of the nutrients through the soil (Gerritse 2002). Neville *et al.* agrees that P is the main stimulator to algal growth, and is typically identified as the limiting nutrient. In his article in 2008 he found that in the Peel-Harvey Catchment, the P nutrient use efficiency was at 20%, and that fertilizer inputs of P were a surplus to requirements (Neville, et al. 2008). A paper by Weaver *et al.* in 2008 explains how farm gate nutrient balances can be used to assess the nutrient use efficiency (NUE), and that they are a less costly option than conventional means, as for example water quality monitoring (Weaver, Neville, et al. 2008).

There are direct and indirect nutrient losses. Direct losses occur when the soil is incapable of storing the amounts of nutrients applied, and indirect losses will occur at a later stage, during wetter periods. Sloping lands, wet soil conditions, shallow groundwater tables and soils directly connected to waterways are all prone to direct nutrient losses (Houlbrooke 2008). To avoid losses, appropriate application depths need to be assessed, as a study on mole and pipe drainage found. Lower depths can result in less loss (Houlbrooke, Horne, et al. 2004a). Indirect losses however occur due to leaching in the winter-spring drainage period (Houlbrooke 2008). Application depth can be measured in practice by setting up catchment containers (e. g. cut-up cans) during irrigation (S. Birchall 2017)(verbal conversation). Penetration depth in the soil can be established by application of a lysimeter (Ho 2017)(verbal conversation). There are different kinds of lysimeters; the sampling lysimeter, the soil moisture probe lysimeter, the weighing lysimeter, the pan lysimeter and the wick lysimeter (Forster 2017). Simplest in application is the pan or zero-tension lysimeter, which is inserted laterally into the soil from a pit or a trench. However, it is also the most inaccurate, and should therefore only be used if budget constraints exist. The cost is around $20 plus labour (Radin Mohamed, et al. 2012). Leachate is collected in a collection vessel and emptied on a regular schedule. The paper by Radin Mohamed *et al.* suggests a weekly, biweekly or monthly schedule, however due to time constraints this might be reduced to daily, or after each application of irrigation water.

Within a nutrient balance the losses from the system are;

- Plant uptake
- Transformation to gaseous N_2 and loss
- Net accumulation of nutrients in the soil

Seasonal changes need to be accounted for in the balance, such as plant uptake, net mineralisation and leaching. In addition to groundwater sampling, long term monitoring below the root zone is needed for feedback on determination of non-polluting application rates (Agriculture and Resource Management Council of Australia and New Zealand; Australian and New Zealand Environment and Conservation Council 1999).

Simple arrangements such as fencing off streams can help significantly to avoid nutrients leaving the property. Standard buffer distances can range from 25 to 100 m (Natural Resource Management Ministerial Council; Environment Protection and Heritage Council 2006). However, Department of Water points out that for protection of waterways, site-specific negotiated outcomes may be more viable than set buffer distances (Department of Water; Government of Western Australia 2008). Interesting is the difference in priorities.

For the council, the fencing helped nutrient containment. The reasoning for the farmer to do so was more likely stock management (Bewsell and Kaine 2006).

2.3 TREATMENT

Typical components of dairy shed effluent are 8% excreta, 4% teat washing and 86% wash down water (Longhurst, Roberts and O'Connor 2000). More detailed components found throughout a study conducted in North-Eastern Victoria are shown in Table 3.

TABLE 3 - CHARACTERISTICS OF DAIRY SHED EFFLUENT

Component	**Mg/L**
BOD	3200
Suspended Solids	2400
Total Nitrogen	187
Ammonia	84
Total Phosphorus	26
Sodium	119
Potassium	200
Magnesium	27
Chloride	180
Carbonate/Bicarbonate	155
pH	8
Veterinary Chemicals	Maybe present in significant concentrations
Cleaning/Disinfectants	Concentrations variable
Bacteria, viruses, helminths	Concentrations variable
Salt (as EC)	1.12 dS/m
Sodium Adsorption Ratio	4.3

Source: (Wrigley 1994)

In comparison to Wrigley (Table 3), the DEC manual agrees with the pH of 8; however Longhurst found that the solid content is 0.9%, average N is 269 mg/L instead of 187 mg/L and P is 69 mg/L instead of 26 mg/L (Wrigley 1994) (DEC manual 2006) (Longhurst, Roberts and O'Connor 2000). These differences show how variable effluent components are from site to site and indicate the importance of site specific investigations and plans. There are different treatment options for effluent that allow for reuse on site. Primary treatment should allow for separation of the solid components by solids/sediment traps. This will protect effluent handling equipment and the life of storage ponds. The existing treatment technologies are lagoons, biofilters, activated sludge and dissolved air floatation. Physical and chemical treatments are mainly present in sediment traps and sometimes screening equipment. The purpose is reduction of sludge buildup in ponds and reduction of BOD. Theoretically chemicals can be used for enhancement, however onsite observations seem to show that in reality chemical treatment is not practicable, as shown in unpublished reports (Geographe Catchment Council 2016). Tertiary treatment might be necessary if disposal of effluent is considered instead of reuse on site (Agriculture and Resource Management Council of Australia and New Zealand; Australian and New Zealand Environment and Conservation Council 1999).

Direct vs Deferred Application

The two main methodologies for irrigating with effluent currently in use are(1) direct application, and (2) deferred application. These are directly linked to the treatment that is necessary to be able to choose sufficient treatment technologies. Direct application uses the effluent generated during milking immediately on the paddocks, while deferred application stores the effluent before application onto paddocks (Agriculture and Resource Management Council of Australia and New Zealand; Australian and New Zealand Environment and Conservation Council 1999).

The Two-Pond System

The common treatment in New Zealand has been the two-pond system, where one pond is anaerobic and the other facultative (Sukias, et al. 2001). The combination of anaerobic and aerobic treatment reduces BOD and sediment, but nutrient concentrations remain high

(Hickey, Quinn and Davies-Colley 1989) (Ledgard, et al. 1996) (Craggs, et al. 2003). The resulting liquid following the two-pond system has been reported to contain N level of 91 mg/L and P level of 23 mg/L (Longhurst, Roberts and O'Connor 2000). However, this is not sufficient to cause concern considering the levels suggested to likely cause aquatic weed growth are at 0.61 mg N/L and 0.033 mg P/L (ANZECC 2000).

Bewsell & Kaine confirmed the above findings in 2006. They reported the first pond to be a sedimentation pond and the second a storage for liquid effluent. They are connected via a T-piece, preventing solids from entering the anaerobic part (DairyNZ Limited 2011).

The Effects on the Pasture

The post-treatment liquid is pumped into a paddock for irrigation. The sludge from the sedimentation pond is cleaned out either every or every other year and spread out onto the paddocks. Farmers reported an inability to recognise the difference between potable water irrigation and effluent irrigation, hence they would apply the same amount of fertiliser to all paddocks. Farmers who used direct application whilst ‘shandying’ fresh water into the line could not see a difference in application paddocks either. The only group of farmers who did observe and report changes were those irrigating pure effluent (Bewsell and Kaine 2006).

Rainwater Diversion

Rainwater diversion is not a treatment as such, however it is another aspect of total reduction of effluent waste that should be considered as a potentially effective option. Benefits of uncontaminated water diversion are, as suggested by the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) and the Australian and New Zealand Environment and Conservation Council (ANZECC), an opportunity for use within the shed or the possibility of diverting it into natural environmental flows to recharge aquifers. Furthermore, it will reduce the nutrient-rich effluent volume and hence the storage necessary (Milk Development Council 2007) (Crowley 2005).

2.4 STORAGE

The Effluent Management Guidelines for Dairy Sheds in Australia state that ponds (storage and treatment) should be designed to “safely contain their maximum operational load” and “cope with the wettest year in 10” (Agriculture and Resource Management Council of Australia and New Zealand; Australian and New Zealand Environment and Conservation Council 1999). The locations and placement of ponds need to be well thought out with respect to soil characteristics, buffer distances of, for example 250 m, from neighbouring properties and prevailing wind direction (Government of Western Australia; Department of Water 2009).

Storage accommodates for deferred application practices. The concept was developed at the Massey University No. 4 Dairy farm. The application criteria established that “the existing soil moisture deficit in the root zone plus the depth of applied farm dairy effluent is required to be less than maximum soil water storage (Houlbrooke 2008). During months where rainfall exceeds evaporation, storage will be necessary. If irrigated during these times, the effluent would penetrate beneath plant roots causing contamination.

Current approaches for storage are:

- Single ponds (combination of solids removal and storage)
- Two-pond system or three-pond system (clay or synthetic lined), typically solids removal followed by storage
- Turkey nest (above ground ponds)
- Tanks (need solids separation prior)

(S. Birchall, Session 5: Effluent systems overview 2016).

An innovative opportunity for storage, presently untried for dairy effluent management, which has been applied successfully within the Dan Region Project in Israel, is the Soil-Aquifer Treatment (SAT) which warrants consideration in future research. The partially treated effluent infiltrates through the soil into the aquifer, moves horizontally and is extracted once it reaches extraction bores. Biological, chemical and physical treatments take place during soil penetration. With this approach a closed system is established, provided monitoring bores are adequately spaced (Idelovitch and Michail 1984). Within Australia, this approach has been successfully trialled by the Water Corporation in Halls Head under the infill sewerage project (Water Corporation 2016) and the Mawson Lakes project in Salisbury, SA (Hurlimann and McKay 2006).

2.5 SUMMARY

The dual treatment methods of direct (without storage) and deferred (with storage) application provide varying degrees of effectiveness within the framework of resources and requirements. The main difference is that direct application is cheap and simple; however it is likely to cause environmental concerns. Deferred application is more beneficial for fertilizer applications and environmental constraints, however installation of equipment is costly and management is more difficult. Both applications need solids separation before irrigation. Solids separation can be done by either a trafficable solids trap or ponds. Table 4 below summarises the general treatment options; however, depending on site specifics, additional or hybrid options might be viable:

TABLE 4 - SUMMARY OF TREATMENT OPTIONS

Application	**Direct**	**Deferred**
Solids separation	Yes ▪ Trafficable solids trap	Yes ▪ Trafficable solids trap ▪ Pond
Solids handling	Range of options: ▪ Dry on site and spread ▪ Spread whilst wet ▪ Transport off site Selection depending on equipment on site and contractor availabilities.	Range of options: ▪ Dry on site and spread ▪ Spread whilst wet ▪ Transport off site Selection depending on equipment on site and contractor availabilities.
Biological/ chemical	Very limited	More advanced

treatment	Sole treatment occurs in trafficable solids trap (TST).	TST plus range of options: ▪ Two-pond system ▪ Three-pond system Selection depending on cost, guidelines, soil properties etc.
Storage	None	Range of options: ▪ Clay lined pond ▪ Synthetic lined pond ▪ Turkey nest ▪ Tank Selection depending on soil characteristics, groundwater table etc.
Pumps	Preferably not; depending on elevations.	Preferably not; depending on elevations.
Irrigation	Range of options: ▪ Flood irrigation ▪ Travelling irrigator ▪ Pivot irrigator ▪ And more Selection depending on previous treatment, flood and travelling irrigator most likely as less tendency to block, however incorporates less uniformity.	Range of options: ▪ Flood irrigation ▪ Travelling irrigator ▪ Pivot irrigator ▪ And more Selection depending on previous treatment, if possible pivot preferred as best uniformity, however risk of blockages.

The cost for an effluent system is highly variable depending on the farm, system chosen and location on the farm. Usually components are already in place and an upgrade can range from approximately $50,000 for a farm to approximately $400,000 for an initial, well-designed and advanced system. Estimate range is based on general quotes given by both suppliers and consumers of such systems.

In the SWWA soils can range from clay-loam to sandy, and groundwater levels from 5 m below surface to above surface level. Depending on these conditions, the approach to achieve ZWD would be different for each farm.

Strong collaboration with the farmer is essential, as any system designed will only work if it is properly maintained. It would not be valuable to design a highly engineered system that the farmer was unable to operate, so the site could potentially end up in a squalid state. Prior to any design effluent samples, soil samples and site surveys are essential.

However, on some occasions the best recommendation towards an effluent treatment system may not be the one with least maintenance. It was found that deferred application of stored effluent, when applied at times of soil moisture deficit resulted in a significant reduction of environmental risks. Clay or synthetic lining of storage ponds is essential to avoid leakage. Irrigation equipment needs to be correct for the specific site's application depth. Regular maintenance on equipment needs to be scheduled. Monitoring soil and effluent samples is an important step towards a methodologically sound system and management. A fully developed maintenance plan will prevent unintended reductions in farm productivity, resulting in economic savings for the farmer.

As the treatment highly depends on site-specific characteristics, it is recommended that more reviews and research in the SWWA be undertaken, including gathering data about systems that have worked sustainably in the region. It is advisable that a connection to costs be included, as this will be a decisive factor for the farmer. This is often overlooked as even in other regions cost did not seem to be included in data collection.

3 SITE DESCRIPTION

The site is known as The Peninsula Downs Dardanup farm, also called Twomey's farm, and is part of the Peninsula Downs Dairy Pty Ltd, an Australian private company owned by Ross Woodhouse. Managing and operating the dairy farm is Michael Twomey with three other employees.

The farm is located at 127 Collins Rd, Boyanup, WA 6237. See Figure 1 for general location within Australia. Most of the farm is located within the Shire of Capel, some of it is in the Shire of Dardanup, 200 km south of Perth and 20 km south-east of Bunbury.

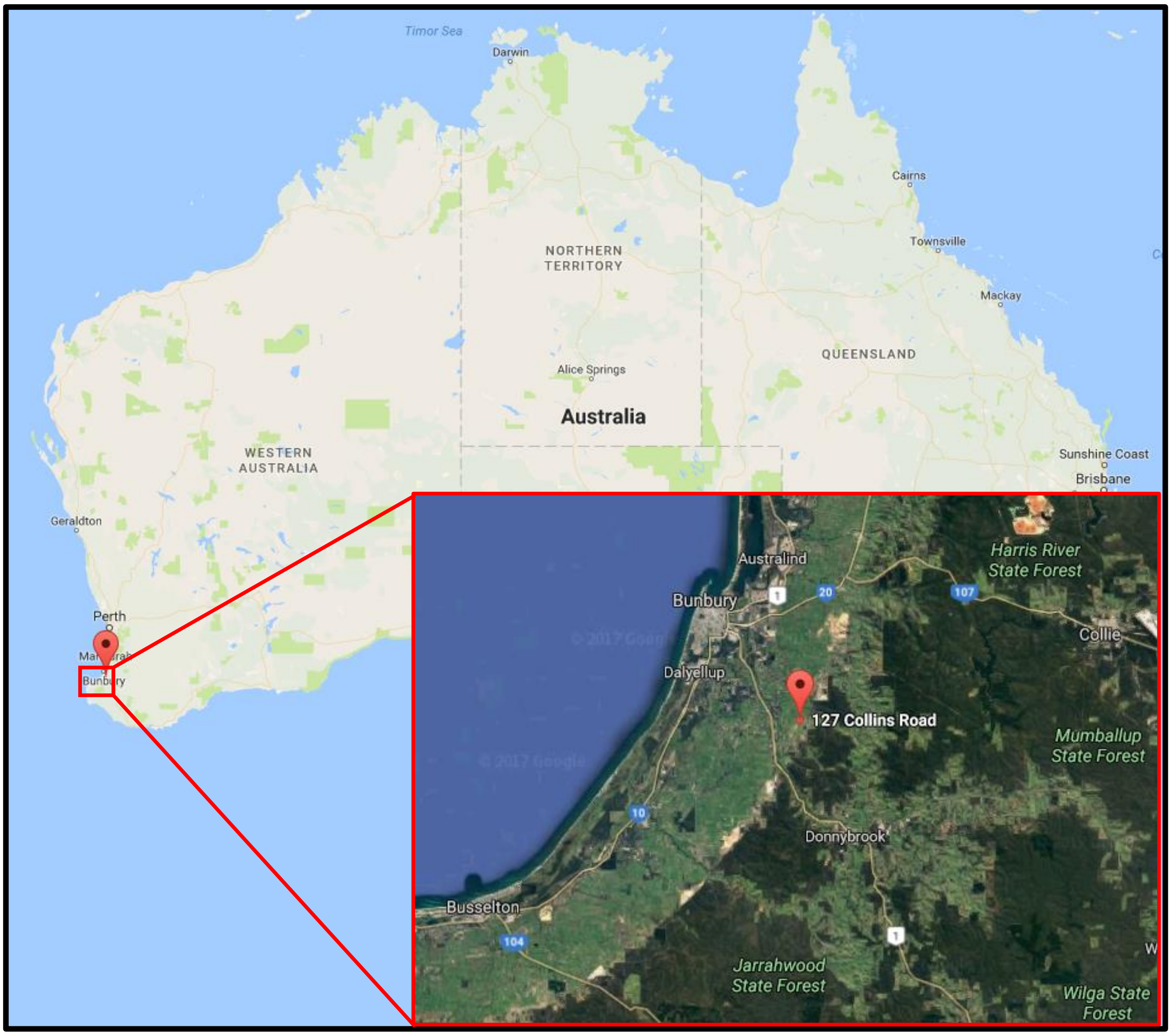

FIGURE 1 - TWOMEY'S FARM - GENERAL LOCATION

3.1 SITE OVERVIEW & MAPS

Figure 2 below shows a map of the farm outlining the paddocks and dairy location (marked as yards), including arable and unarable areas and sizes.

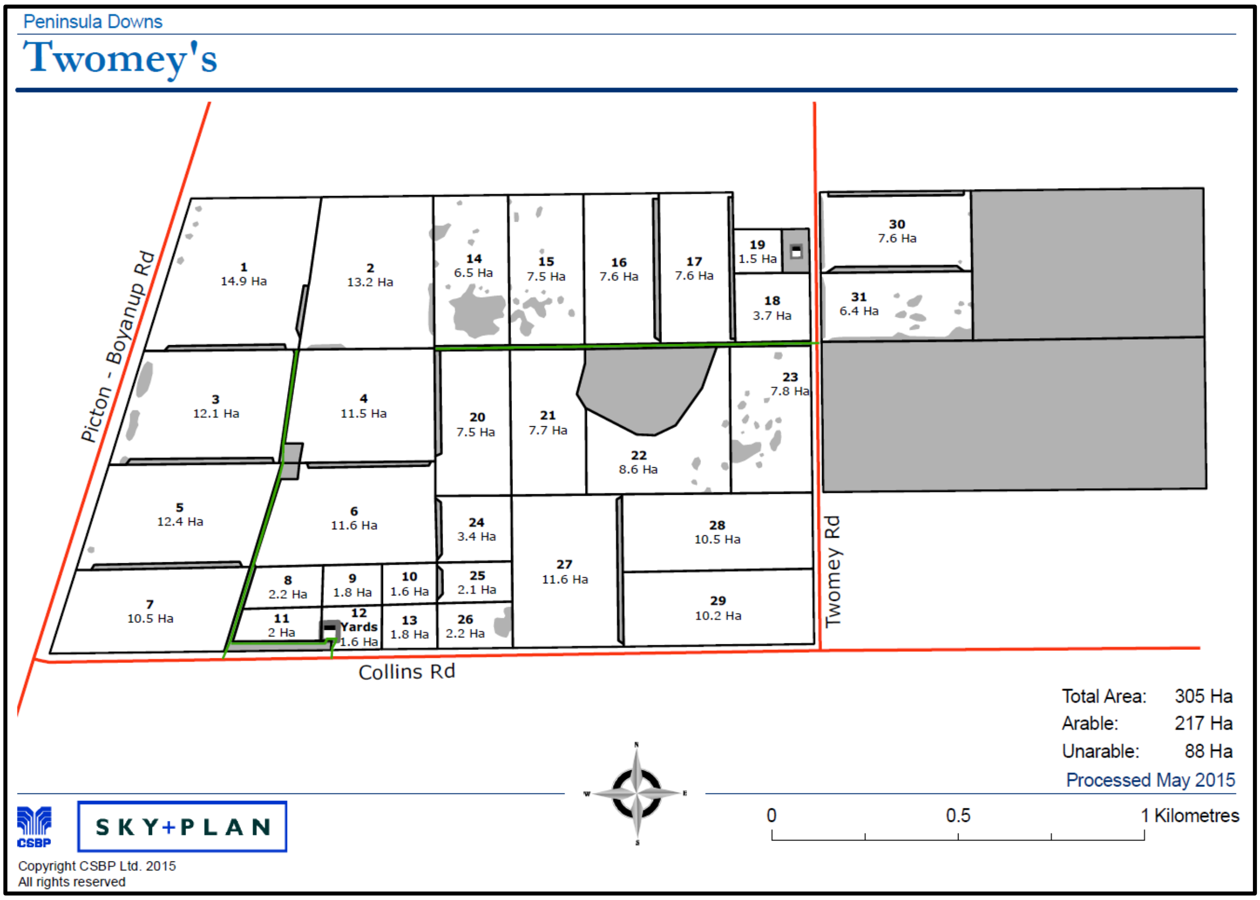

FIGURE 2 - FARM MAP

A bird's eye view of the property is shown in Figure 3 below. It also shows that a new dairy has been constructed. The old and new locations are marked.

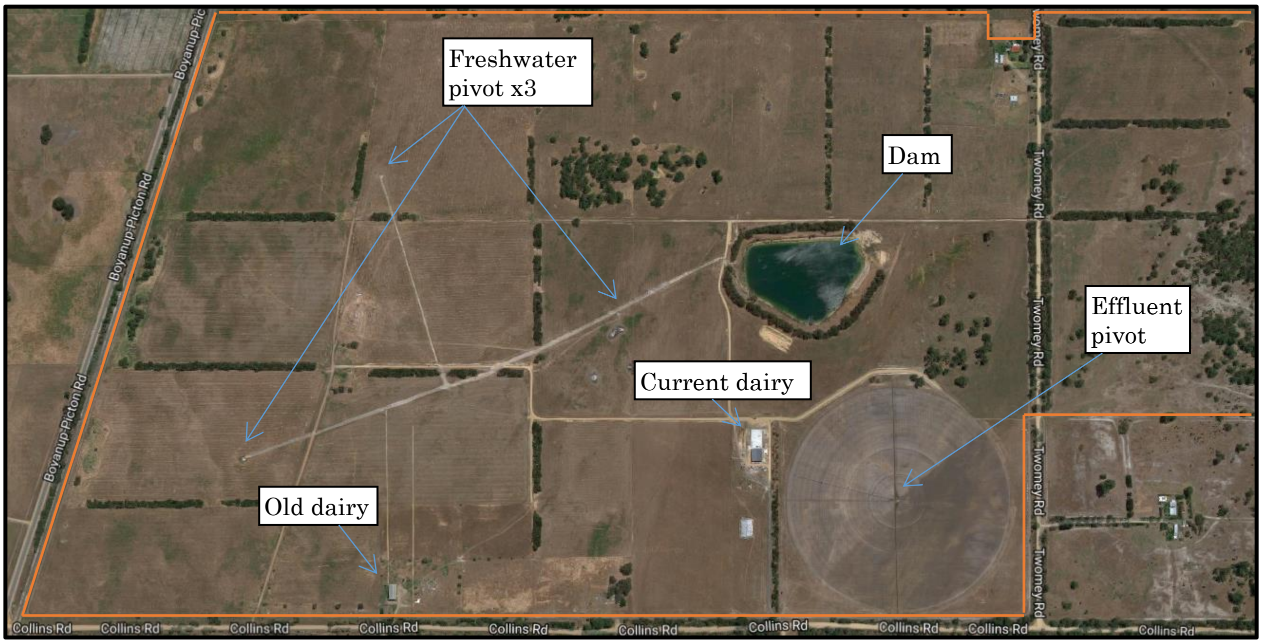

FIGURE 3 - OVERVIEW WHOLE FARM

A close-up of the dairy and the effluent pivot is shown below in Figure 4. The effluent is pumped to the pivot centre, which is a distance of approximately 300m from the dairy.

FIGURE 4 - DAIRY AND EFFLUENT PIVOT
Source: https://www.google.com.au/maps/@-33.4535958,115.7615037,197m/data=!3m1!1e3

A photo of the dairy from bird's eye view can be seen in Figure 5 below. It shows the dairy still in construction, however all essential components are installed. The water flow throughout the process is indicated by the large blue arrows. The freshwater tank is filled continuously by water pumped from the dam. Level switches are installed in the tank for pump control.

FIGURE 5 - DAIRY WITH WATER FLOWS FROM BIRD'S EYE VIEW

All hoses (outlets) within the dairy are pressurised by pumps, so are the hydrants on the yard. At the bottom end of the yard the water is channelled into the trafficable solids trap. It then flows through a T-piece into the sump, from where it is pumped to the effluent pivot after every milking. Level switches in the sump allow for automatic pumping to the paddock. The cows spend an average of two hours on the yard and in the shed per milking cycle.

3.2 SITE SPECIFICS

The area is characterised by a Mediterranean like climate with wet but mild winters and hot, dry summers (Engineering and Development Services Division of the Shire of Capel 2010). In the sub-sections below, further details about the specific site where the audit was taken can be found.

3.2.1 SOILS

The farm is situated within the Swan Coastal Plain, typically consisting of level to slightly undulating, marine, sandy alluvial and aeolian sediments. It consists of relatively infertile, deep sandy soils (Engineering and Development Services Division of the Shire of Capel 2010). The geographic area is in general low lying, with the farm located at about 40m elevation (Australian Height Datum).

The geology mainly consists of a Jurassic/Cretaceous sedimentary sequence formed by granitic rocks of the Yilgarn Craton (east) and the Leeuwin Complex (west). At the deeper end of the sediments is the Bunbury Basalt and Yarragadee formation, overlain by the Quindalup, Mowen and Vasse members of the Leederville formation (Milligan 2016). The upper sediments include the superficial and sand aquifer.

The superficial formation mainly consists of Bassendean Sand and Guildford Clay, the first consisting of fine to medium grained quartz sand whilst the latter mainly consists of alluvial clay, sand and beach sand. On the Swan Coastal Plain this deposit is usually found at a depth of 6 to 30 m, this formation also contains the superficial aquifer.

Below the superficial formation is the Leederville formation with a thickness of about 200 m on the Swan Coastal Plain and Blackwood Plateau.

The third formation is the Yarragadee formation, terminated at the lower end by the Bunbury Basalt, a cretaceous igneous deposit, consisting of lava flows. It has a low permeability and is about 20 m thick. The Yarragadee formation above is about 500 m thick, represented by a fluvial deposit of 80% - 95% sands, including various sizes of quartz granules with little feldspar (Baddock 2005).

3.2.2 RAINFALL AND CLIMATE

The hot and dry summers show temperatures of 14 – 40°C, whilst the wet and cold winters are between 5 and 26 °C. Ninety per cent of the rainfall occurs during winter, mainly between May and September, whilst summer only shows an average of three wet days between December and February and a monthly rainfall around 13 mm (Weatherzone 2017). The closest weather station is North Boyanup, WA, 33.43˚S, 115.69˚E, station number 009990. Figure 6 below shows monthly average rainfall, based on data collected at this weather station from 2004 to 2016 (Bureau of Meteorology 2017).

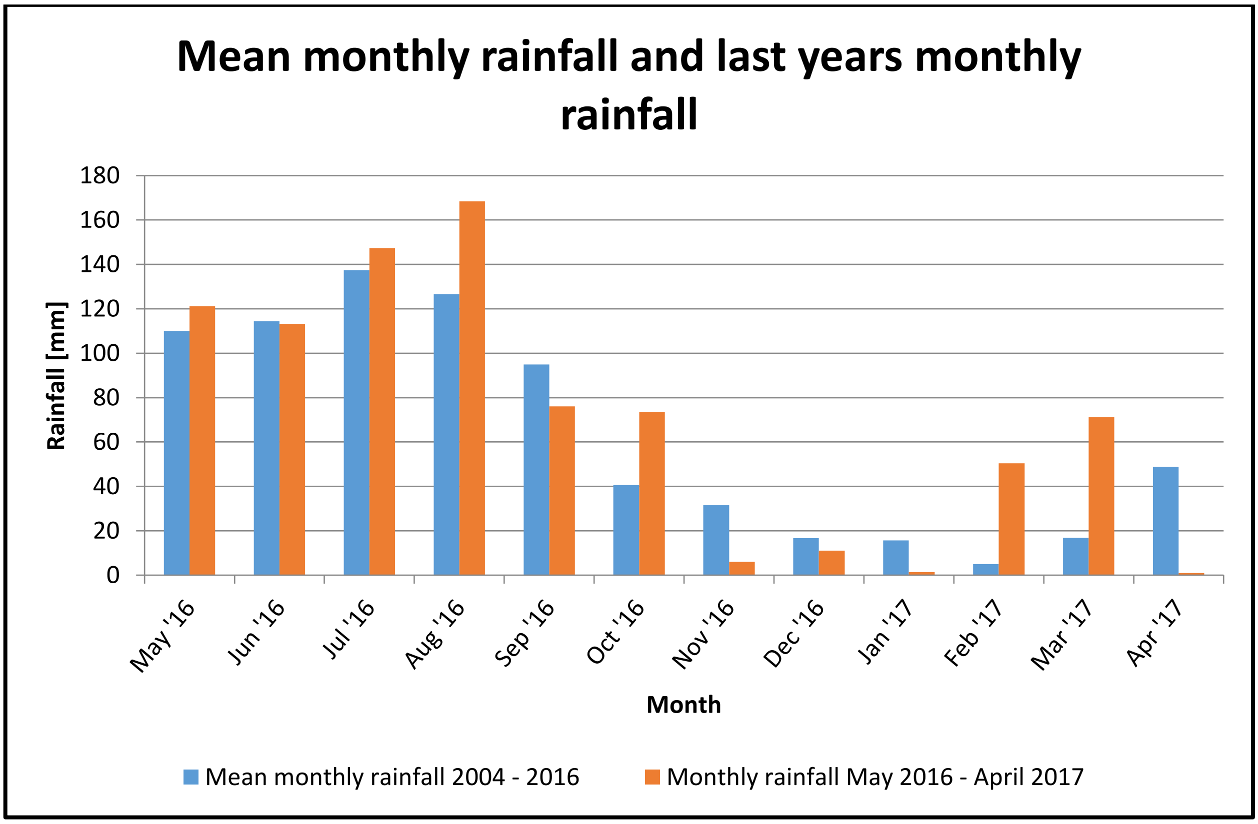

FIGURE 6 - RAINFALL DATA

Annual rainfall for 2016 – 2017 was 840.8 mm, slightly above the annual average of 772.2 mm from 2004 – 2016.

3.2.3 CATCHMENT& LIMNOLOGY

The dairy is located in the Leschenault Catchment, starting at the Darling Plateau and draining into the Leschanault Estuary. Major rivers throughout this catchment are the Preston, Ferguson, Collie, Brunswick and Wellesley rivers (Department of Water 2012). Many of the creek systems and lower reaches of the rivers have been modified as part of artificial drainage systems to drain the very low lying and now cleared plain in order to enable its use for agriculture (Engineering and Development Services Division of the Shire of Capel 2010).

Around the farm, the closest river to the north is the Carson River, to the west it is Preston River. Carson River discharges into Preston River, which then combines with Ferguson River just before opening out into the Leschenault Estuary.

3.2.4 GROUNDWATER HYDROLOGY

The superficial aquifer is the closest aquifer to the surface. As mentioned above, it is part of the superficial formation and water can be expected at levels of 5 – 10 m below ground level (SWAMS 2.0 2005). In developed areas this aquifer is widely exploited, receiving recharge from direct rainfall and runoff.

On Twomey's farm, the dam represents the superficial aquifer, with bore name EX1. The license for this dam covers 347,190 kL per annum.

Below the superficial aquifer is the Leederville aquifer. It is recharged by direct infiltration of rainfall to the outcropping formations and by leakage of the superficial aquifer. This aquifer represents a thickness of about 300 m, however is also widely exploited in development areas (Milligan 2016).

The farm for this project has a Leederville bore at a depth of 60 m, bore name PBL1. Its annual license covers 180,300 kL.

Beneath the Leederville aquifer is the Yarragadee aquifer, likely to be found at 400 m below ground level (Milligan 2016). A proposal for a bore with a license for 240,000 kL was proposed in 2016, however has not been installed.

The superficial aquifer was the only aquifer of relevance for this project due to its proximity to soil surface.

4 WATER AUDIT

The water audit on Twomey's farm was conducted from Saturday 13 May 2017, 5:30 am till Sunday 14 May 2017 10:30 am. Time restrictions meant that the audit had a short duration however as the process was the same every day a long sample period was not required. Data was collected for three milking processes during the audit period.

4.1 WATER SOURCES AND SINKS

4.1.1 SOURCES

- Rainwater catchment
- Bore water
- Dam water

4.1.1.1 RAINWATER

The rainwater is collected from the roof of the dairy shed and channelled into the fresh water tank adjacent to the dairy. The capacity of the tank is 130,000 L, however it is also filled from the dam. The rainwater caught on the yard is directed into the TST.

Rainwater catchment calculations

The mean annual rainfall in Boyanup WA from 2004 to 2016 was 772.2 mm (Bureau of Meteorology 2017). A runoff coefficient of 0.9 was used due to adsorption for all rainwater calculations below, as not all rainwater would be collected due to adsorption (Novak, Van Giesen and DeBrusk 2014).

The roof area was measured on site at 25.0 m x 20.3 m, hence 507.5 m^2.

EQUATION 1 - ANNUAL RAINWATER CATCHMENT OF THE DAIRY SHED

$$\boxed{Annual\_Rainwater\_Catchment\_Shed = \frac{772.2mm}{1000mm/m} * 507.5m^2 * 0.9 = 352.7m^3 \approx \underline{\underline{350kL}}}$$

With Equation 1 above, the average annual rainwater that can possibly be caught with the existing catchment area was calculated to be 350 kL. The size of the tank is 130,000 kL. The yard area was measured on site to be approx. 890.0 m^2. With Equation 2 below, the annual rainwater catchment of the yard was calculated to be 620 kL. This volume contributes to the effluent stream on site.

EQUATION 2 - ANNUAL RAINWATER CATCHMENT OF THE YARD

$$\boxed{Annual\_Rainwater\_Catchment\_Yard = \frac{772.2mm}{1000mm/m} * 890.0m^2 * 0.9 = 618.5m^3 \approx \underline{\underline{620kL}}}$$

Furthermore, the rainwater catchment of the TST contributes to the effluent stream, calculated in Equation 3 below.

EQUATION 3 - ANNUAL RAINWATER CATCHMENT TST

$$\boxed{Annual\_Rainwater\_Catchment\_TST = \frac{772.2mm}{1000mm/m} * 87.3m^2 * 0.9 = 60.7m^3 \approx \underline{\underline{60kL}}}$$

With an area of approx. 87.3 m^2, the rainwater catchment of the TST contributes annually 60 kL to the effluent stream.

4.1.1.2 BORE WATER

The fresh water supply to the dairy originates from two bores, a Leederville bore with an annual licence of 180,300 kL and a superficial aquifer bore, or dam, with an annual licence of 347,190 kL. Therefore, Twomey's farm has a licence for a total of 527,490 kL annually. These licences are free of charge.

4.1.2 SINKS

- Ground (irrigation)
- Evaporation
- Evapotranspiration

4.1.2.1 GROUND

The irrigation system on site contains three pivot irrigators connected to fresh water supply and a forth pivot irrigating effluent from the dairy after each milking. During summer, this fourth pivot still irrigates freshwater in addition to effluent.

4.1.2.2 EVAPORATION

Evaporation occurs at all times when water is at the surface. Therefore, evaporation would occur at the dam, from the yard, the TST and sump, during irrigation and when ponding after effluent irrigation.

4.1.2.3 EVAPOTRANSPIRATION

Evapotranspiration takes place when plants are taking up water from the soil and maintaining transpiration. It is the total evaporation and plant transpiration within a certain area.

4.1.3 RECYCLED AND REUSED WATER

Water is recycled after each milking and used for irrigation through the effluent pivot. The waste water from the milking process is caught at the end of the yard and channelled into a TST. Within the TST, solids separation takes place due to sedimentation. The primary treated water is then channelled through a T-piece and a shopping trolley acting as a filter into a sump, from where it is pumped to the pivot in the paddock. The T-piece contributes towards solids separation. The arrangement is shown in Figure 7 below.

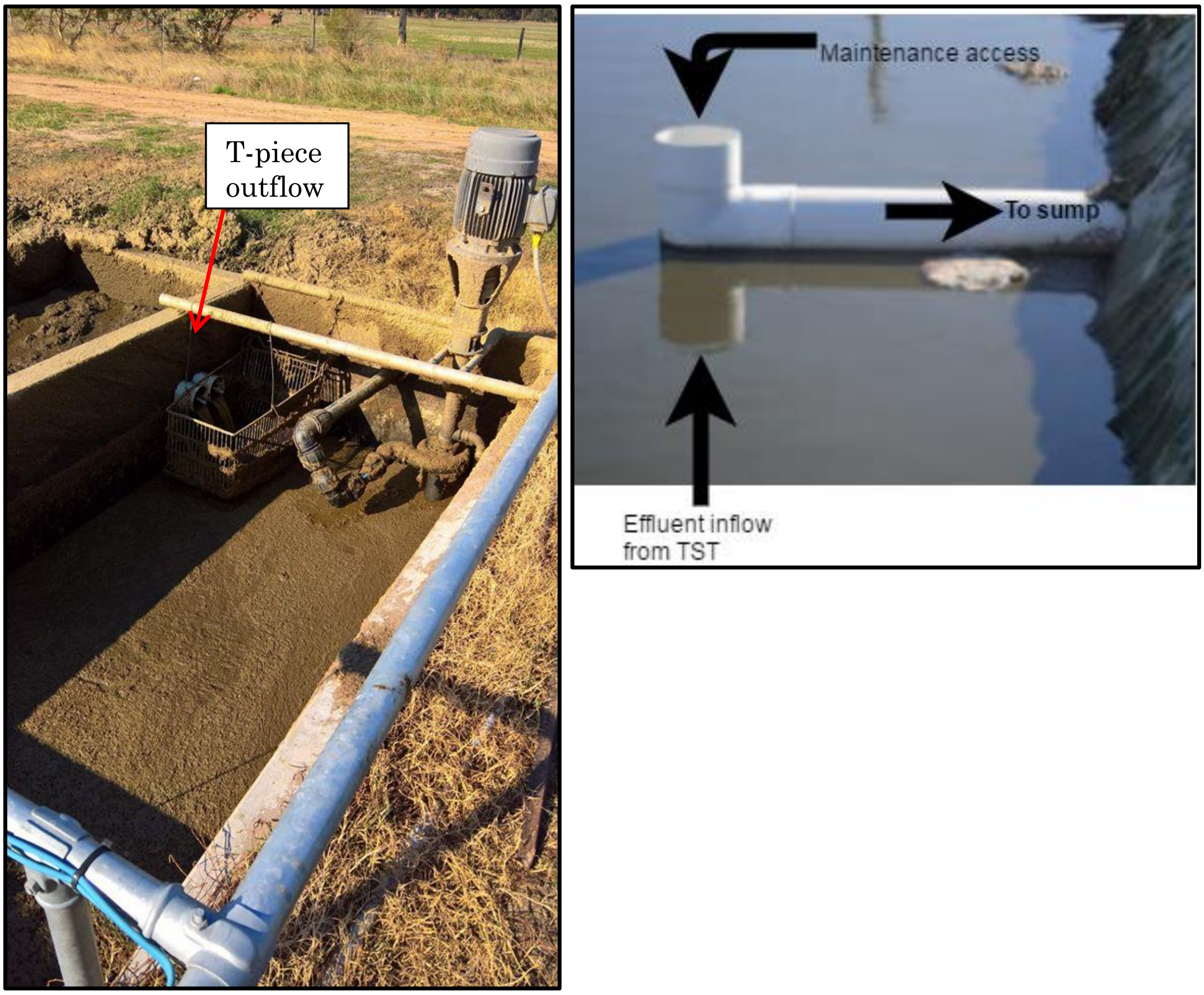

FIGURE 7 - TRAFFICABLE SOLIDS TRAP AND T-PIECE TO SUMP

4.2 AUDIT DATA COLLECTION

4.2.1 OUTLET FLOWS INSIDE DAIRY

The flow of each outlet (mainly hoses) was measured directly using the bucket and stopwatch method. Results can be found in Table 5. It was not possible to measure the flow rate of the hydrants used for wash down of the yard, as no large enough drum was available. The flow rate was adjusted to one measured during a previous audit (unpublished) on Hayes Dairy in Cookernup, also using hydrants for yard wash (Senge 2017). The vat wash flow rate could not be measured as it is an enclosed, automated system. The total volume used per wash after each milking is 1000 L as stated by the farmer.

TABLE 5 - FLOW RATES OF OUTLETS

Outlet	**Measured flow rate**	**Adjusted flow rate**	
Rotary entry spray	15 L / 15 s	1 L/s	60 L/min
Green hoses	15 L / 14 s	1.1 L/s	64 L/min
White hoses	52.5 L / 30 s	1.75 L/s	105 L/min
Hydrants	N/A	11.1 L/s	666 L/min
Vat wash	N/A	N/A	N/A

The duration employees were using the outlets was timed during the water audit. The average usage time per milking can be found in Table 6. The time taken for vat wash was again not applicable as it is an automated process using 1000 L each time.

TABLE 6 - AVERAGE TIME OUTLETS WERE USED DURING/AFTER EACH MILKING

Outlet	**Time used**
Rotary entry spray	1 hour 28 min
Green hoses	8 min
White hoses	28 min
Hydrants	24 min
Vat wash	N/A

From the data collected in Table 5 and Table 6 a water usage breakdown was developed. Figure 8 and Figure 9 below show the water usage breakdown described in kL and percentage.

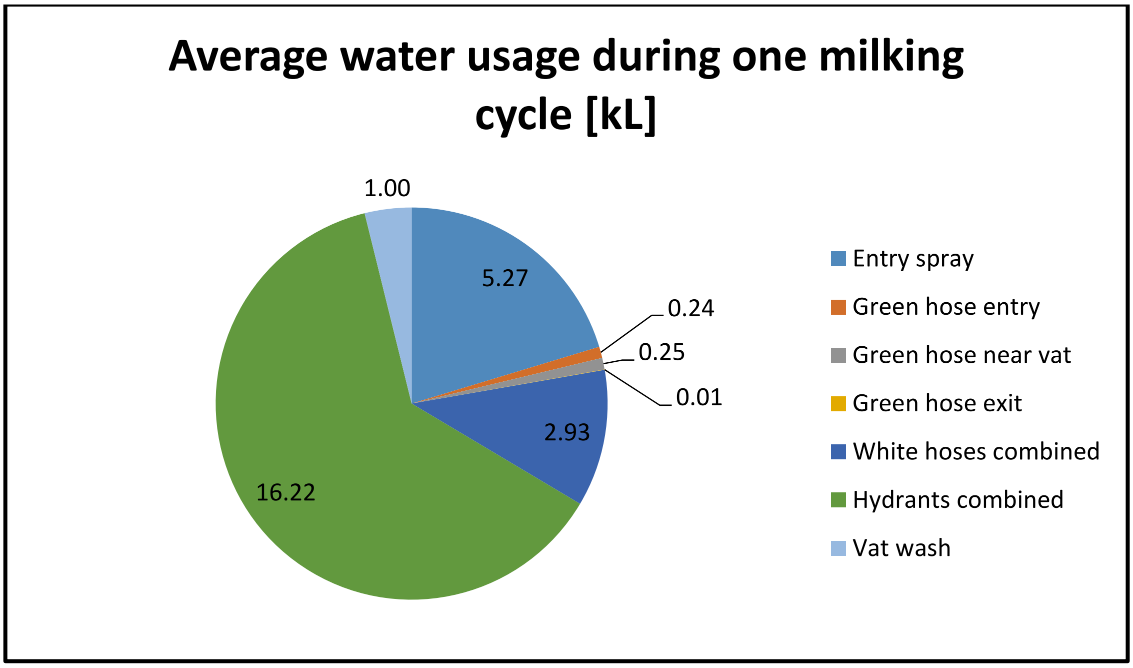

FIGURE 8 - AVERAGE WATER USAGE DURING ONE MILKING CYCLE IN KILOLITRES

At the current herd size of 500 cattle the water usage per cow is 52 L/cow/milking.

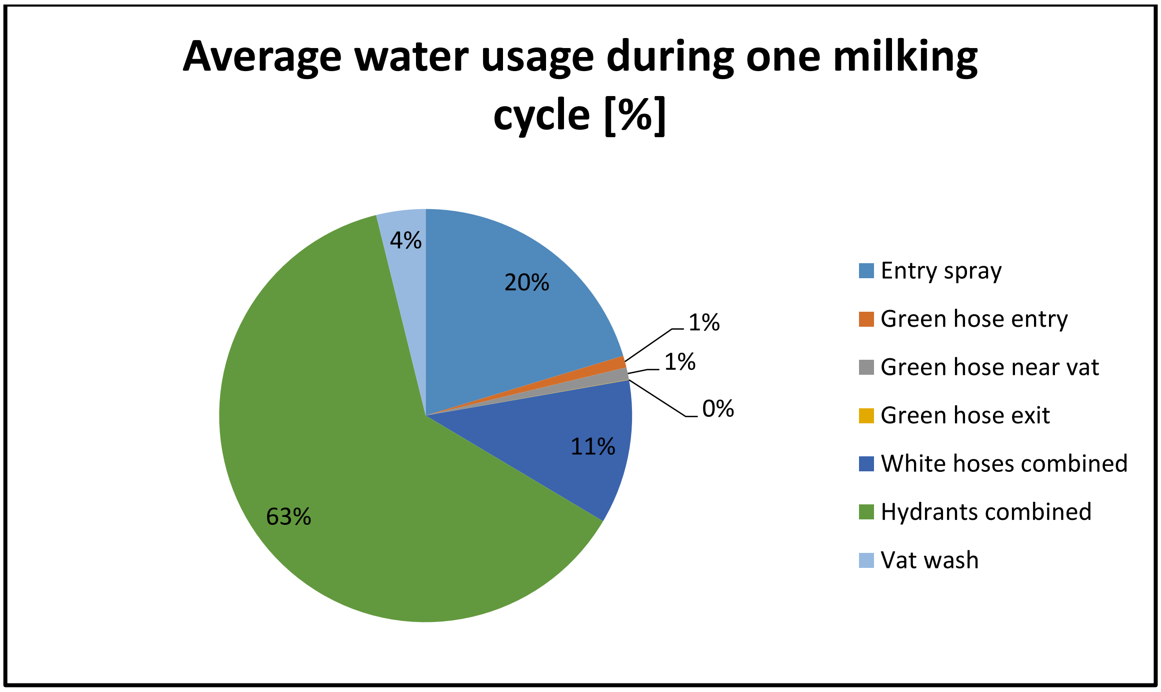

FIGURE 9 - AVERAGE WATER USAGE DURING ONE MILKING CYCLE IN PERCENT

It was found that the greatest volume of water usage occurred via the hydrants used for wash down of the dairy yard. With an average use per milking cycle of 16.22 kL they represented 63% of the water usage per milking cycle. The second largest usage was observed at the entry spray, which can be explained by it being used for the whole duration of the milking process. Negligible was the usage of the green hoses at a combined volume of

0.5 kL, or 2% of the total water usage. The total average water usage per milking cycle is 26 kL. The total water consumption per day observed during the audit was 52.8 kL, showing that 800 L daily was used for other purposes outside the milking procedure. This excludes irrigation, however it does include any other water usage on the farm throughout a day, such as wash down of equipment. A breakdown of the water usage per day can be found in Figure 10 below.

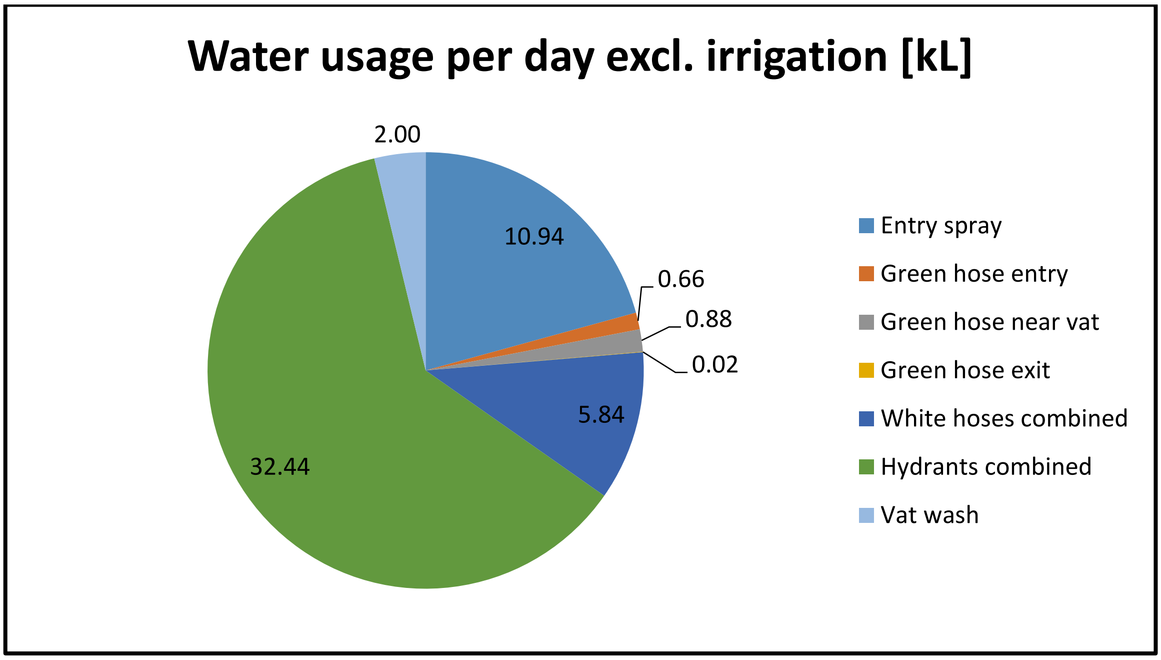

FIGURE 10 - BREAKDOWN OF WATER USAGE PER DAY

With the total average water usage per day being 52.8 kL (excl. irrigation), the average water usage per cow per day is 106 L.

4.2.2 OUTLET FLOWS OUTSIDE DAIRY

Outside the dairy, water is solely used for irrigation. A detailed breakdown of irrigation equipment with flow rates at Twomey's farm can be found in Table 7.

TABLE 7 - IRRIGATION FLOW RATES

Outlet	**Flow rate**
3x freshwater pivot	70 L/s each
1x effluent pivot	70 L/s
Travelling irrigator	20 L/s

During the water audit, no irrigation occurred except for effluent irrigation. Data on irrigation throughout the year was obtained from the farmer and is shown in Figure 11.

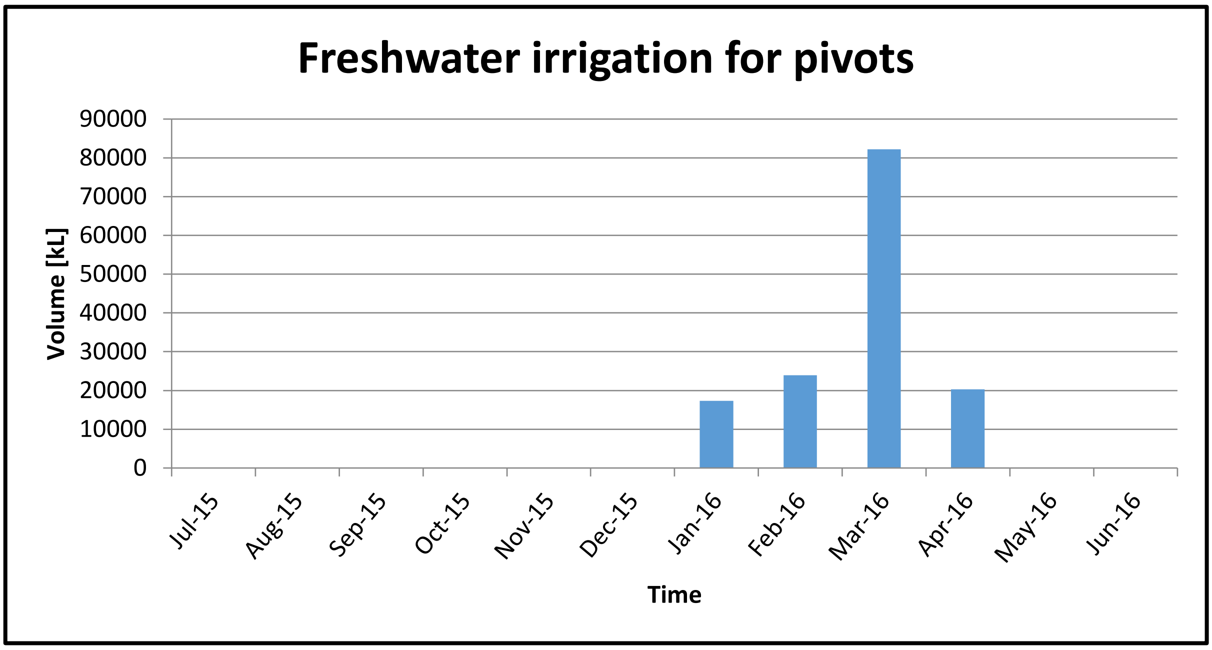

FIGURE 11 - WATER USE FRESHWATER PIVOTS

The graph above shows that last year it was irrigated from January to April only, with a total volume of 143,790 kL, using 42.4% of the licence and being the largest outlet on the property throughout a year.

The previous year, combining all sinks, a total of 339,515 kL were used. With a licence allocation of 527,490 kL, that equates to 64.4% of the allocated licence.

4.2.3 PRESENT FLOW DIAGRAM

A present flow diagram of water flows throughout the farm is displayed in Figure 12. The water sources are at the top, sinks at the bottom.

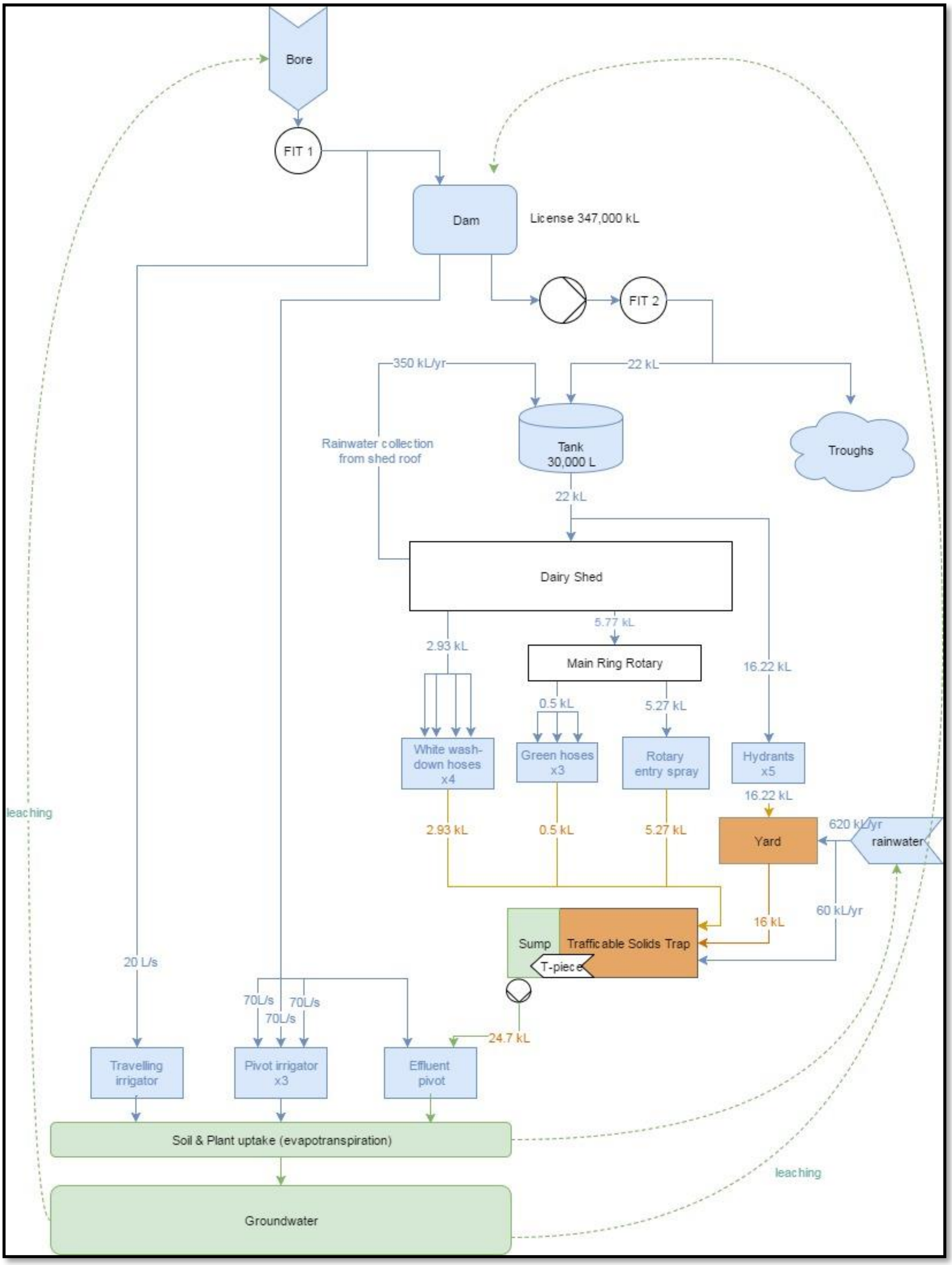

FIGURE 12 - CURRENT FLOW CHART OF TWOMEY'S FARM

4.2.4 LEAKAGE TESTS

Several leakage tests were conducted on site.

4.2.4.1 LEAKAGE TEST 1

The first leakage test was conducted overnight from 13 May 2017 to 14 May 2017, as the meter readings for all green hoses and the entry spray had not changed overnight there had been no leakage. It needs to be noted that this leakage test did not accommodate for leakage at the hydrants or the white hoses. Therefore, a second leakage test was undertaken.

4.2.4.2 LEAKAGE TEST 2

The inlet valve of the tank at the dairy was closed overnight. The next morning, no drop in tank level could be observed; hence leakage of any outlets at the dairy itself could be excluded.

4.2.4.3 LEAKAGE TEST 3

Leakage at the fresh water irrigation system was assessed over the whole audit period, as no irrigation was used. The meter reading for the pivot irrigators remained the same over the course of the whole two days.

4.2.4.4 LEAKAGE OBSERVED

Apart from the above tests, leakage was observed at the effluent pivot after irrigation. This was observed visually at occurrence. The flow rate of this leakage was assessed with the bucket and stopwatch method and determined to be at 2.5 L/min. It was unclear at that stage over what duration the leakage occurs after each milking.

Prior to the audit it was planned to install an ultrasonic flow meter at the effluent irrigation pipe. This flow meter would have picked up the leakage of the effluent irrigator. However, this was not practicable as there was not sufficient equipment available.

During wash down of the yard the first hydrant always needed to be slightly open and leaking, otherwise the pump would switch off and the wash down could not be completed.

4.2.5 CLOSURE

The predetermined closure for the audit was set to 10%.

EQUATION 4 - CLOSURE FORMULA

$$\boxed{Closure = \frac{\sum(water\ input\ quantities) - \sum(water\ output\ quantities)}{\sum(water\ input\ quantities)} < predertermined\ tolerance}$$

(Sturman, Ho and Mathew 2004)

A total closure analysis over the whole audit period is not possible due to the flow arrangements on the farm with troughs as outlets when cows are drinking. Constant evaporation of large surface areas is a problem.

However, a closure for one milking cycle was assessed, see Equation 5 below. The total water input observed for one milking cycle was calculated by tank level drop. A reduction in water level height of 450 mm equalled a volume of 27 kL being used out of the tank. The total volume used for this milking cycle was 25.6 kL.

EQUATION 5 - CLOSURE CALCULATED

$$\boxed{Closure = \frac{27{,}000L - 25{,}600L}{27{,}000L} * 100\% = \underline{\underline{5.2\%}}}$$

A closure of 5.2 % is very accurate considering the equipment available. However, it would be recommended to rely on further meter installation in the future than to use estimations such as tank level drops and reliance on one person timing the usage of each outlet for the duration of the audit.

4.3 IMPROVING EFFICIENCY

The following raw options are ideas on how to improve efficiency regarding the water audit. A detailed techno-economic options assessment was conducted at the end of this paper. Figure 13 below shows the methodology of water conservation, with source elimination being the most preferable approach and freshwater use as the least preferable.

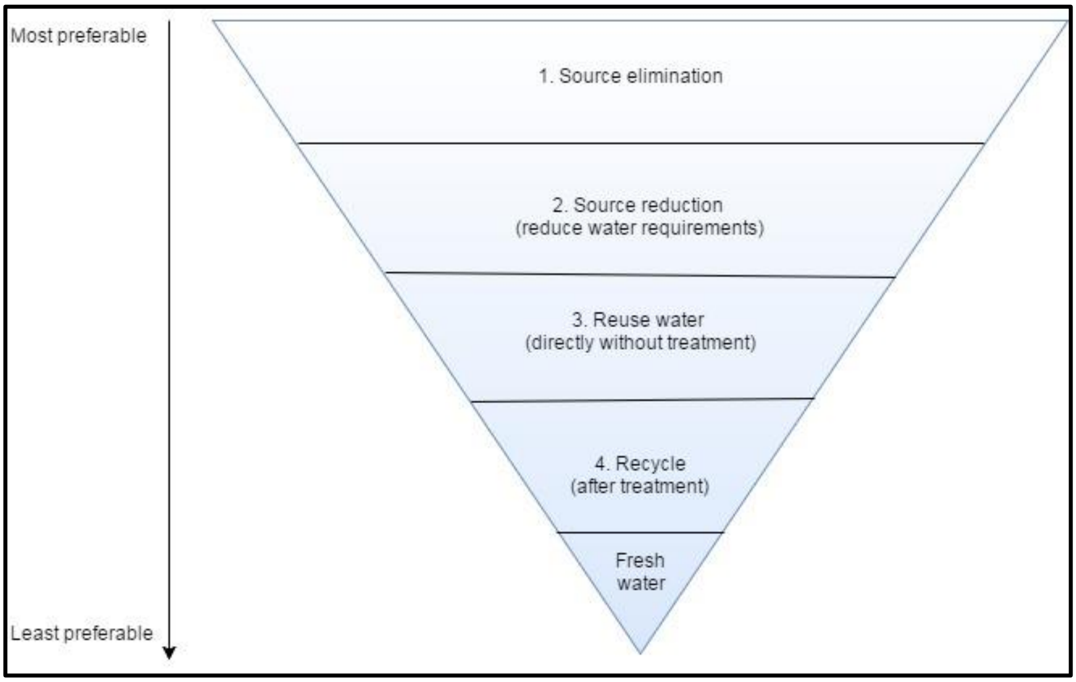

FIGURE 13 - WATER CONSERVATION PYRAMID

The current situation of water streams with possible future conservation measures can be found in Table 8.

TABLE 8 - CURRENT AND FUTURE CONSERVATION MEASURES

	Currently	**Possible future**
Source elimination	-	Entry spray
Source reduction	-	Freshwater irrigation
Reuse water	-	-
Recycled water	Effluent pivot	Effluent pivot Hydrants
Freshwater	Green hoses White hoses Entry spray Hydrants	Green hoses White hoses

4.3.1 RAW OPTIONS

4.3.1.1 BEHAVIOURAL

- Wash down yard only once a day
- Reduce time of washing down yard
- Scrape yard before wash down
- Wash down rotary only with green hand hose instead of entry spray

4.3.1.2 STRUCTURAL

- Dismantle entry spray
- Use recycled water by installation of flood wash tanks for yard wash down
- Construct roof on yard to add to rainwater catchment (also reduce heat stress)
- Construct advanced treatment facility to reuse water as freshwater in whole dairy
- Larger tank to collect additional rainwater

4.3.2 EVALUATION OF RAW OPTIONS

A rough evaluation of the raw options can be found in Table 9. Detailed options assessment to be found in Section 6.

TABLE 9 - EVALUATION OF RAW OPTIONS FOR WATER AUDIT

No	Option	Advantages	Disadvantages	Keep option
1	Yard wash once a day	Reduce water usage, reduce labour	Odour, disease due to uncleanliness	No
2	Shorten yard wash	Reduce water usage, reduce labour	Less clean, disease and odour risk	No
3	Scrape yard	Reduce water usage	Increases labour, undesirable kind of work	No
4	Dismantle entry spray	Reduce water usage	Increases labour as all excrements need to be removed by hand hose	Yes
5	Recycled water for yard wash	Reduce water	Potential of increasing nutrient load	Yes
6	Roof on yard	>Catchment, < Water in effluent system	Cost	Yes
7	Larger rainwater tank	Catch more rainwater	Cost	No

The larger rainwater tank was ruled out, as the largest daily rainfall over the past 15 years with extension of catchment area would have resulted in a total catchment of 109 kL, which would still be accommodated by the current tank size of 130 kL. In addition, 52 kL are used out of the tank daily, hence only 57 kL would have required storage.

4.4 CONCLUSION AND PROCESS REVIEW IN WATER AUDIT

The water audit showed that there were strategies that could be implemented to save water. The dairy's daily water use of 53 kL was around 30% above industry benchmarks, as is clear when compared to data collected in Victoria where use in a dairy of the same herd size and type was roughly 40 kL (S. Birchall, Effluent Toolkit ver11_6 2016). The greatest savings would be achieved if recycled water was used for yard wash. This would result in savings of 16.22 kL per milking cycle, hence 35.5 kL per day. Additionally, dismantling the entry spray would result in aproximately 9 kL of water savings per day, resulting in total savings of 44.5 kL per day. This would reduce the water consumption by 80%, bringing the dairy farm down to a daily water usage of 8.5 kL per day, which would be an outstanding 50% below industry benchmarks.

Even though a closure of approximately 5% was achieved, a future recommendation is reliance on additional meter installations rather than a person being on site with a stopwatch. Timing the outlets without meter (here white hoses and hydrants) was not always accurate as multiple outlets were used by employees whilst the auditor was only one person.

This approach would also allow extending the closure test over the yard and trap rather than just inside the dairy. On this site, that could be achieved by installing a meter at the effluent pipe going from the sump to effluent irrigator. This closure would be expected to be larger, as runoff from outside surfaces would occur and water would remain after wash down.

The effluent leakage observed had no contribution to the closure, as it occurred after the milking process included in the closure assessment.

The largest weakness of the closure assessment was the inflow being estimated by tank level drop. An inaccuracy of only 5 cm results in 3 kL difference of inflow, hence a difference of 7%.

5 NUTRIENT BALANCE

5.1 NUTRIENT SOURCES AND SINKS

5.1.1 SOURCES

The nutrients on the dairy farm originate from animal excreta, diluted with water from wash down. These excreta are collected on yard and in the dairy, during the milking process. On Twomey's Farm, the duration of one milking cycle is two hours, occurring twice per day. Therefore, the median cow spends an average of two hours per day on yards and in the dairy. Under the assumption that stock deposit excreta at a constant rate over a 24 hour period, an approximate of 10% of their excreta will be collected on yards and in the dairy per day (Cameron and Trenouth 1999) and diluted with the 52.8 kL of water used per day on the farm.

5.1.2 SINKS

All effluent collected on yard and in the dairy is channelled into the TST and is then used for irrigation on paddocks 28 and 29. Therefore, the sinks are the same as for the water audit, section 0.

5.2 OBTAINED DATA DURING THE AUDIT

During the audit, samples were taken at five different locations throughout the process.

5.2.1 SAMPLING

Sample 1 was collected (in a bottle) at the channel that directs the nutrient rich water from the yard into the TST. This sample will represent the raw input to the process, prior to any treatment occurring.

Sample 2 was taken at the outlet of the T-piece by collection in a bottle. This sample shows treatment by the TST, before the effluent is pumped to the irrigator and should therefore contain fewer nutrients than the first sample.

Sample 3 was taken on top of the soil by placing containers on the paddock and collecting irrigation water. This sample is expected to show very similar levels to Sample 2. Some anaerobic treatment may have occurred in the sump, this however is unlikely due to very short retention time. In Figure 14 below, the current flow is illustrated and sample 1-3 locations shown.

Sample 4 was taken with a lysimeter after penetration through 200 mm of soil. This sample should have experienced nutrient uptake by plants and soil, and therefore contain less nutrients than previous samples.

Sample 5 was taken with a lysimeter after penetration through 550 mm of soil. This sample should show the lowest levels of nutrient contents.

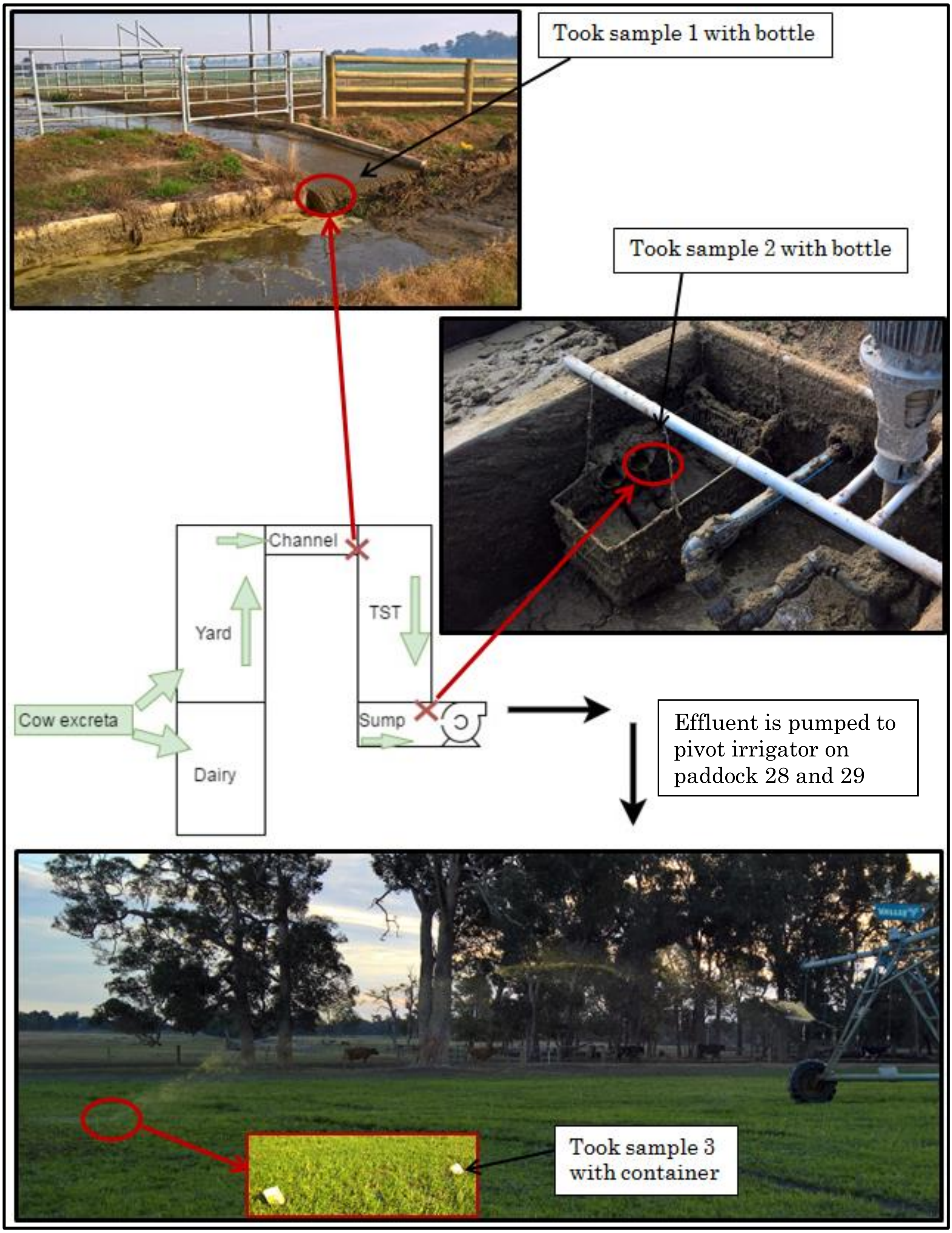

FIGURE 14 - SAMPLE LOCATIONS AND FLOW OF SAMPLES 1 – 3

Samples 4 and 5 were taken below ground. A hole was dug to install two lysimeters. A catchment device diverted the water through a hose into a collection container. The installation is illustrated in Figure 15 below.

FIGURE 15 - LYSIMETER INSTALLATION

All samples were tested for NH_3, PO_4^{3-}, NO_3 and NO_2, total phosphorous (TP), total nitrogen (TN) and K by Marine and Freshwater Research Laboratory (MAFRL). Test results are shown in Table 10 below. The CoC can be found in Appendix 1 – Chain of Custody.

TABLE 10 - NUTRIENT SAMPLE RESULTS

Sample	**Location**	**Sampling Date**	**NH_3** mg/L	**PO_4^{3-}** mg/L	**$NO_3 + NO_2$** mg/L	**TP** mg/L	**TN** mg/L	**K** mg/L
1	Yard	15/05/2017	110	8.4	0.042	57	380	430
2	T-piece	15/05/2017	110	28	0.02	40	200	210
3	Irrigator	15/05/2017	140	28	0.018	57	340	330
4	200mm	14/05/2017	95	28	0.025	44	210	230
5	550mm	14/05/2017	91	24	0.024	46	200	210

Sample 4 and 5 in Table 10 have been marked green, as they were taken the day before the samples marked in blue. These two samples were taken via lysimeter below ground surface. As shown in the table, sample results were generally higher at a depth of 200 mm below ground surface than at a depth of 550 mm. This was to be expected as plant and soil uptake occurred during infiltration. However TP is showing a result outside of the expected range; as its concentration increased from 44 mg/L to 46 mg/L.

A possible explanation for the increase in TP is that it accumulated in the soil after being washed down during irrigation.

The sample results throughout the current treatment system (locations 1 – 3) show an overall drop in concentration from location 1 (raw input at end of yard) to location 2 (T-piece within TST). However, almost all concentrations show a dramatic increase from TST to pivot irrigator.

The only component not showing an increase from TST to irrigation is PO_4^{3-}, with a concentration of 28 mg/L at both locations. However, this is also the only component showing a significantly lower concentration at the yard, the raw input into the system. The overall rise of concentrations at the irrigator outlet is remarkable.

The only location where more than one sample has been taken was the T-piece within the TST. One sample had been taken during milking on the 04/05/2017 and one sample on the 14/05/2017 after milking. A comparison of the results is shown in Figure 16 below.

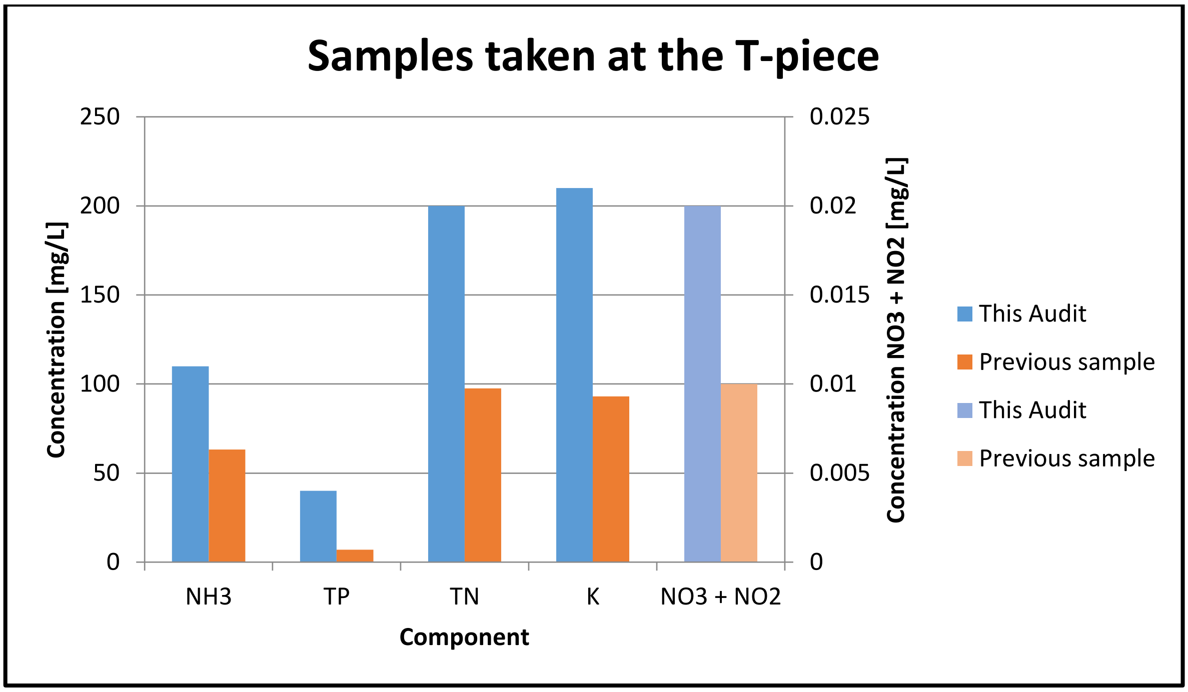

FIGURE 16 - COMPARISON OF SAMPLES TAKEN AT TST

It is notable, how different these two samples are regarding their concentrations. Even though they had both been taken during the milking process in the morning, the previous sample shows approximately half the concentration of every component compared to the sample of this audit. The difference between these two samples was the time within the milking process they were taken. The sample of this audit was taken as soon as the TST was overflowing through the T-piece, whilst the previous sample was taken at the very end of the milking cycle.

5.2.2 LEAKAGE INTO THE SOIL/GROUNDWATER

The uptake in between the lysimeter at a depth of 200 mm and 550 mm was to be found due to soil uptake, whilst above 200 mm plant uptake needed to be considered. Therefore, an extrapolation of the uptake of nutrients over these 350 mm has been performed to the depth where concentrations were down to zero, as shown in Figure 17.

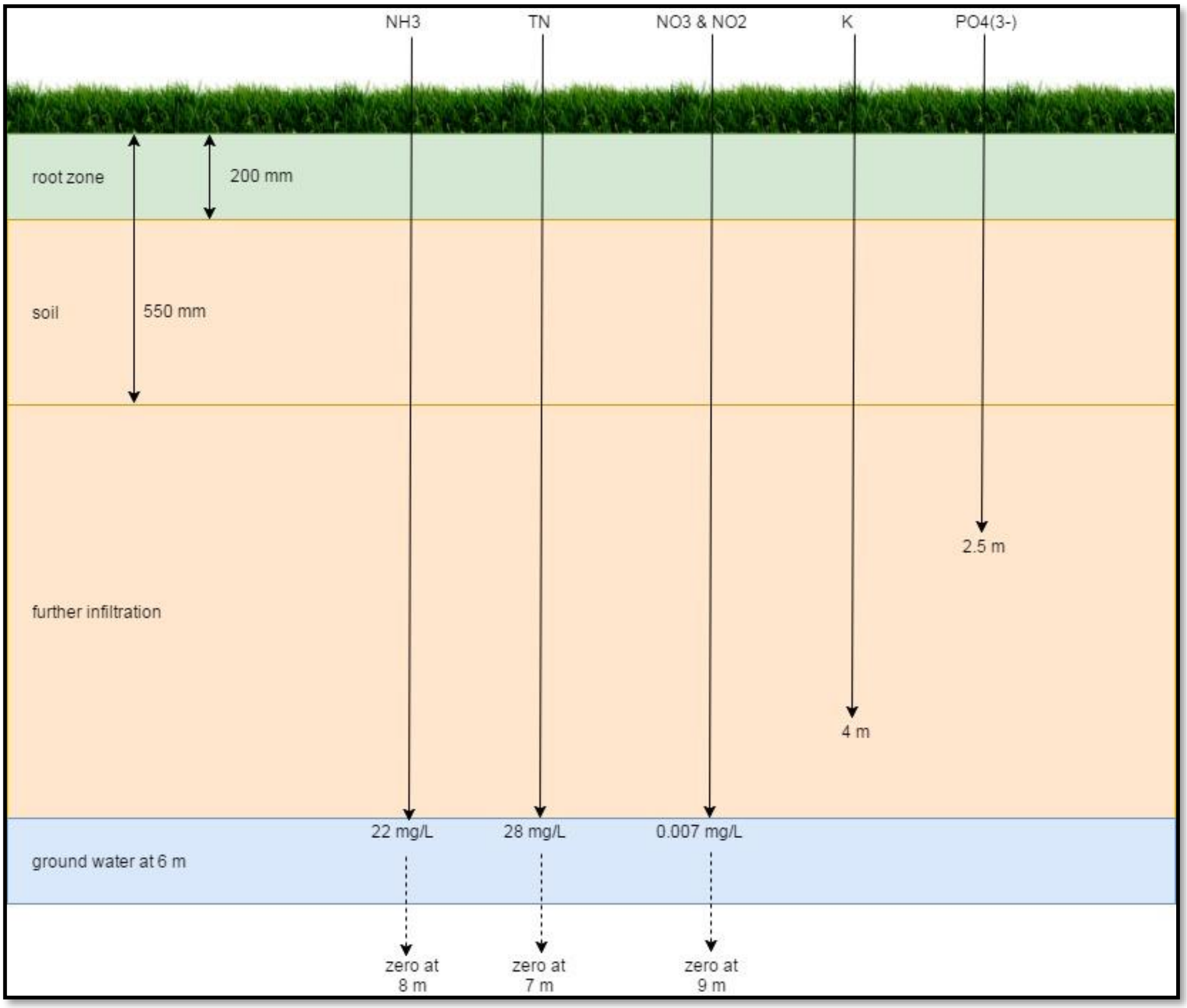

FIGURE 17 - LEACHATE INTO SOIL

Figure 17 shows that K and PO_4^{3-} do not reach the groundwater table according to expected leachate.

However, NH_3, TN and $NO_3 + NO_2$ do, especially during wet seasons when the concentrations leaking into the groundwater table will rise, as the soil moisture will be too high to take up any more effluent.

It needs to be noted that for the extrapolation in Figure 17 homogenous soil and linear uptake was assumed. In real-life the uptake would not be linear, especially in the saturated zone (ground water table). Therefore, this figure is solely an indication.

5.3 IMPROVING EFFICIENCY

The following raw options are ideas on how to avoid nutrient leakage into ground water and environment. A detailed techno-economic options assessment was conducted at the end of this paper.

5.3.1 RAW OPTIONS

5.3.1.1 BEHAVIOURAL

There is no acceptable behavioural change option that would reduce the nutrients going into the cycle. Reduction of milking cycles from two down to one per day would be an option, however this is not applicable as it would disturb the farm's procedures and result in immense financial losses.

5.3.1.2 STRUCTURAL

- Recycle effluent for yard wash
- Accelerate pivot to reduce application rate
- Reduce nozzle size to reduce application rate
- Storage of effluent over winter period
- Diversion of rainwater to reduce effluent volume that needs treatment

5.3.2 EVALUATION OF RAW OPTIONS

A rough evaluation of the raw options can be found in Table 11. A combined options assessment can be found in Section 6.

TABLE 11 - RAW OPTIONS FOR WATER AUDIT

No	Option	Advantages	Disadvantages	Keep Option
1	Recycle effluent for yard wash	Reduction of effluent volume, reduction of labour	Cost of new infrastructure	Yes
2	Accelerate pivot	Reduction of application rate	None	Yes
3	Reduce nozzle	Reduction of application rate	Likelihood of blockages	No
4	Storage	Compliance with Code of Practice	Cost of new infrastructure	Yes
5	Diversion of rainwater	Reduction of effluent volume	Cost of new infrastructure	Yes

The above options resulted in an elimination of option 3, with all other options being taken further into the final options assessment.

5.4 CONCLUSION FOR NUTRIENTS

There are different strategies that would reduce nutrient leakage; it is recommended that during wet month no application of effluent should occur (Western Dairy, Dairy Australia, GeoCatch Catchment Council 2012).

It was observed, that the application rate is too high (up to 30 mm), resulting in ponding after excess application for plant and soil uptake as leakage into the ground was calculated.

However, the number of samples taken was not large enough. As the water needs time to go through the system, to sample only for one day does not produce certainty regarding a direct connection between the different samples taken. It is strongly advised that the sampling process be extended over at least a seven day period. That was not possible for this audit due to budget constraints. An additional benefit of taking more samples is that an average can be developed, and issues like random activity impacting on yard run off will be less likely to disturb the samples overall trend. As the comparison between the different T-piece samples has shown, samples can vary significantly from each other, even if only taken over a time span of 30 minutes.

The extreme drop in concentration at the T-piece location together with the higher concentration at the irrigator may be explained by the effluent from the milking machine wash down being discharged at the top of the TST, near the T-piece. Therefore, at the end of the milking process, the composition at the T-piece would contain largely milking machine wash down water, instead of a diverse mix of yard effluent and water.
After the T-piece, everything is mixed together again in the sump and when pumped out to the irrigator it contains more yard effluent than the composition going into the T-piece. Taking a larger number of samples is essential to achieve a representing average.

With regards to the lysimeter results, it was shown that soil and plant uptake occurs. There was clearly a need for a groundwater sample to be taken at the effluent paddock to verify levels of leakage. Furthermore, leakage would be higher during winter, when soils are wetter and it was determined that the audit should be repeated during wet periods.

6 TECHNO-ECONOMIC OPTIONS ASSESSMENT

Several approaches and technologies were investigated to achieve ZWD for Twomey's farm, whilst not affecting the milking process and the ongoing economics of the corporation. These options were assessed and the most viable option presented as the final recommendation.

6.1 REGULATORY REQUIREMENTS

There are currently no regulatory requirements that are actually enforced. However, this is expected to change as the state Government becomes more concerned with environmental matters and more proactive about enforcing the Code of Practice for Dairy Shed Effluent (COP). The purpose of the COP is to respect environmental and commercial objectives while establishing clear industry standards.

The Standards:

1. Prevention of effluent entering surface and groundwater
    a. No discharge into rivers, creeks, wetlands or drains
    b. No storage on land where it is likely to enter rivers, creeks, wetlands, drains, dams or groundwater
    c. Maintain riparian vegetative buffer zones and revegetate if degraded
2. Have an effective effluent management system
    a. Collect, contain and reuse all effluent from dairy sheds and adjoining yards
    b. New systems to be designed by qualified persons
    c. Either year round direct application or storage during wet months
    d. Contingency procedures to be in place for incidents and accidents
3. Systems to be monitored, maintained and reviewed
    a. Maintenance program for system
    b. Ongoing monitoring of structures
    c. Can combine new technology with existing system
    d. Review system if herd increases
4. Maximise water use efficiency
    a. Undertake operations to minimise water use/generation of wastewater
    b. Where practical wash down water will be reused
    c. Divert uncontaminated stormwater away from effluent system
5. Effluent will be reused on farm
    a. Nutrients reused on paddocks, effluent paddocks rotated
    b. Stored effluent to be analysed periodically for efficient fertiliser reuse
    c. Reuse under controlled rates to avoid leakage
    d. Regular soil testing at application sites
    e. Allow set back distances
    f. Recommended 2 weeks withholding on grazing after application

New Sheds:

1. Site selection will consider waterways, groundwater, soil types, topography and nearby land use
    a. Furthest position from sensitive environments
    b. Clear demonstration of suitability
    c. Set back distances respected

2. System design
    1. Effluent management plan by specialist
    2. Potential expansion considered
    3. Ensure effluent is drained and contained within system
    4. Reuse areas properly sized and located
3. Monitoring program to demonstrate system is not impacting nearby waters
    1. Sampling points upstream and downstream in nearby waterways for biannual sampling
    2. Regular soil testing for nutrient build-up

Setback Distances:

1. Dairy shed
    - a. 200 m from waterways
    - b. 200 m from neighbouring residence
    - c. 30 m from property boundary
    - d. 2 m vertical separation to maximum winter groundwater level (if possible)
2. Effluent storage facility
    - a. 200 m from waterways
    - b. 200 m from neighbouring residence
    - c. 30 m from property boundary
    - d. Distance that does not increase flies or odour at dairy shed
    - e. 1 m vertical separation from bottom of pond to winter max water table
3. Effluent reuse areas
    - a. 100 m from waterways and sensitive areas
    - b. 100 m from neighbouring residence
    - c. Where sufficient arable soil is available
    - d. Away from waterlogged land
    - e. 2 m minimum to water table depth

(Western Dairy, Dairy Australia, GeoCatch Catchment Council 2012)

6.2 ASSUMPTIONS

The current herd size on the farm is 500 cattle. The assessment below was calculated with an accommodated herd growth of 50 cattle; hence any design would accommodate for a total of 550 cows on the property.

It was furthermore assumed that the current trafficable solids trap will not be enlarged. It was observed that sufficient solid separation occurred to not damage the pump. Measurements on site have shown that the current size will be sufficient to accommodate for the 52 kL effective volume required even if the herd size was expanded to 550 cows.

6.3 CONSTRAINTS

A large constraint on utilising advanced treatment options such as Sequencing Batch Reactor (SBR), Membrane Bioreactor (MBR) and Moving Bed Biofilm Reactor (MBBR) at early stages was the cost implications connected to these advanced treatment methods. A single farm will not be able to accommodate for the installation cost nor the maintenance requirements at such high technical operation levels. These options may only become viable if extreme industry intensification occurs and multiple farms could share a facility and their costs. At that stage, it needs to be kept in mind that transportation of the effluent to a common treatment facility will be an additional cost.

Furthermore, struvite precipitation as a treatment method was excluded at an early options screening stage. An intention of usage of the effluent on site as a fertiliser was the major argument. Chemicals would be involved in the process and make it more unlikely to be operated by the farmer or employees during daily farm operations.

As fresh water supply in the usually remote locations of dairy farms is not a limiting factor, the above further treatment options show more disadvantages than advantages to the current situation in the dairy industry. They might be reviewed in ecologically sensitive areas where the use of effluent on paddocks is impossible.

Wetlands were eliminated as a possible treatment option, as within property boundaries all available land is preferably used for agricultural purposes such as grazing and crop growing and wetlands take up a rather large area.

6.4 OPTION 1 - NO ACTION

This option represented the possibility of keeping current operations as they were. The farmer had primary treatment on site in the form of a trafficable solids trap and the effluent was pumped out in the paddock after every milking. This occurred twice a day, regardless of any other conditions.

No new infrastructure would be necessary; no additional costs would be incurred. Labour requirements would stay the same. The system was already compliant with the COP, however irrigation during wet winters is not ideal as nutrients are lost due to plants and soil not being able to take up any more substances. ZWD would not be achieved with this option.

6.5 OPTION 2 – SINGLE POND FOR STORAGE

Incorporating a single pond for storage in the existing system would open the possibility of more effective use of the effluent as fertilizer during wet months (April till September for this region). Effluent would be stored and irrigated during summer, when needed. This option would comply with the Code of Practice and accommodate for ZWD.

6.5.1 SPECIFICATIONS AND CAPABILITIES

The pond was designed based on the values below, using the Effluent Toolkit Version 11_6, provided by Scott Birchall:

- Current water usage of 52.8 kL per day
- Six months storage capacity
- Desludge period of every two years
- Freeboard 0.6 m
- Internal batter 3:1
- Residual depth 0.3 m
- Total depth 4 m
- Top width max. 35 m to allow for excavator to reach during desludging

The effective storage required with the above values and accommodating for rainfall on the pond, will be 14.79 ML. To allow for this volume at a depth of only 4 m (ensuring enough buffer to groundwater table) and a maximum top width of 35 m (to enable desludging within reach of an excavator) the top length of the pond would be 230 m. This would result in an effective storage available of 15 ML, i.e. a total capacity of 20.2 ML (S. Birchall, Effluent Toolkit ver11_6 2016). The measurements of the pond can vary, if sufficient effective storage volume is attained.

The installation cost of a pond this size is hard to estimate, and a final price will only be possible to obtain via quotes. In Victoria, where many contractors are available for pond construction, prices range from $1,500 to $3,000 per ML storage. In W.A. with rare contractor availability this range can be expected around $3,000 to $6,000 per ML (S. Birchall, Design Livestock Effluent Systems: Session 16 - Economics 2016). This would result in a construction cost of $45,000 to $90,000 for a pond this size.
The maintenance cost would comprise of the desludging every 2 years and trimming back of vegetation to allow for easy access of the excavator. There are two options for this; the farmer can do it himself by purchasing or hiring an excavator, or employing a contractor to do the works.

The labour requirement would be slightly higher than the current load. Effluent distribution would not be initiated automatically by level transmitters and pump anymore; it would have to be managed by the farmer. However, the level of management required was rather low. During winter, the effluent would solely be channelled into the pond, during summer irrigation would have to be managed by a well-designed plan.

There are not many risks implicated with this option. The pond needs to be clay lined to avoid leakage into the below aquifer. A synthetic plastic liner would be another option however this is excluded at this stage as it can be expected to be costlier than the clay lining. With a groundwater table at a depth of 6 m and a pond depth of only 4 m, there is very little risk of the groundwater table rising to the level of the bottom of the pond. Therefore, clay lining would be likely be sufficient and less expensive.

6.5.2 PRELIMINARY DESIGN

A sketch of pond dimensions for clarification can be found in Figure 18 below.

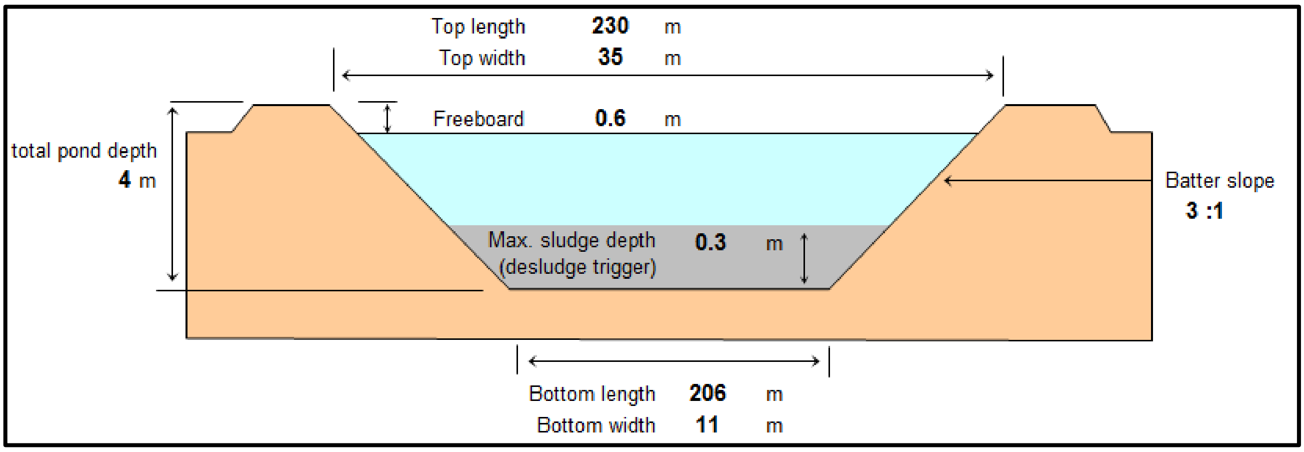

FIGURE 18 - SKETCH OF POND DIMENSIONS

(S. Birchall, Effluent Toolkit ver11_6 2016).

With regards to the practicability of a pond location, it would be proposed to construct the pond near the TST and the effluent pivot, to allow for the least changes to the existing system and least pumping requirement. A preliminary location is shown in Figure 19 below.

FIGURE 19 - OPTION 2 PRELIMINARY DESIGN

The pond would be easily accessible from the adjacent road for desludging.

6.5.3 SUMMARY

The main findings regarding Option 2 was the advantage of irrigation only during summer as it would make the use of the effluent as a fertilizer more effective. Even though according to the Code of Practice it is not necessary to store effluent over winter, with the storage during wet months ZWD would be achievable. Capital cost for this option is estimated at around $70,000.

6.6 OPTION 3 – TANK FOR STORAGE

Incorporating a tank for storage in the existing effluent system would open the possibility of more effective use of the effluent as fertilizer. During wet months (April till September for this region) effluent would be stored and irrigated during summer, when needed. This option would comply with the Code of Practice and accommodate for ZWD.

6.6.1 SPECIFICATIONS AND CAPABILITIES

The tank was designed with regards to the details below, using the Effluent Toolkit Version 11_6, provided by Scott Birchall:

- Current water usage of 52.8 kL per day
- Six months storage capacity
- Desludge period of every year
- Freeboard 0.2 m
- Residual depth of 0.1 m
- With cover
- Flat base

The effective storage volume required with the above values and excluding rainfall as it is covered will be 9.91 ML. To allow for this volume at a tank height of assumed 2.5 m the tank diameter would be 76 m. This would result in an effective storage available of 9.98 ML, i.e. a total capacity of 11.34 ML (S. Birchall, Effluent Toolkit ver11_6 2016). The measurements of the tank can vary, if sufficient effective storage volume is attained. It would depend on product availabilities of suppliers.

The installation cost of a tank this size is immense. Most usual suppliers cannot accommodate for a tank this size (e.g. Rhino Tanks), whilst ATM Tanks gives a cost indication for panel tanks of $220,000.00 for a 250,000 L tank (Innomind Technologies 2017). Extrapolating that cost, a tank of about 10,000,000 L would cost around $8.8 million. Panel tanks are the cheaper option compared to concrete or welded steel tanks.

The maintenance cost would comprise of the desludging of the tank every year and trimming back of vegetation to allow for easy access during desludging. The farmer would most likely need to employ a contractor to do the works, it could be done with an agitator and a suction pump.

The labour requirement would be slightly higher than the current load. Effluent distribution would not be initiated automatically by level transmitters and pump anymore; it would have to be managed by the farmer. However, the level of management requirement is rather low. During winter the effluent would solely be channelled into the tank, during summer irrigation would have to be managed per a plan.

The risks associated with this option are not substantial. Leakage from the tank or people falling into it is unlikely.

6.6.2 PRELIMINARY DESIGN

A sketch of the tank dimensions are shown in Figure 20 below.

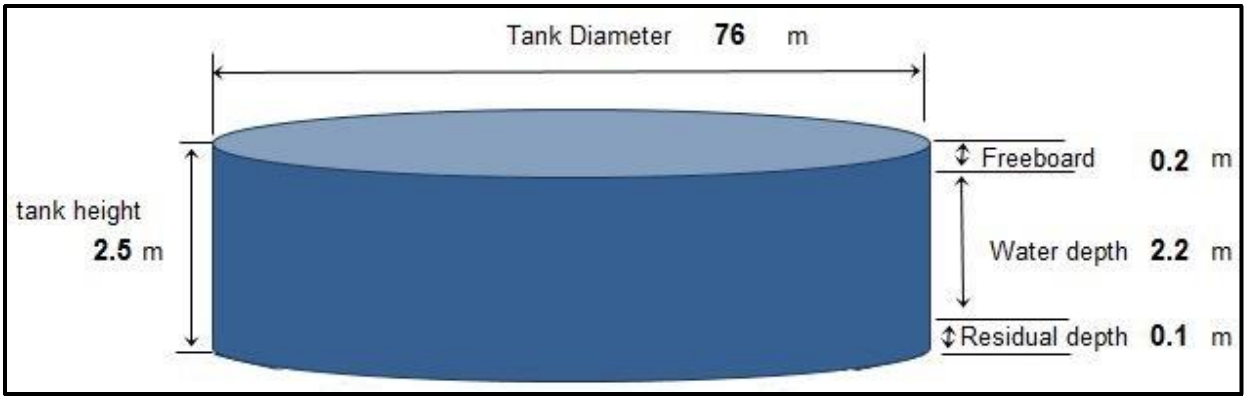

FIGURE 20 - SKETCH TANK DIMENSIONS

A location figure was at this stage disregarded as a tank at that size would be too expensive and the option would only be reviewed if a smaller volume would be incorporated.

6.6.3 SUMMARY

The main findings regarding Option 3 were that the cost is too high for adoption on a farm. However, it does have the advantage of irrigation only during summer as it would make the use of the effluent as a fertilizer more effective. Even though according to the Code of Practice it is not necessary to store effluent over winter, with the storage during wet months ZWD would be achievable.

Option 3 is not viable at the current required size of tank. It should be reviewed if the volume required was lower, for example if used in combination with Option 4.

6.7 OPTION 4 – YARD ROOF AND FLOOD WASH

Constructing a roof on the yard to collect rainwater would reduce the fresh water needed for dairy operation and furthermore reduce the effluent volume that needs treatment to accommodate for ZWD, as the rainwater collected on the yard is not an addition to the fresh water used anymore. As fresh water supply is not a limiting factor and rather cheap (solely pumping cost), the reduction of effluent volume is the more beneficial factor. An added benefit of a roof on the yard would be a reduction of heat stress to cows during summer and hence benefit the commercial objectives of the farm.

The second part of this option is the construction of a flood wash system for yard wash down. The effluent would be recycled after the TST, into tanks at the elevated side of the yard (near the dairy). These tanks would be filled with effluent as a priority, when full; effluent would be used on the paddock.

6.7.1 SPECIFICATIONS AND CAPABILITIES

The construction of the roof on the yard would reduce the volume of effluent that needs treatment by 620 kL a year. Most of this rainfall occurs during winter, when it is undesirable to irrigate. The collected water would be stored in the existing freshwater tank next to the dairy.

The flood wash tanks were designed using the below characteristics:

- Yard width 22.5 m
- Yard length 38.2 m
- Yard slope 3%
- Yard surface roughness (Manning's n) n = 0.020
- Minimum flow depth 50 mm
- Minimum flow velocity 1 m/s
- 1/3 yard length contact time (10.87 s)

Using the above design factors, the flushing volume required for the yard would be 14,325 L. Typical commercially available flood wash tanks have a flushing tank diameter (D_T) of 2.3 m with a storage height (H_T) of 4.2 m, resulting in a tank volume of 17,500 L. That volume is 3,000 L larger than what is required, and would keep costs lower than a custom-made item. As the tank will be filled with effluent, the additional 3,000 L may be considered negligible as it would be recycled water.

The dead storage capacity (H_B) for the above tank would be 2.1 m, due to insufficient head pressure for appropriate cleaning. To allow for the dead capacity of 2.1 m in addition to the storage capacity of 3.45 m, the total construction height (H_0) needs to be 5.55 m. Therefore, the 4.2 m high standard tank would need to be installed at an elevated position (e.g. platform) of 1.35 m.

The installation cost for a typical standard size flood wash tank (17.5 kL) is roughly $9,000, depending on outlet diameter (Cobden Floodwash 2017). A contingency of 50% was added for construction of new pipework and platforms for the tanks. Therefore, the total approximate cost is $27,000 for installation.

The labour requirement would reduce by about 40 minutes per day as yard wash down with hydrants would be omitted.

The risks associated with this option initially seem larger compared to the other options, however can be easily mitigated. The concrete bounding of the yard needs to be checked on a regular basis to ensure no runoff occurring. The optional installation of a catchment trap at the bottom end of the yard ensures further risk reduction in case any runoff of effluent during yard wash is observed.

6.7.2 PRELIMINARY DESIGN

Figure 21 below shows the arrangement of the flood wash tank installation with two outlets.

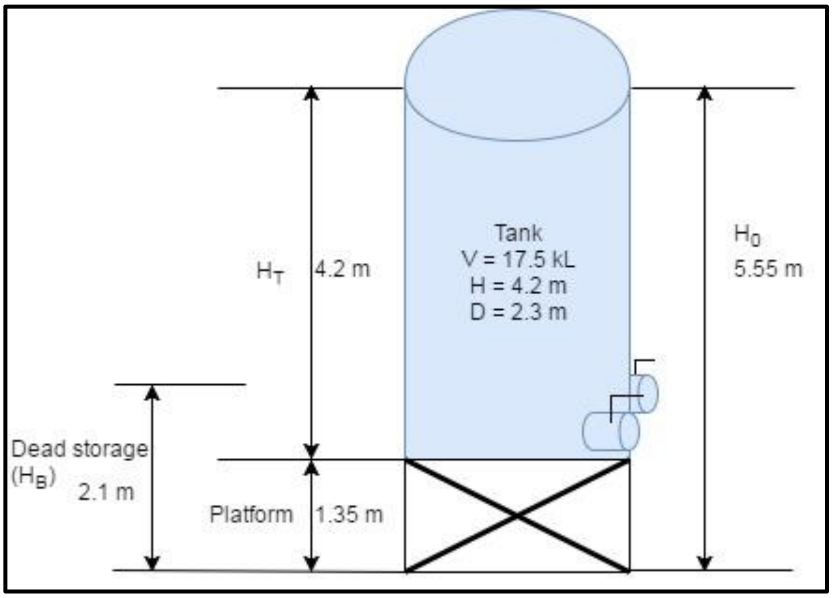

FIGURE 21 - ARRANGEMENT FLOOD WASH TANK

Figure 22 below shows the location of the two flood wash tanks and the indicative flow direction of effluent when used for yard wash.

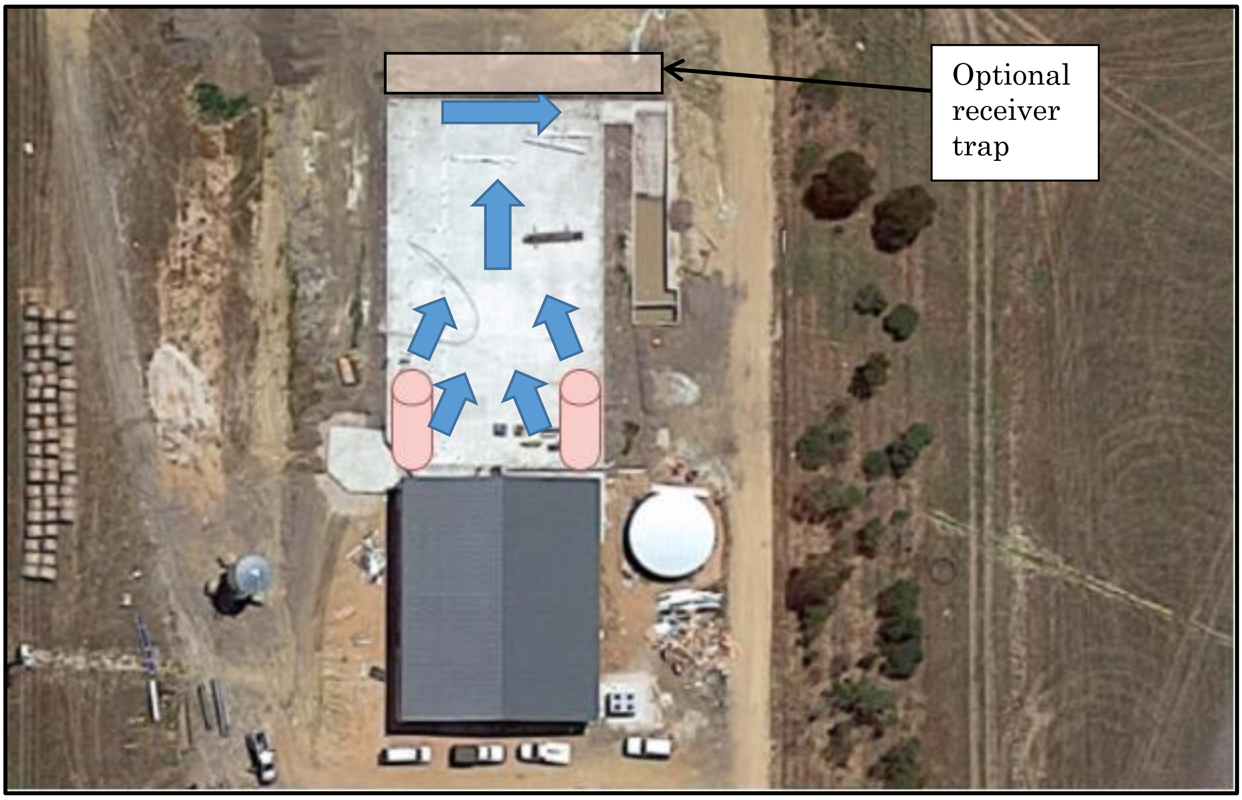

FIGURE 22 - LOCATION OF FLOOD WASH TANKS

The trafficable solids trap has a total volume of estimated 53 kL, hence should be able to handle the 35 kL combined volume of both flood wash tanks. If overflow is observed, an additional receiver trap can be installed, shown as optional in Figure 22 above. This would accommodate for the large initial volume to be caught and then channelled into the TST. Cost for this optional feature have been excluded at this stage.

6.7.3 SUMMARY

This option would reduce the fresh water use by 60%, reduce the effluent volume that needs treatment and benefit the commercial objectives by reducing heat stress on cows and reducing labour requirements for yard wash down. It complies with the Code of Practice and accommodates for ZWD.

The daily fresh water usage is reduced from 52.8 kL to 20.3 kL, if a pond was to be installed its required size for storage would be reduced from 14.79 ML to 14.05 ML due to rainwater diversion and down to 6.4 ML (uncovered pond) or 4.7 ML (covered pond or storage tank) due to effluent use for yard wash.

6.8 SUSTAINABILITY MCA

In Table 12 below, the options have been assessed by giving them different rankings. Firstly, every criterion that the options were assessed on was given a weighting, 5 being the most important and 1 the least important. Then the option itself was given a ranking in that criterion, place 1 being the best out of the four options and place 4 being the worst. The option with the lowest overall ranking was the most preferred. The detailed scoring for the weightings by person can be found in Appendix 2 – Weightings for MCA.

TABLE 12 - SUSTAINABILITY MCA

	Weighting	**Rank**	**Preliminary**	**Final score**
Option 1 – Do nothing				
Achievement ZWD	5	4	20	
Installation cost	4	1	4	
Maintenance cost	1	1	1	
Labour requirement	2	2	4	
Risk	3	4	12	**41**
Option 2 – Single pond				
Achievement ZWD	5	3	15	
Installation cost	4	2	8	
Maintenance cost	1	3	3	
Labour requirement	2	3	6	
Risk	3	2	6	**38**
Option 3 – Tank				
Achievement ZWD	5	2	10	
Installation cost	4	4	16	
Maintenance cost	1	4	4	
Labour requirement	2	4	8	
Risk	3	1	3	**41**
Option 4 – Yard roof and Flood wash				
Achievement ZWD	5	1	5	
Installation cost	4	3	12	
Maintenance cost	1	2	2	
Labour requirement	2	1	2	
Risk	3	3	9	**30**

Table 12 above shows, that Option 4 – Yard roof and flood wash is the most preferred option in regards to the criteria chosen. With 30 points, it was 8 points better than Option 2 at 38 points, followed by Option 3 and 4 with 41 points.

7 DETAILED DESIGN FOR ZERO WASTE DISCHARGE

Looking at the points each option has received, the preferred final recommendation would be a hybrid combination of option 2 and option 4, as only deferred application with pond usage would ensure safety in design towards zero waste discharge. The designed system would therefore comprise of:

- Recycled effluent for yard flood wash
- Rainwater collection via roof over yard
- Single pond for storage

The farmer has the option of considering decommissioning the entry spray of the dairy and only using the green hose for washing, however this feature will be neglected in this detailed design.

7.1 TECHNICAL FACTS

The following figures are used for detailed design of the final hybrid solution:

General

- Herd size: 550 cows
- Fresh water use in dairy: 20,340 L/day
- Catchment area contributing to effluent: TST with 87 m^2
- Existing TST volume: 53,625 L
- Desludge period for TST: 30 days

Pond specific

- Storage period: 6 month (Apr – Sep)
- Desludge period for pond: 2 years
- Freeboard for pond: 0.6 m
- Internal batter: 3:1
- Residual depth: 0.3 m

Flood wash specific

- Yard width: 22.5 m
- Yard length: 38.2 m
- Yard slope: 3%
- Yard surface roughness (Manning's n) n = 0.020
- Minimum flow depth 50 mm
- Minimum flow velocity 1 m/s
- 1/3 yard length contact time (10.87 s)

As calculated under option 4, the required volume to use recycled effluent for yard wash down is 14,325 L.

This would be achieved by two tanks with two outlets each, of a volume of 17,500 L each. Their diameter is 2.3 m and height 4.2 m. They would need to be constructed on an elevated platform of 1.35 m height.

The cost of these tanks is approximately $18,000 (Cobden Floodwash 2017).

A roof, diverting the collected rainwater into the existing fresh water tank adjacent to the dairy, would cover the yard. The cost for this roof is approx. $60,000 (Earl 2017).

The effective volume required for the pond at the above factors would be 6.38 ML, allowing for rainwater catchment of the pond. At a total depth of 4 m to assure sufficient buffer to the groundwater table, the pond would be 35 m wide and 105 m long, see Figure 23 below.

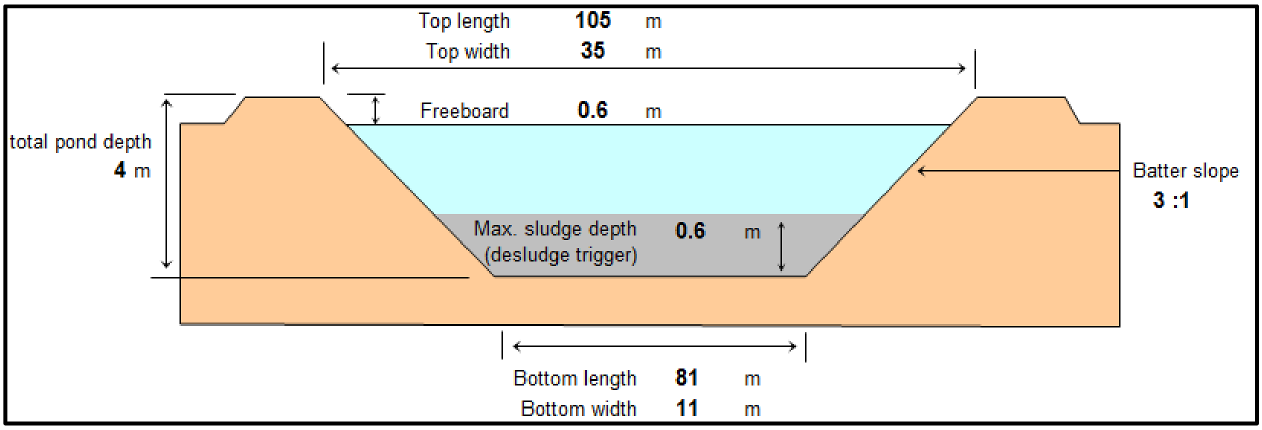

FIGURE 23 - FINAL DESIGN POND

The cost for construction of this pond is expected around $42,000 referring to works previously done in WA. A survey and geotechnical investigations (included in cost) are essential to determine final location and soil suitability.

A proposed overall system design from a bird's eye view can be found in Figure 24.

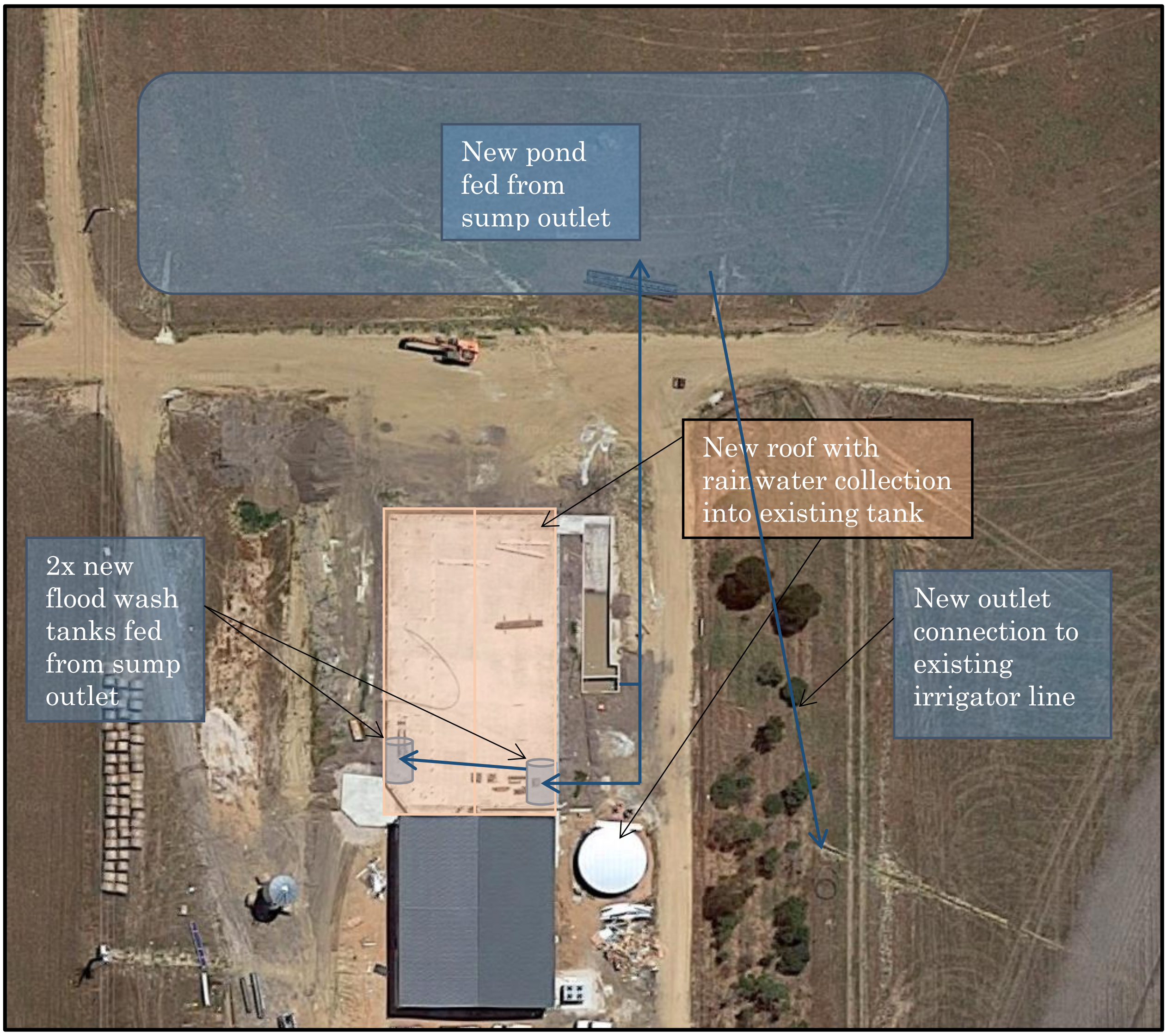

FIGURE 24 - FINAL OVERALL SITE LAYOUT

7.2 PROPOSED FLOW DIAGRAM

The proposed flow diagram can be found in Figure 25. It includes a fit for purpose hierarchy, based on three water classes, laid out in Table 13 below.

TABLE 13 - FIT FOR PURPOSE HIERARCHY

	Description	**On site purpose**
Class 1	Freshwater from bore/dam	Tabs, toilet, hoses inside the dairy shed
Class 2	Primary treated effluent	Yard wash, storage in pond, irrigation
Class 3	Untreated effluent	Solely collection in TST for treatment

In the below proposed flow diagram, Figure 25, units are kilolitres per milking cycle, except where stated otherwise. Colour codes for the above water classes are

- Class 1 – blue
- Class 2 – green
- Class 3 – brown

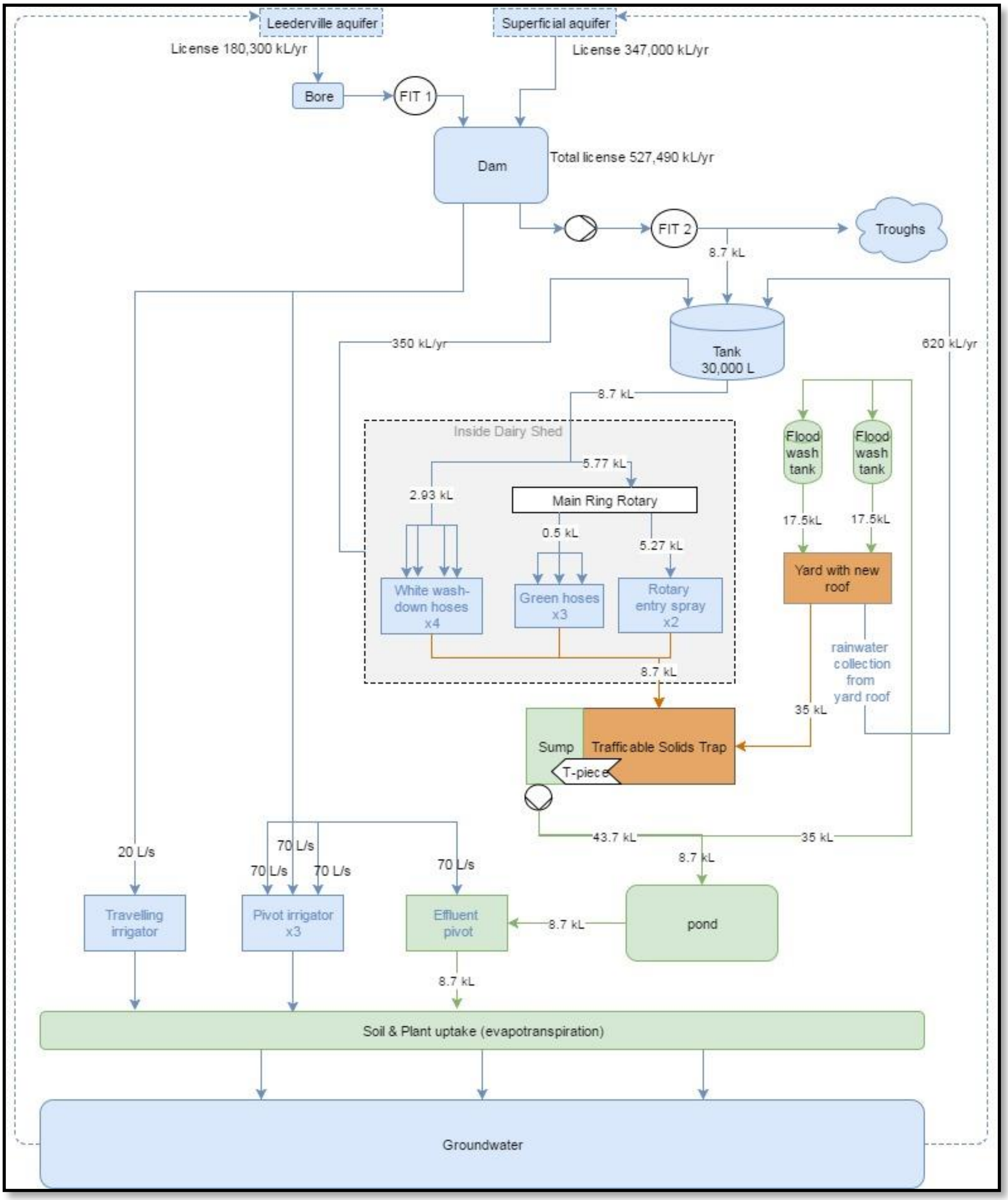

FIGURE 25 - PROPOSED FLOW DIAGRAM

7.3 NUTRIENT FOOTPRINT TRANSPORTATION

The area required for application of effluent, based on effluent samples taken at the pivot outlet would be 46.4 ha (S. Birchall, Effluent Toolkit ver11_6 2016). Currently, the farmer applies the effluent over an area of 21 ha. To avoid excess application, based on a desired application rate of 60 kgN/ha, 10kgP/ha and 60kgK/ha, the effluent application rate for irrigation would be 18 mm (S. Birchall, Effluent Toolkit ver11_6 2016). Observations of samples caught underneath the pivot have shown that the current application rate is not uniform and can go up to 30 mm.

It is therefore recommended to double the current speed of the pivot during irrigation to apply to a larger area Furthermore, a second pivot should be connected to the pond. The same system with the underslung line can be used as on the current pivot. Most suitable would be the pivot in between the dairy and the dam, as it is of the closest proximity and is of the same size as the current pivot.

7.4 FINAL BUDGET

The total approximate cost for the outlined construction is set out in Table 14 below.

TABLE 14 - FINAL COST SUMMARY

Item	**Cost**
Yard roof	$ 60,000
Flood wash tanks	$ 18,000
Pond	$ 42,000
New pipe work	$ 10,000
Connection of second pivot for effluent	$ 10,000
Contingency (20%)	$ 28,000
Total	**$ 168,000**

Therefore, the total budget of the proposed zero waste discharge system would equate to an approximate of $168,000. The pond has been estimated at a rather large cost and a contingency was included, therefore the cost might turn out to be lower during installation rather than exceed the estimated budget.

7.4.1 PAYBACK PERIOD

The following savings need to be considered when calculating the payback period:

- Increase in production due to less heat stress on cattle
- Reduction of labour due to yard wash by tanks
- Reduction of electricity due to less fresh water pumping from bores

To determine the payback period an analysis of the theoretical increase in overall milk production resulting from reduced heat stress is required. According to P.G. Mallonée *et al.*, cattle kept in the sun produced up to 20% less milk yield than cattle kept in a shed (Mallonee, et al. 1985).

The milk production for Twomey's farm is 3,000,000 L annually and sold at a price of $0.45 per litre. Assuming a conservative increase of only 10% in production, over a 2 month period per year would result in an increase in production of 50,000 L. At a selling price of $0.45 this equals to $22,500 savings in a year.

Additionally, labour reduction of 40 min per day equals about 240 hours per year. At an estimated hourly wage for a labourer of $20 savings of $4,800 would be achieved within a year.

The cost benefits from reduction in energy due to less fresh water pumping from the bore were at this stage neglected as they were not significant. At a pumping depth of 60 m the cost per ML for an electrical pump in southeast Australia can be estimated at $37/ML (Robinson 2002). Daily fresh water savings of 32 kL would therefore result in about $400 per year. The energy benefits are negligible compared to production and labour benefits and therefore neglected in the payback period calculation.

The payback period was calculated in Equation 6 below.

EQUATION 6 - PAYBACK PERIOD

$$\boxed{Payback\_period = \frac{Initial\_Investment}{Savings/Period} = \frac{\$168{,}000}{\$27{,}300/year} = \underline{\underline{6.2 years}}}$$

A payback period of just over six years makes the suggested system a viable option.

The break-even point would be even further reduced if in the future the supply of fresh water from licences was not to be free of charge anymore or effluent discharge legislations would be enforced.

8 PROJECT REVIEW

The most remarkable constraints throughout this project were the time and budget limitations. The site for the project was only confirmed at the very end of the timeframe allocated to the works. At this stage, it was only possible to audit over one weekend, including mobilisation and demobilisation. The budget constraints had immense impact on the nutrient balance, as one sample per location, taken on the same day (instead of waiting for the water to pass though the treatment process) is not sufficient.

However, keeping these constraints in mind and the progress made from there onwards, it was found that good and viable options could be developed to present to the farmer and to be used for future implementation in the industry.

9 CONCLUSION

The desired goal of achieving a zero waste discharge on a dairy farm was found to be possible. There would be a reduction of fresh water usage significantly higher than expected. Although the cost of fresh water was not an issue for Twomey's farm, the lower volume of fresh water being used meant a reduction of contribution to the effluent stream. The planned improvements to the site included an additional rain water catchment area resulting in a further reduction of fresh water use. Implementing the covered yard component would reduce heat stress on the cows and thereby increase the volume of production at the farm. If followed the suggested solution of recycling wastewater after primary treatment would reduce labour costs and effluent discharge to the paddock, therefore providing a reduction of the size of the effluent application area.

In summary the system proposed would:

a) Reduce fresh water usage by 32 kL (60%) per day

b) Provide additional rainwater catchment of 620 kL per year

c) Increase production by reduction of heat stress on cows

d) Reduce labour costs

The total cost for the proposed system was estimated at $168,000.00.

The payback period was calculated at 6.2 years.

The system proposed was found a viable option as it can be expected that legislation will be enforced in the future, as environmental issues become more relevant and the government has started to arrange projects to implement better treatment facilities.

In conclusion, it is recommended to employ the benefit of zero waste discharge systems. For future projects, it is at a first stage recommended to review this project in further detail to conclude on additional audit/monitoring work. In general, the audit and sampling periods need to be extended over a year if possible, to allow for consideration of dry and wet seasons and larger sampling ranges.

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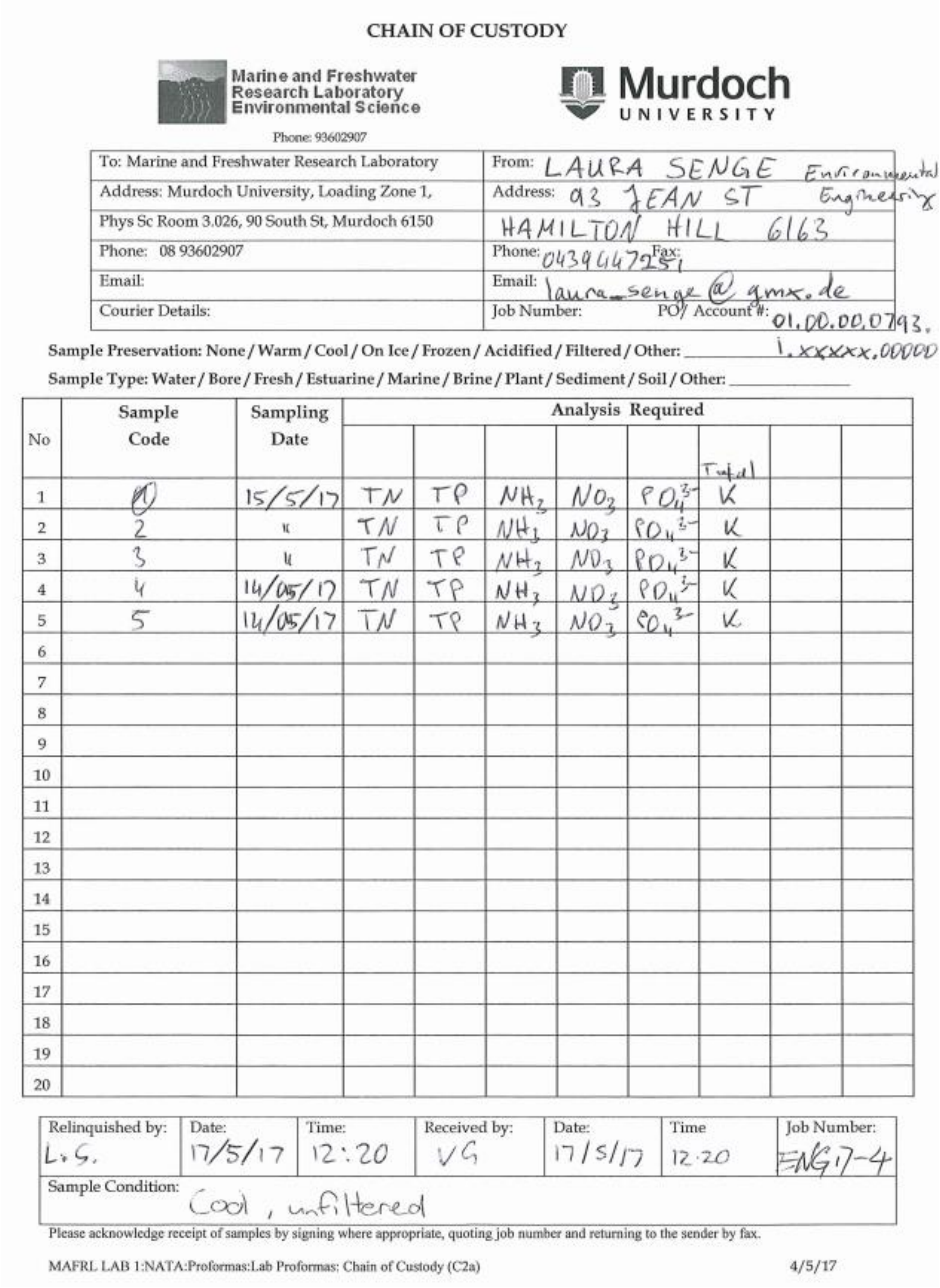
11 APPENDICES

11.1 APPENDIX 1 – CHAIN OF CUSTODY



CHAIN OF CUSTODY

Marine and Freshwater Research Laboratory Environmental Science

Murdoch UNIVERSITY

Phone: 93602907

To: Marine and Freshwater Research Laboratory	From: LAURA SENGE Environmental Engineering
Address: Murdoch University, Loading Zone 1,	Address: 93 JEAN ST
Phys Sc Room 3.026, 90 South St, Murdoch 6150	HAMILTON HILL 6163
Phone: 08 93602907	Phone: 0439447251 Fax:
Email:	Email: laura_senge@gmx.de
Courier Details:	Job Number: PO/ Account #: 01.00.00.0793.1.xxxxx.00000

Sample Preservation: None / Warm / Cool / On Ice / Frozen / Acidified / Filtered / Other: ______________

Sample Type: Water / Bore / Fresh / Estuarine / Marine / Brine / Plant / Sediment / Soil / Other: ______________

No	Sample Code	Sampling Date	Analysis Required							
								Total		
1	①	15/5/17	TN	TP	NH_3	NO_3	PO_4^{3-}	K		
2	2	〃	TN	TP	NH_3	NO_3	PO_4^{3-}	K		
3	3	〃	TN	TP	NH_3	NO_3	PO_4^{3-}	K		
4	4	14/05/17	TN	TP	NH_3	NO_3	PO_4^{3-}	K		
5	5	14/05/17	TN	TP	NH_3	NO_3	PO_4^{3-}	K		
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Relinquished by:	Date:	Time:	Received by:	Date:	Time	Job Number:
L.S.	17/5/17	12:20	VG	17/5/17	12:20	ENG17-4
Sample Condition:	Cool, unfiltered					

Please acknowledge receipt of samples by signing where appropriate, quoting job number and returning to the sender by fax.

MAFRL LAB 1:NATA:Proformas:Lab Proformas: Chain of Custody (C2a) 4/5/17

11.2 APPENDIX 2 – WEIGHTINGS FOR MCA

Criterion	**Chenoa**	**Laura**	**Breanne**	**Michael**	**Goen**	**Sam**	**Sum**	**Weighting**
ZWD	4	5	5	5	5	5	29	**5**
Installation cost	5	4	3	4	5	3	24	**4**
Maintenance cost	3	1	2	2	5	2	15	**1**
Labour	1	3	2	1	5	4	16	**2**
Risk	2	2	4	3	5	5	21	**3**

Each individual mentioned in the table above was asked to allocate a weighting to each criterion according their significance of that criterion to that person.

For each criterion, the sum of all weightings was calculated, resulting in a final weighting of 5 for the criterion with the highest overall sum, 4 for the second highest etc. and 1 for the lowest. This weighting was then used in the multi criteria assessment to determine the importance of each criterion.