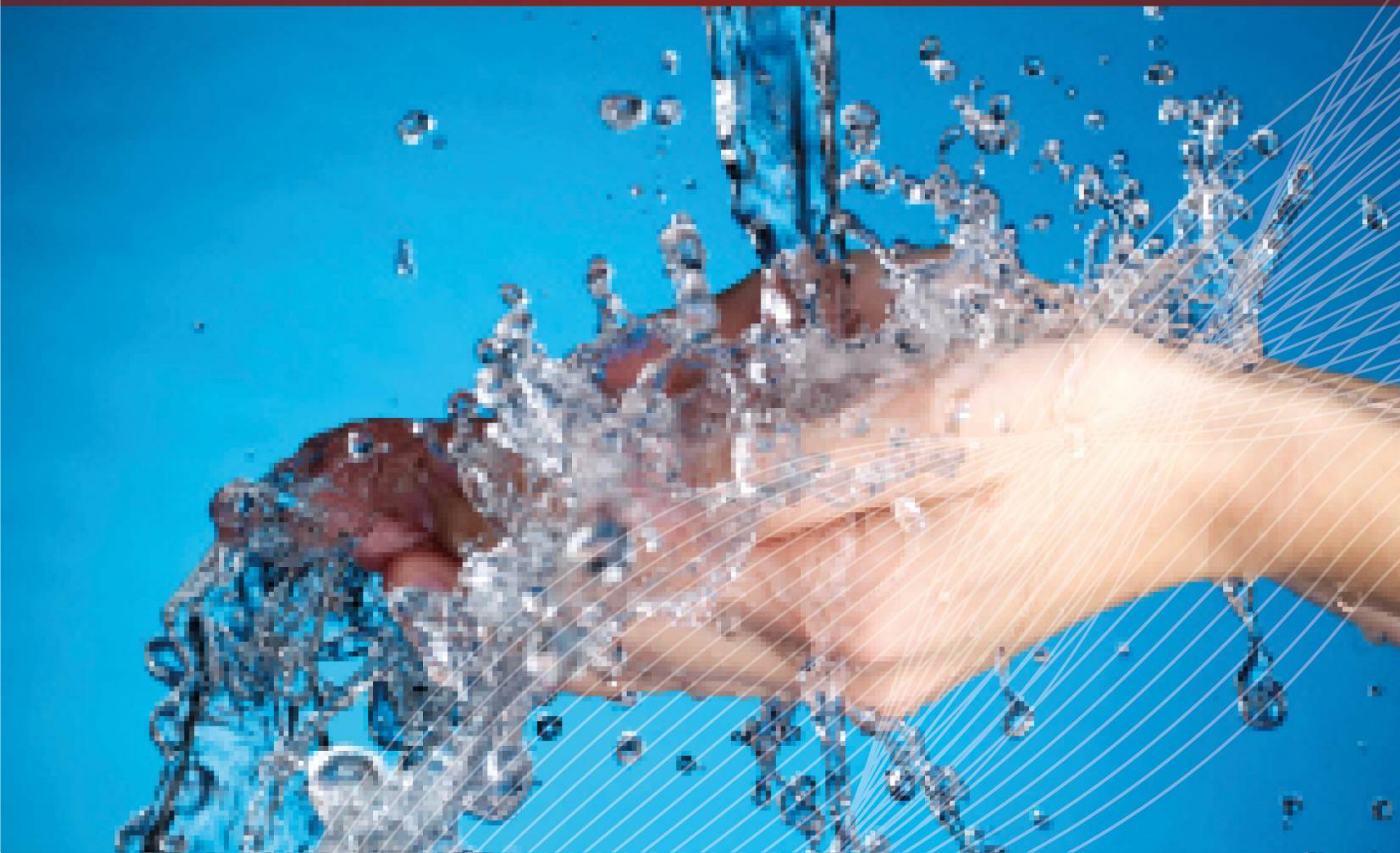
Australian Water Recycling
Centre of Excellence

Project Report

Managing the Long Term Impact of Water Recycling on Irrigated Dairy Farms: The Bega Cheese Case Study

A report of a study funded by the
Australian Water Recycling Centre of Excellence

CSIRO, October 2014



Managing the long term impact of water recycling on irrigated dairy farms: The Bega Cheese Case Study

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CSIRO has been commissioned by the Australian Water Recycling Centre of Excellence, Dairy Innovation Australia Ltd. and Bega Cheese, to undertake this project. For further information about CSIRO, please visit www.csiro.au

About the Australian Water Recycling Centre of Excellence

The mission of the Australian Water Recycling Centre of Excellence is to enhance management and use of water recycling through industry partnerships, build capacity and capability within the recycled water industry, and promote water recycling as a socially, environmentally and economically sustainable option for future water security.

The Australian Government has provided $20 million to the Centre through its National Urban Water and Desalination Plan to support applied research and development projects which meet water recycling challenges for Australia's irrigation, urban development, food processing, heavy industry and water utility sectors. This funding has levered an additional $40 million investment from more than 80 private and public organisations, in Australia and overseas.

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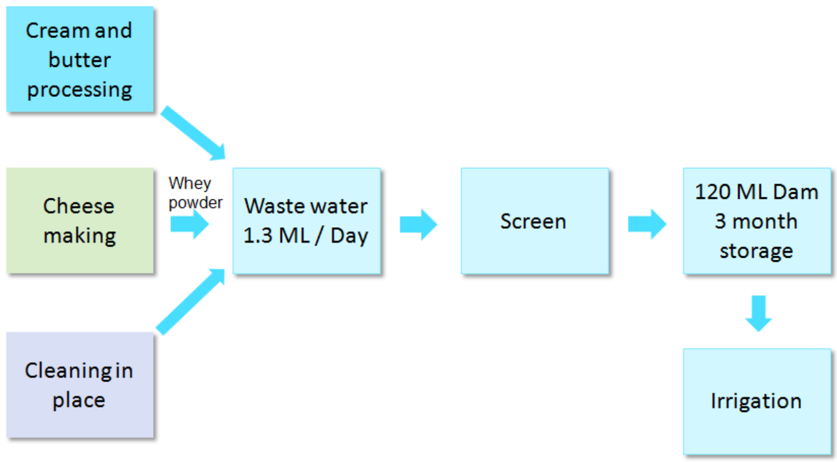
Executive Summary

Introduction and Objectives

Vast amounts of wastewater are generated in dairy processing and a significant amount of work has been carried out to minimise the generation, reuse and recycling of wastewater. In addition, wastewater is also used for irrigation. Although opportunities for water recycling in the dairy industry are well known and largely understood, the cost-effectiveness and sustainability of actually implementing these opportunities are less well understood. This is particularly true when considering associated disposal and management of sodium and nutrients from recycling operations.

Bega Cheese is a large dairy company located in the Bega Valley, NSW that generate around 1.3 ML of wastewater per day. After screening, this effluent is stored in a dam and is used to irrigate the surrounding land for pasture and cropping when there is inadequate rainfall in the Bega Valley. An overview of the wastewater system at Bega Cheese is shown below.



As part of the overall water recycling project for food production and manufacture that CSIRO is carrying out for the Australian Water Recycling Centre of Excellence, and following discussions with Dairy Innovation Australia Ltd., Bega Cheese was chosen as a case study to evaluate the technical, environmental and regulatory issues when wastewater from a large dairy company is used for irrigation. It is proposed to use the learnings and outcomes from this case study more broadly in the dairy sector so that the dairy sector will reduce its water footprint and contribute to a sustainable environment.

The objectives from this case study were to:

- Carry out an analysis of the impact of current farm application of effluent on total P and N loading and sodicity;
- Undertake a preliminary desktop modelling study for nutrient and salt cycling and nutrient uptake by crops, using the Agricultural Production Systems sIMulator (APSIM);
- Identify technology options for treating the wastewater to reduce nutrient and salt loadings;
- Develop a value proposition for potential water irrigation options to fulfil environmental and regulatory requirements; and
- Develop a regulatory framework within which to operate.

Methodology

APSIM modelling

Preliminary desktop modelling for nutrient and salt cycling and nutrient uptake by crops was carried out using APSIM, which is a well-known tool for modelling agricultural production systems.

The following work was undertaken prior to using APSIM:

- Literature review and data collection;
- Systems analysis and mapping sources and sinks of recycled water for selected areas in the dairy sector; and
- Analysis of the impact of current farm application of effluent on total P and N loading and sodicity.

Bega Cheese has collected data from selected irrigated dairy areas that receive irrigation water and effluent for supplementary irrigation from Bega Cheese. Data provided by Bega Cheese and additional published data were used in this model. The sites included in this case study and the data collected are described in Gourley *et al.* (2012).

APSIM was used to determine the following:

- The water demand associated with potential pasture or crop production;
- The impact of different pasture systems (Grazed on site and Cut-and-Carry) on pasture biomass;
- The impact of wastewater irrigation on pasture and crop production and soil water, nutrient and salt balances;
- The impact of three cropping systems; wheat, maize and wheat-maize double cropping system; and
- The salt (Na and K) balance of the different systems.

Because data on the soil water retention, soil water balance, changes in soil water during the year, including the flux of water moving beyond the root zone, and plant biomass production was not available, the results predicted by APSIM were not fully validated. Collection of this type of information, and other key data was beyond the scope of this project.

Technology options

The technology selection framework developed by the project team was used to identify three options to treat the wastewater to reduce its nutrient and salt concentrations. The volume and the concentration of nutrients and salt in the wastewater and the target reduction of nutrient and salt concentrations were taken into account when proposing technology options for treating the wastewater.

Value proposition

It was not possible to use the value proposition tool developed by the project team in this case study because sufficient data was not available. The scope of the project was limited to using “available data” provided by Bega. Resources were not made available to collect any additional data. However, this tool was used with some assumed data to demonstrate its use. Different value propositions were evaluated when the concentrations of nutrients and salt in the wastewater were reduced by a) dilution and b) by treatment.

These scenarios are not intended to reflect the operations at Bega Cheese and do not provide recommendations for investment options. The demonstration illustrates the type of analysis that the tool is capable of and may provide a starting point for analysis of actual options.

Regulatory framework

For this study, *Phase 1 of the Australian Guidelines for Water Recycling (National Resource Management Ministerial Council (NRMMC), EPHC, AHMC, 2006)* and the *NSW Department of Environment and Conservation Environmental Guidelines for the use of Effluent by Irrigation (DEC, 2004)* were consulted to extract information relevant for water reuse and recycling within the dairy industry.

Results

APSIM modelling

Irrigation with wastewater in the Bega Valley

Rainfall in the Bega Valley is highly variable with annual rainfall ranging from 377 to 1634 mm (1960-2012). Potential evaporation exceeds rainfall for most months of the year and irrigation is needed to maximise the growth of pasture and grain crops. A monthly water balance for Bega shows soil water depletion (negative mass balance) from September 2011 to February 2012 with leakage through deep drainage in other months. Future timing of irrigation should be based on crop water demand to reduce crop water stress and avoid water and nutrients leaching below the crop root zone. Such optimisation would reduce the risk of downstream impacts from wastewater irrigation.

Nutrient mass balances

Based on the wastewater irrigation currently being undertaken by Bega Cheese, the loading rate for nitrogen is 306 kg/ha each year. Storage of nitrogen in the soil is low, and 20 to 80 kg/ha is predicted to leach below the crop root zone each year. Each year about 75 kg/ha of phosphorus is applied and approximately 10 to 30 kg/ha is predicted to be retained in the soil each year. Without management intervention, this would see the upper 1 m of the soil profile become saturated with phosphorus in as little as 23 years (23-70 yrs).

Soil nutrient and salt levels

Data on salt (measured as electrical conductivity; EC), phosphorus (total P) and nitrogen (total N and nitrate–N) levels for soil profiles sampled by Bega Cheese show the accumulation of salt and nutrients in the soil profile for all sites irrigated with wastewater, compared to control sites. Much of the phosphorus applied in the wastewater was retained in the soil, meaning there is no need for these pastures to be fertilized with phosphorus.

Summary of modelling results

- In Bega, the potential evapo-transpiration significantly exceeded rainfall in most months during the year and in most of the years. Irrigation is needed to grow pasture or crops to achieve their potential productivity.
- The annual water requirement of the plants (crop and pasture) is much higher than the current average wastewater irrigation of 153 mm (volume available from the factory). In all years, it was possible to apply this average wastewater of 153 mm for irrigation.
- On average, about 650 mm of irrigation (wastewater plus fresh water) is needed to maximise the biomass production (equivalent to 6.5 ML/ha).
- Our modelling suggests that the current practice results in N and salt being leached beyond the root zone.
- The fate of nutrients and salt that goes beyond the root zone and the impacts to the environment needs to be explored. This aspect was not included in this study.
- Adoption of a cut-and-carry system maximised the capture of nutrients. However, it will only be of benefit if the cut material is not returned to the same area when the material is fed to the cows.
- Chloride and other salts contained in the wastewaters, which are not taken up by pasture plants, are leached from the soil profile. The fate of these and the impact on the environment needs to be considered.
- Phosphorus is retained in the soil profile – around 10 to 30 kg net loading per hectare each year – which would give the soil profile an estimated irrigation life from 23 to 70 years. Reducing the phosphorus application rate will increase the longevity of the site. Continued application of nutrients through existing irrigation protocols will result in saturation of the soil profile with phosphorus to a greater depth, thereby increasing the risk of phosphorus movement beyond the root zone.

Technology options

Three treatment options of varying complexity could be considered to reduce the nutrient and salt concentrations of the wastewater. These are:

1. Screening → fat removal → P removal → Dilution
2. Screening → fat removal → P removal → Membrane Bio Reactor(MBR) → Salt removal
3. Screening → fat removal → P removal → Anaerobic digestion → Salt removal

Approximate capital costs for these options are estimated to be in the range $1 to $3M.

Value proposition

As real data was not used in this study to develop a value proposition for different options, only simulated results are shown to demonstrate the use of the value proposition tool. Detailed quotations should be obtained for capital costs for different technology options when developing the value proposition.

Regulatory framework

A comparison of the Australian Water Recycling Guidelines and NSW EPA Guidelines with the water quality parameters of the wastewater indicates that the salt concentration in the wastewater fits within the recommended limits but the nitrogen and phosphorous concentrations are higher than the recommended limits.

A comparison of the guideline assessment of potential environmental impact and the outcomes from the APSIM modelling demonstrate that the guidelines must be used as an initial guide only and that more in-depth local investigations determining long term impacts taking into account issues such as loading rates and soil conditions are also important.

Conclusions and Recommendations

The results of APSIM modelling illustrate the importance of the geographic location of an irrigated dairy farm. The site-specific climate and soil conditions determine the types of crops, the intensity of cropping in a year, as well as the maximum yield and demand for various nutrients. In turn, this determines the frequency and amount of wastewater that can be irrigated and over what area. Crop or pasture harvesting and removal strategies also impact on nutrient cycling. The irrigated pasture management system can be optimised for achieving a sustainable use of the resources in the wastewater; however, salt applied to the soil must be managed through leaching it out of the soil. As a result of the wastewater application, phosphorus accumulates in the soil profile.

It is recommended that:

- The nutrient balance in the current effluent irrigation be improved and Bega Cheese should consider different options to reduce the nutrient load in the soil when wastewater is used in irrigation. Options to consider are:
  - Treating or diluting the effluent to match the loading to crop nutrient demand (200kg N/ha, 50kg P/ha);
  - Increasing the area of irrigation (by 40-225% depending on the volume of wastewater used in irrigation); and
  - Adoption of suitable pasture / cropping systems.
- As all these options will have cost implications, a value proposition should be developed to choose the best option. The tool developed by the CSIRO team may help Bega Cheese to develop value propositions for different wastewater treatment and irrigation options to assist investment decisions to be made.
- The Australian Water Recycling Guidelines and NSW EPA Guidelines should be referred to when developing strategies in using the wastewater for irrigation at Bega Cheese.
- The APSIM model predictions for nutrient and salt uptake by crops and their accumulation in the soil should be validated with actual soil data.

Abbreviations

AHMC	Australian Health Ministers' Conference
APSIM	Agricultural Production Systems sIMulator
BD	bulk density
BOD	biological oxygen demand
CIP	cleaning in place
COD	chemical oxygen demand
CROSS	cation ratio of soil structural stability
DAF	dissolved air floatation
DEC	NSW Department of Environment and Conservation
EC	electrical conductivity
EDR	electrodialysis process
EPA	Environmental Protection Authority
EPHC	Environment Protection and Heritage Council
ET	evapo-transpiration
FSANZ	Food Safety Standards Australia New Zealand
HACCP	hazard analysis and critical control point
MBR	membrane bioreactor
NRMMC	National Resource Management Ministerial Council
PAR	potassium adsorption ratio
PAW	plant available water
PAWC	plant available water capacity
PV	present value
RO	reverse osmosis
SAR	sodium adsorption ratio
WICA	NSW Water Industry Competition Act

1. Introduction and objectives

Vast amounts of wastewater are generated in dairy processing and a significant amount of work has been carried out to minimise the generation, reuse and recycling of wastewater. In addition, wastewater is also used for irrigation. Although opportunities for water recycling in the dairy industry are well known and largely understood, the cost-effectiveness and sustainability of actually implementing these opportunities are less well understood. This is particularly true when considering associated management of salts and nutrients from the recycling operations.

Bega Cheese is a large dairy company located in the Bega Valley, NSW, that generates around 1.3 ML of wastewater per day. After screening, this effluent is stored in a dam and is used to irrigate the surrounding land when there is inadequate rainfall in the Bega Valley for pasture and cropping.

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2. Nutrient and salt loading from irrigated wastewater

Rainfall and evaporation in the Bega Valley

There is significant inter-annual variability in rainfall in the Bega Valley, as observed in the historical weather data (1960-2012)[1], with annual rainfall ranging from 377 to 1634 mm (Figure 1a). Annual potential evaporation (Eo) exceeds annual rainfall in most years. This means that irrigation is required to provide the water needed to maximise the growth of pasture and grain crops.

Monthly evaporation exceeds rainfall in all months except in June, on average, although they are similar in May and July (Figure 1b). Irrigation is therefore likely to be required for most of the year, with less reliance on irrigation during winter months. The amount of irrigated water will depend on inter-annual variability and will need to be of sufficient amount to reduce the water deficit and meet the water demand of crops.

A monthly and annual water (mass) balance was calculated for Bega, based on 2011-12 weather data and the amount of wastewater used for irrigation (Source: Gourley *et al.* 2012). The water balance assumes that no other irrigation sources (river or groundwater) are used. The results presented in Figure 2 indicate soil water depletion (negative balance) from September 2011 to February 2012 with predicted leakage through deep drainage in other months. These results demonstrate that the timing of irrigation should be based on crop water demand in order to reduce crop water stress and to avoid water and nutrients leaching below the crop root zone. Such optimisation would minimize the risk of off-site impact from wastewater irrigation.

[1] Bega weather station, Newton Road; number 069002

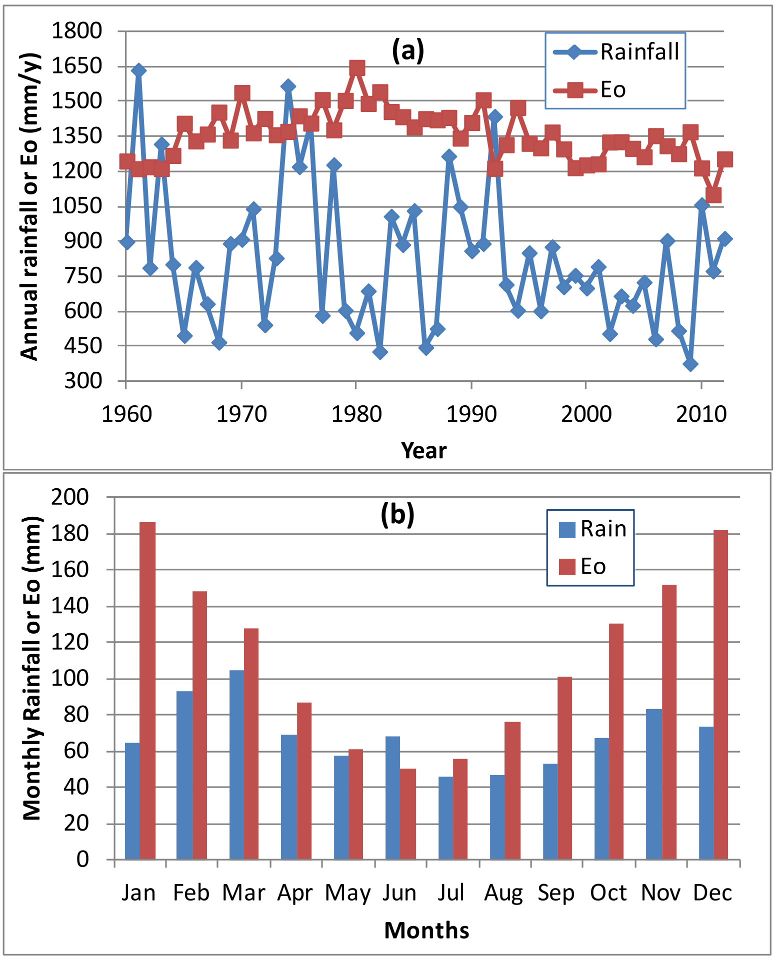

Figure 1. Annual rainfall and pan evaporation (Eo) (a) and mean monthly rainfall and pan evaporation (b). Source: Bega weather station (Newton Road; number 069002) from 1960 to 2012.

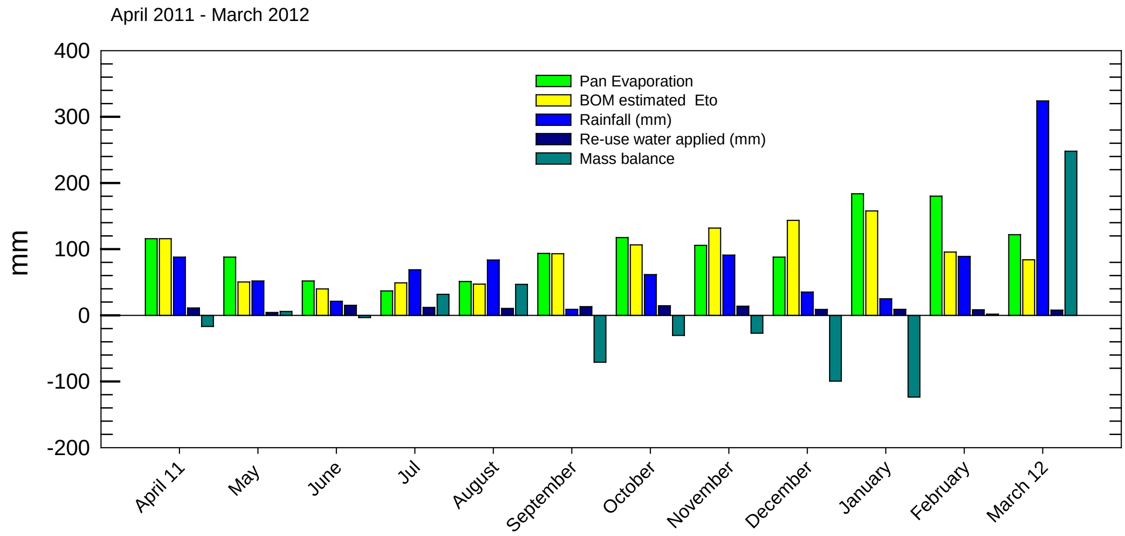

Figure 2. Water balance (input minus output) for Bega in 2011-12, including wastewater irrigation. Source: Gourley *et al.* (2012).

Wastewater nutrient and salt loads

During 2011-12, 461.4 ML of wastewater was applied to 301.7 hectares (source: Bega Cheese annual soil sampling – 27 March 2012) corresponding to an average application of 153 mm/yr. Nitrogen, phosphorus and chloride concentrations were 200 mg/l, 47 mg/l and 501 mg/l respectively (Table 1). These correspond to an average loading of 306.5 kg/ha of nitrogen, 72 kg/ha of phosphorus and 766.6 kg/ha of chloride. These figures were used to generate the modelling results presented in Chapter 3.

Table 1. Wastewater nutrient concentrations and average loading rates for 2011-12 (Gourley *et al.*, 2012).

Month	Total Nitrogen	Total Phosphorus	Calcium	Potassium	Sodium	Magnesium	Chloride	Sodium Adsorption Ratio
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	n/a
April 2011	320	31	54	220	260	15	320	8
May	220	62	77	290	200	17	430	4.3
June	240	41	110	305	235	15	330	5.1
Jul	190	47	57.0	200	220	15.0	370	6.8
August	200	45	76	455	285	17.0	360	5.8
September	210	53	63	515	355	15.00	580	13
October	230	55	54	390	430	15.0	570.0	13
November	160	50	68	390	410	15.0	670	12
December	185	45	63.0	345	345	15.0	485	10.45
January 2012	170	37	53	305	275	14	470	9.8
February	120	40	52	360	450	15	610	14
March	160	59	76	420	540	18	820	15
Av Analysis	200	47	67	350	334	16	501	10
kL applied/yr	461,385	461,385	461,385	461,385	461,385	461,385	461,385	461,385
Area applied (ha)	301.7	301.7	301.7	301.7	301.7	301.7	301.7	301.7
Av Loading (kg/ha)	**306.5**	**72.0**	**102.3**	**534.6**	**510.4**	**23.7**	**766.6**	**14.9**
Min	120	31	52	200	200	14	320	4.3
Av	200	47	67	350	334	16	501	10
Max	320	62	110	515	540	18	820	15

Information provided by Bega Cheese forecasts that the volume of wastewater will increase to 1.5 ML per day over time, corresponding to 547.5 ML per year. The estimated average nutrient concentrations for the wastewater are 164.4 mg/L of nitrogen, 102.3 mg/l of phosphorus and 600.9 mg/l of potassium (PersCom. Bega Cheese).

If 1000 ha of land are irrigated, the annual nutrient loadings[2] are predicted to increase to 90 kg/ha of nitrogen, 56 kg/ha of phosphorus, 185 kg/ha of sodium and 330 kg/ha of potassium. If the wastewater was applied to 1,000 ha, the depth of wastewater irrigation[3] would be 54.75 mm.

[2] The loading of a nutrient (L_{nut}) is the product of the volume of effluent applied (Lw; mm) and the concentration of the nutrient (C; mg/L). The equation is L_{nut} = Lw * C /100 to give the loading in kg/ha.

[3] Hydraulic loading is calculated as the depth of irrigation applied: L_w (mm) = volume (L) / area irrigated (m^2); i.e. L_w (mm) = $(547.5 * 10^6) / (1,000 * 10^4) = 54.75$ mm.

Soil nutrient and salt levels

Figure 3 presents salt (measured as electrical conductivity; EC), phosphorus (total P) and nitrogen (total N and nitrate–N) levels for soil profiles provided by Bega Cheese from annual soil sampling. These data show the accumulation of salt and nutrients in the soil profile.

An increase in soil salinity (EC) was found on all sites irrigated with wastewater, compared to control sites that were not irrigated with wastewater.

Nutrient levels also showed higher levels at sites irrigated with wastewater, compared to control sites. High levels of total N and nitrate-N were found in the surface soil of irrigated sites, and they decreased with depth. Much of the phosphorus applied in the wastewater was retained in the soil as evidenced by total P values for the soil being greater than 200 mg/kg. At the site referred to as Ranch River Flat, high concentrations of phosphorus were found to a depth of 80 cm. Such accumulation of phosphorus at depth in the profile indicates that the sorption capacity of the soil has been exceeded and that the phosphorus is being transported to depth in the soil.

Phosphorus does not generally leach, as the amount in excess to plant requirements is sorbed to the soil. This is known as the phosphorus retention capacity of the soil. The phosphorus application from wastewater exceeds plant requirements; therefore there is no need to fertilise the pastures with additional phosphorus fertiliser.

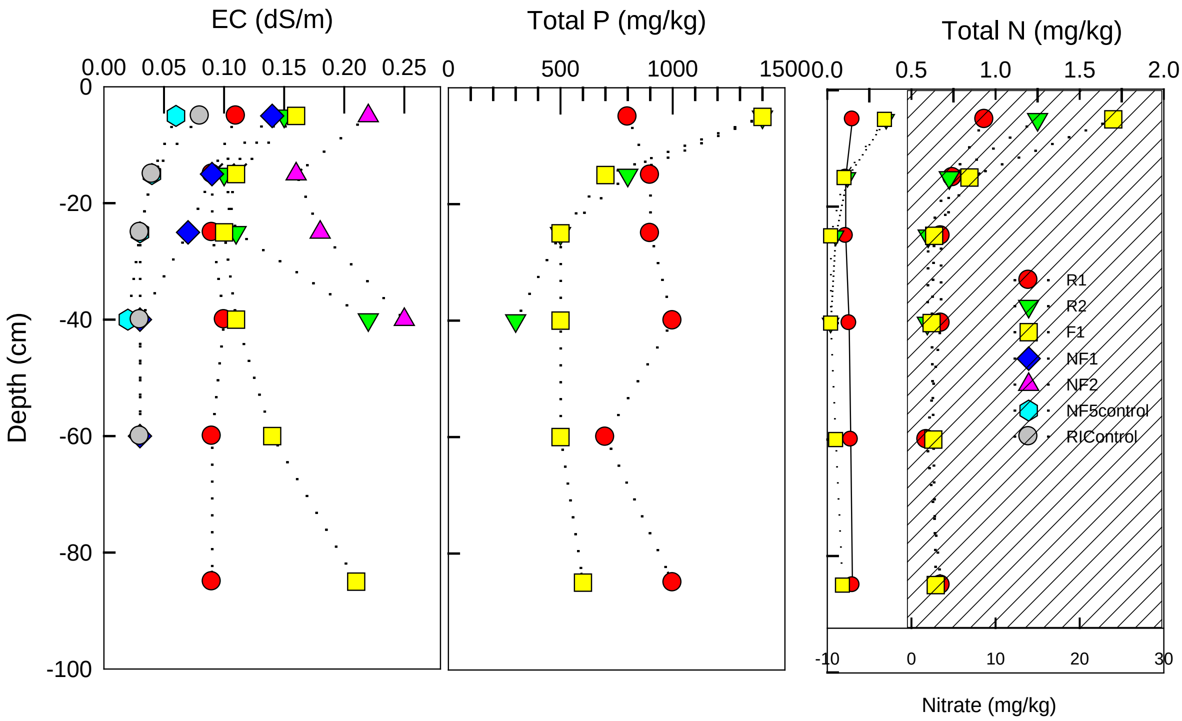

Figure 3. Soil Profiles of salt (EC), total P, total N and nitrate–N. Data from Bega Cheese annual soil sampling – 27 March 2012: R1–Ranch River flats, R2–Ranch gentle slopes, F1–Apps farm River flats, NF1–Chris Apps New farm river flats, NF2–Chris Apps New Farm silage cart, NF5control–Chris Apps farm control, RIControl–River flat irrigation control.

Figure 4 presents chloride profiles measured in 2012 and shows a downward movement of salt, especially on the river flat of the Apps farm. The accumulation of chloride at depth at this site indicates that the salt has not been leached. In contrast, the profile from Ranch River flats, where crops have been irrigated with wastewater for many years and with the highest P concentration in the soil (Figure 3), the Cl concentration is similar to the control. The explanation is that irrigation with wastewater ceased at this site (Gourley *et al.*, 2012) and salt has leached from the soil over time. However, the soil continues to have a high total phosphorus concentration throughout the soil profile as a result of the phosphorus retention.

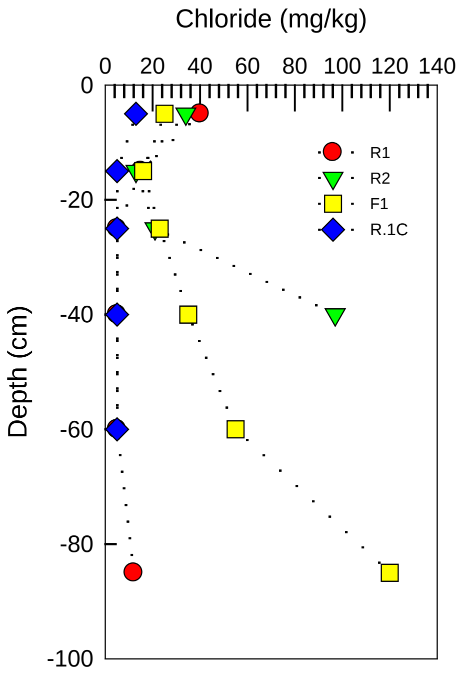

Figure 4. Selected soil profiles of chloride from wastewater irrigation and control sites. Source: Bega Cheese annual soil sampling – 27 March 2012.

3. Application of APSIM

The Agricultural Production Systems sIMulator (APSIM; Keating *et al.*, 2003; Wang *et al.*, 2002) was used in the Bega case study to model:

1. The water demand associated with potential pasture or crop production;
2. The impact of two pasture systems: **Grazed** on site and **Cut-and-Carry** on pasture biomass;
3. The impact of wastewater irrigation on pasture and crop production and soil water, nutrient and salt balances;
4. The impact of three cropping systems: wheat, maize and wheat-maize double cropping system; and
5. The salt (Na and K) balance of the different systems.

Weather

Daily weather data from 1889 to 2013 were obtained from the Bega weather station[4]. Simulations were run for 53 years from 1960 to 2012. This period was considered to be a reliable data period that adequately captured the impact of inter-annual climate variability.

Soil

Information provided in the Annual Report to Bega Cheese on the assessment of the impact of recycled water application to soil (Gourley *et al.*, 2012) indicates that the soils are a mixture of alluvial soils formed from sediments from higher slopes. They are generally light textured, granitic, naturally infertile, with low nutrient retention and high infiltration capacity. These soils are considered to have a low to moderate phosphorus buffering capacity when compared across the wide range of phosphorus buffering capacities found in Australian soils (Burkitt *et al.*, 2002).

Detailed information on soil hydraulic properties was unavailable to parameterize the APSIM. Instead, hydraulic properties for two soils – one at the Towamba River (TR) site and another at the Lower

[4] Newton Road; number 069002; latitude = 36.6884, longitude = 149.8380 Decimal degrees.

Brogo (LB) site – were combined with the data reported by Gourley *et al.* (2012) to provide the information needed to run APSIM.

While the parameters used in this study are the best available, detailed soil profile analysis would benefit future work by providing the parameters used by the soil modules in APSIM.

Irrigation

The irrigation settings in APSIM were set as follows:

- The average wastewater application was set at 153 mm/year.
- To avoid pasture water stress and maximize pasture growth, irrigation was scheduled to occur when the Plant Available Water (PAW) in soil to 60 cm depth dropped to 85% of its maximum capacity (PAWC).
- Irrigation amount was determined as the amount of water required to fill the 60 cm soil profile to field capacity.
- Each year (1960 to 2012), irrigation of wastewater was limited to 153 mm, and it was applied from the start of the year with a nitrogen concentration of 200 mg/l and chloride concentration of 501 mg/l.
- At each irrigation time, the amount of nitrogen and chloride added to soil was calculated based on the amount of wastewater and the concentrations.
- After 153 mm of wastewater water was used, fresh water was used to irrigate the pasture, assuming the nitrogen and chloride concentrations are zero. Nitrogen will be taken up by pasture plants and will also be leached with downward water movement. Chloride will also be leached with water. The APSIM model simulates these processes dynamically.

Scenarios were also applied that varied the amounts of wastewater irrigation and nutrient concentrations. These scenarios were used to explore options to minimise the movement of nitrate and chloride below the one metre depth root zone.

Pasture production

In the simulation, the pasture mix was assumed to be established and consisting of ryegrass and white clover with an initial biomass of 1500 kg/ha and 350 kg/ha, and rooting depth of 90 cm and 40 cm, respectively. After initialization, APSIM simulates pasture growth, water and nitrogen uptake, and movement of nitrogen and salts dynamically on a daily time step.

Three pasture management scenarios were modelled for the two soil types (described above under Soil):

1. **Grazed**: Pasture grazed every three weeks (21 days) to a minimum biomass of 1000 kg/ha. In this scenario, it was assumed that 85% of the nitrogen in the eaten biomass was returned as excreta, and 60% of the returned nitrogen was in urine with a urine deposit depth of 15 cm.
2. **Cut-and-Carry**: Pasture cut every three weeks (21 days) to a minimum biomass of 1000 kg/ha. In this scenario, it was assumed that all cut biomass and nitrogen contained was moved outside of the field. This is to mimic the **Grazed** scenario with the same frequency of cutting but remove all the cut biomass to investigate the impact on nitrogen balance.
3. **Cut-and-Carry ex**: Pasture cut every three months instead of three weeks to mimic a more realistic cutting frequency. The rest of the scenario is the same as in **Cut-and-Carry**. This is to investigate how cutting frequency impacts on pasture growth, water and nitrogen balances.

Crop production

Three annual cropping systems were modelled; the scenarios are:

1) Winter cereal (wheat) grown for silage production. That is, the cereal is cut and removed from the field, aiming to maximise the export of nutrient from the field. This scenario requires off-field management of the nutrient, carbon and salts in the animal excreta when fed with silage. This is not considered as part of the current analysis.
2) Summer maize where the crop was harvested for biomass, maximizing the export of nutrients.

3) Wheat-maize double cropping system. Under this option, we further explored the impact of adding more nitrogen in the irrigation water on crop growth and nutrient uptake. We doubled the amount of nitrogen contained in the wastewater by adding another 306 kg/ha to freshwater irrigation.

For each of the cropping options, the crop uptake of phosphorus and potassium (K) was calculated based on the average N:P and N:K ratios.

Difference between sites and soils

The simulation results for the Towamba River site and Lower Brogo sites are very similar because the constructed soil profiles are both sandy in nature. Onsite measurement of soil profile is required to verify the hydraulic properties constructed for the two sites in the current study. Because APSIM is a soil-plant systems model that simulates the dynamics of the soil and plant processes, detailed information is needed on the soil hydraulic properties, soil carbon contents, and crop/pasture rooting depth. Ideally, data should be available on seasonal changes in soil water content, biomass production, and nutrient removal.

Measurements needed to optimise use of APSIM

Future studies using a system analysis ideally require:

1) Measurement of the soil properties onsite to enable more accurate soil characterisation for modelling;
2) Measurement of data on pasture or crop productivity to validate model predictions;
3) Soil water contents in soil profile at critical times; and
4) Chemical analyses of the soil.

In addition, it is also necessary to measure the phosphorus sorption and desorption characteristics of the soil.

APSIM results

Irrigated Pasture Water Demand

Figure 5 presents the annual water balance for two of the pasture management scenarios: **Grazed** and **Cut-and-Carry**.

The annual rainfall from 1960 to 2012 was 827 mm, with a maximum of 1634 mm and a minimum of 377 mm. The average amount of irrigation (fresh and wastewater) applied under the scenarios was 670 mm, but ranged from 457 mm in very wet years to 935 mm in years with low rainfall. In all years, the scenarios demonstrated that it was possible to apply the average wastewater irrigation of 153 mm.

It would be possible to apply extra wastewater in dry years, but the impact of doing so on nutrient balance has not been simulated under the scenarios. Rather, the scenarios assume that the wastewater is spread over the entire irrigated area and maintains a constant nutrient and salt loading. Furthermore, we assumed that the additional fresh water needed for irrigation, to maximise plant growth, is not limiting.

The modelling predicted an annual average Evapo-Transpiration (ET) of 1016 mm under the **Grazed** scenario and a lower 910 mm under the **Cut-and-Carry** scenario. These figures are lower than the average Pan Evaporation (1356 mm) but consistent with the Pan Evaporation reported for 2012 in the Gourley *et al.* (2012) (see Figure 1).

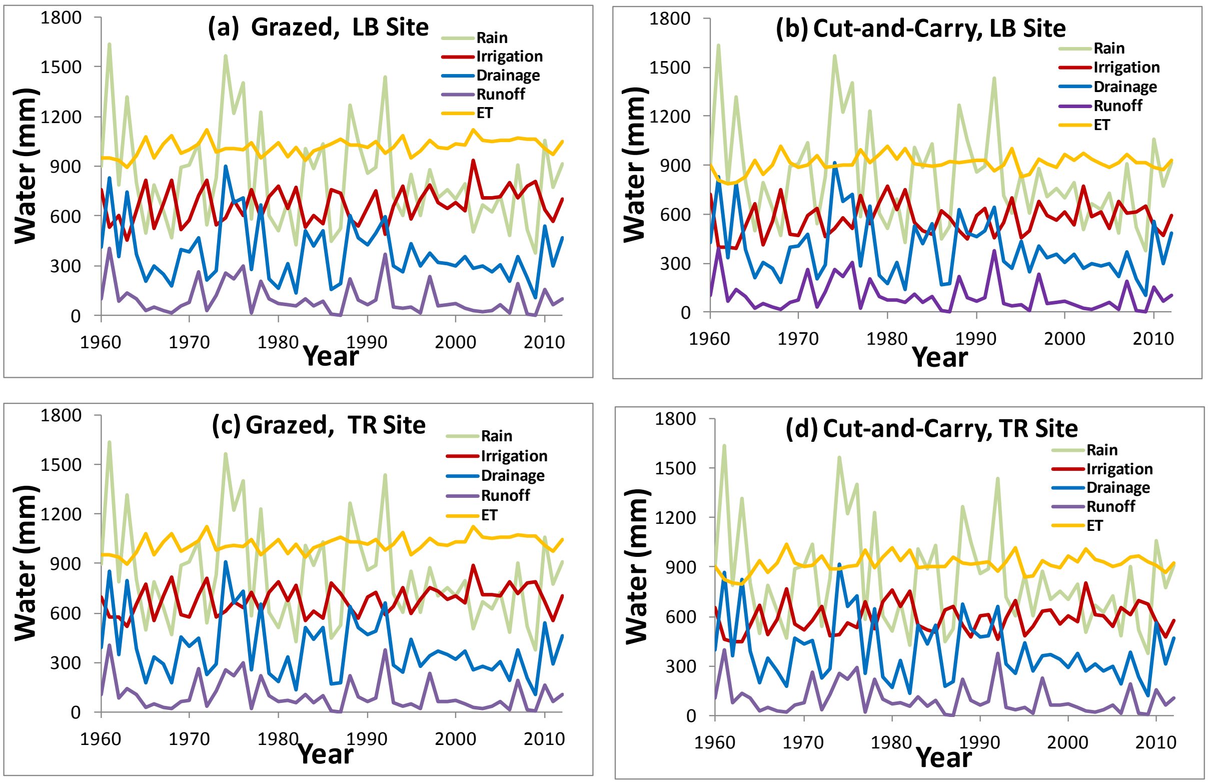

Figure 5. Water balance for irrigated pasture. Modelled data for two sites (LB – Lower Brogo and TR - Towamba River) under two management scenarios (Grazed or Cut-and-Carry) from 1960 to 2012.

Drainage beyond the root-zone ranged from 110 to 890 mm, with an average of 380 mm under the **Grazed** scenario. The predicted annual drainage under the **Cut-and-Carry** scenario was very similar, with an average of 386 mm (102 – 914 mm). As expected, the highest annual drainage occurred for the year with the highest rainfall (1634 mm). The drainage prediction seemed high but is not unexpected given the variable rainfall and the light texture of the soil.

The scenarios illustrate the importance of the geographic location of an irrigated dairy farm. The site-specific climate and soil conditions determine the types of crops, the intensity of cropping in a year, as well as the maximum yield and demand for various nutrients. In turn, this determines the frequency and amount of wastewater that can be irrigated. Crop or pasture harvesting and removal strategies also impact on nutrient cycling. For example, harvesting all the biomass for silage removes the maximum nutrients from the field, enabling more wastewater to be applied next season. Only harvesting crop grains and retaining stubble in the field will result in more nutrients remaining on-site to be recycled through the soil-plant system. If the ultimate aim is to maximise milk production and use the plant biomass as feed on site, expansion of cropping land areas may be needed to achieve sustainable nutrient cycling. Thus, the interaction between the climate, soil, crop or pasture type and various management scenarios, together with the volume of wastewater and its chemical composition determines the land areas required to manage the wastewater. The system can be optimised for achieving a sustainable use of the resources in the wastewater; however, salt applied to the soil must be managed through leaching it out of the soil.

Pasture Biomass Production

Figure 6 presents the pasture biomass production for two of the pasture management scenarios: **Grazed** and **Cut-and-Carry**.

Predicted annual biomass production of pasture varied from 14.2 to 23.9 Mg/ha (average 18 Mg/ha) under the **Cut-and-Carry** scenario. Biomass production showed less variation under the **Grazed** scenario ranging from 19.8 to 28.3 Mg/ha (average 24 Mg/ha). The modelled results are in the expected range according to the climate and soil conditions and the nutrient and water input through irrigation. However, the accuracy of the biomass predictions has associated uncertainty due to a lack of data on pasture growth for validation. Model validation against measured pasture biomass is a task needed to determine the accuracy of model predictions.

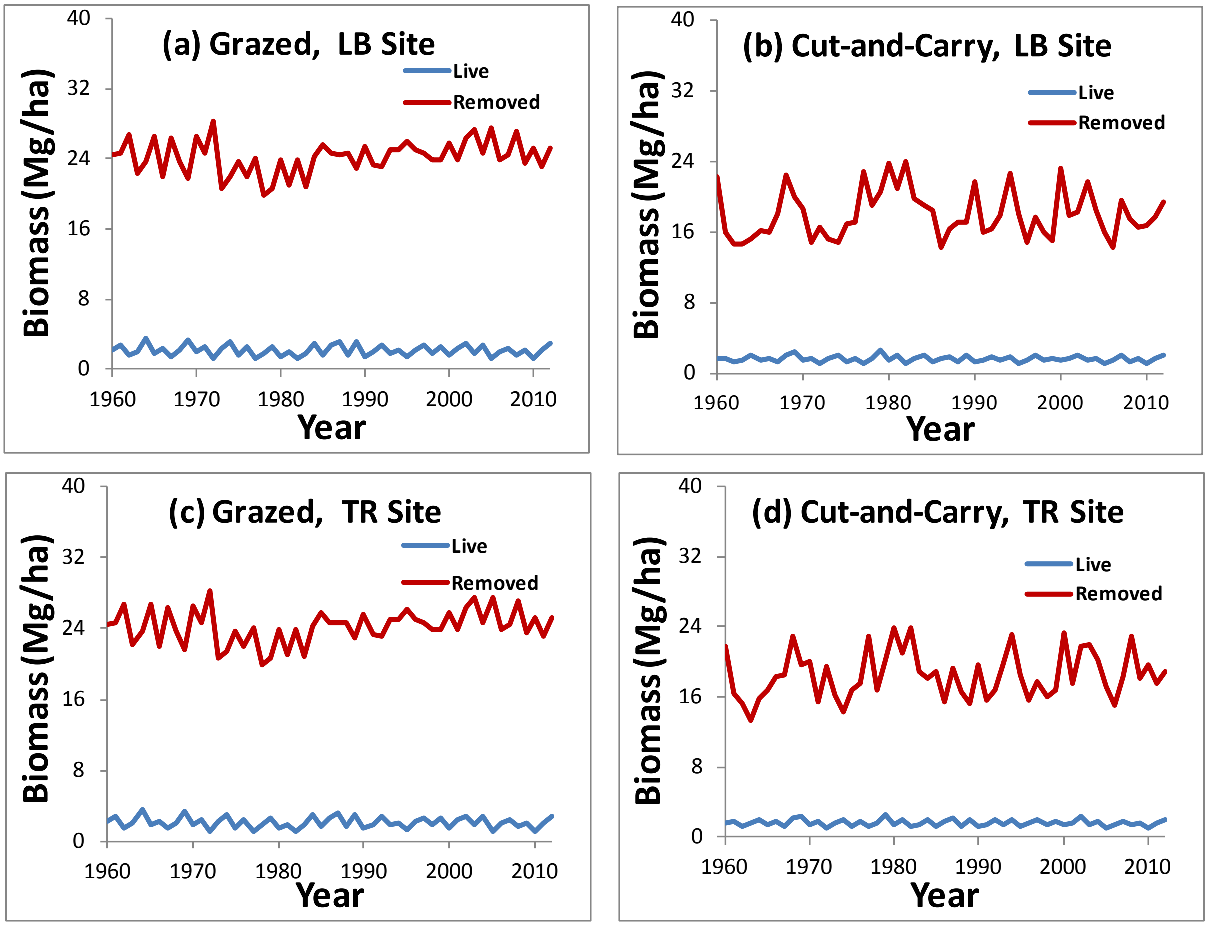

Figure 6. Predicted biomass production. Modelled data for irrigated pasture at two sites (LB – Lower Brogo and TR - Towamba River) and under two management scenarios (Grazed or Cut-and-Carry) from 1960 to 2012.

Pasture Nitrogen Balance

Figure 7 presents the modelled nitrogen balances for the two pasture management scenarios. The graphs show annual nitrogen loads (AddedN), nitrogen in the live pasture biomass (BiomassN), mineral nitrogen in the soil (SoilNmin), and the amount of nitrogen that is leached (LeachedN). In total, the annual addition of nitrogen was 306 kg /ha, which was calculated from 153 mm of wastewater with a nitrogen concentration of 200 mg/l (refer to Table 1). On average, white clover was predicted to fix 125 kg of nitrogen per hectare, every year. The prominent feature in these graphs is the significant leaching of nitrogen (average 380 kg N/ha) under the **Grazed** scenario. The modelling assumes that no nutrients are exported from the site under the **Grazed** scenario.

The results for the **Grazed** scenario indicate that the amount of nitrogen leached increased in the first 10 years of irrigation and then approximated the annual added nitrogen, but with significant inter-annual variation (Figure 7a and c). In contrast, the amount of nitrogen leached under the **Cut-and-Carry** scenario was reduced to an average of 18.2 kg/ha (range 0.01 to 162 kg N/ha).

Under the **Cut-and-Carry** pasture management scenario, most of the nitrogen applied in the wastewater was removed, there was little nitrogen accumulation in the soil and the amount of leached nitrogen was significantly reduced. This result suggests that a **Cut-and-Carry** pasture management system would enable the use of all wastewater from Bega Cheese, produce 24 Mg/ha pasture biomass on average for export from the site, and minimize leaching of nitrogen. However, in this scenario, although the nutrients and carbon are removed from the irrigated area, it ends up on another area (not irrigated with wastewater) and needs to be managed.

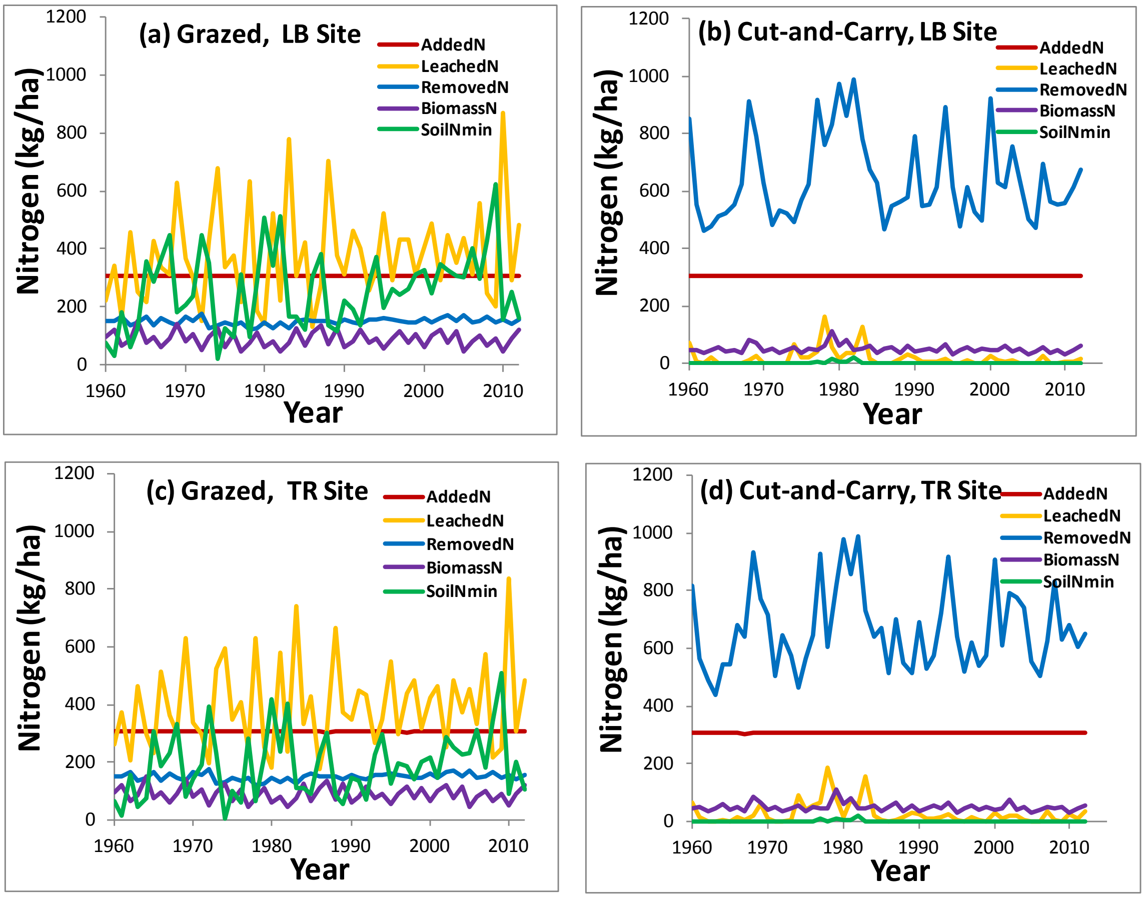

Figure 7. Predicted Nitrogen balances for the irrigated pasture at two sites (LB – Lower Brogo and TR - Towamba River) and with two management systems (Grazed or Cut- and-Carry) from 1960 to 2012.

Nitrogen Balance of Cropping Systems

Figure 8 presents the annual nitrogen balance for the modelled cropping systems. As all plant biomass is exported in these scenarios, the amount of nitrogen exported from the site is equivalent to the nitrogen in the biomass and is represented as BiomassN. In contrast to the previous pasture simulation, there is no additional nitrogen input through biological fixation of nitrogen by clover.

The prominent feature in the graphs in Figure 8 is low soil mineral nitrogen values found in the rotation cropping system. Further, the nitrogen exported through biomass removal averaged 245 kg/ha (median of 240 kgN/ha; stdev= 26) and the leached nitrogen was 100 kg/ha (stdev = 40).

A single crop in each year resulted in less export of nitrogen from the site, a higher nitrogen content in soil and a greater amount of nitrogen moving below root-zone.

The results from the **Cut-and-Carry** pasture management scenario (above) could not be achieved when using a cropping system. This is partly due to the annual crops needing to establish their canopy and root systems every year. In contrast, perennial pasture has established root system and could quickly re-grow every year.

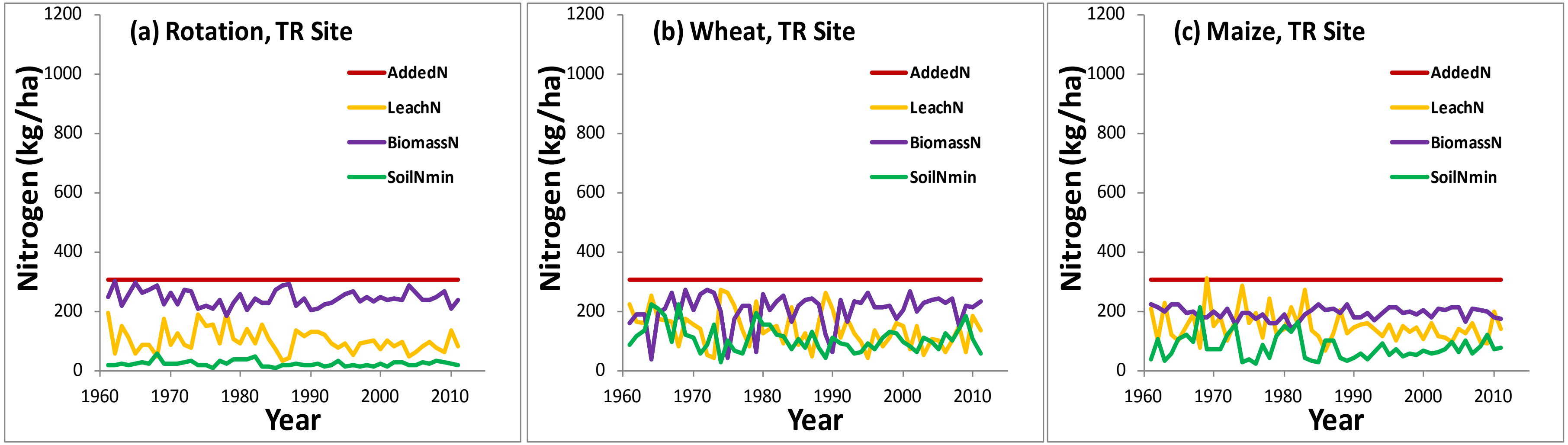

Figure 8. Predicted nitrogen balances for the irrigated wheat, maize and double cropping system. Data is for the Towamba River soil from 1960 to 2012. The crops are harvested for biomass to maximise the export of nutrients from the site.

Impact of Cutting Frequency on Pasture Biomass

Figure 9 shows the impact of biomass cutting frequencies (every 3 months compared to every 3 weeks) on simulated pasture biomass production, drainage, N removal and N leaching. Reduced cutting frequency from every 3 weeks to every 3 months led to reduced biomass production (from 18 Mg/ha to 16 Mg/ha), less nitrogen to be removed, and more N leached (from 18 to 100 kg N/ha), though the changes in annual drainage were not significant. These results imply that more frequent cutting promotes pasture growth, increases the pasture productivity and nitrogen removal, thereby reducing nitrogen leaching.

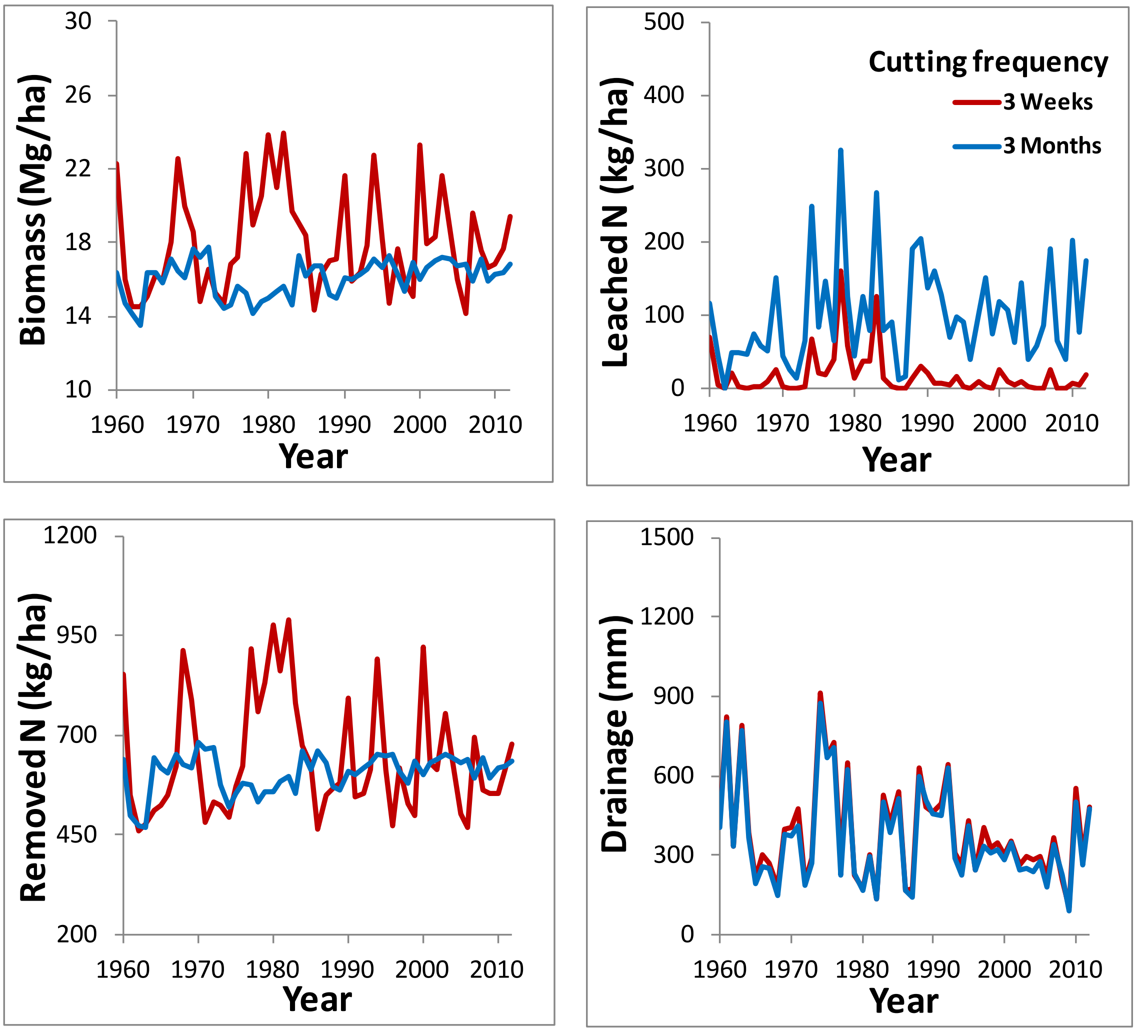

Figure 9. Comparison of simulated annual biomass production of pasture, annual total nitrogen removal and leaching, and annual drainage as impacted by biomass cutting frequency (cut every 3 weeks vs every 3 months) at the Lower Brogo (LB) site of Bega (1960-2012).

Nutrient Loading from Wastewater Irrigation

Figure 10 shows the relationship between nitrogen and phosphorus loading and wastewater irrigation. The bottom graph in the figure relates irrigation amount (mm) to the area of land that is required for irrigation with a total wastewater volume of 461 (●) and 547 ML (▼). For example, if the plant production system results in the export of nitrogen at 400 kg/ha each year, then this amount can be applied in 200 mm or 250 mm of wastewater (more wastewater needs to be added when the nitrogen concentration is reduced). The amount of phosphorus added to the system is 94 kg/ha or 420 kg/ha for the wastewater with a higher P concentration. The area to be irrigated ranges from 219 to 230 ha.

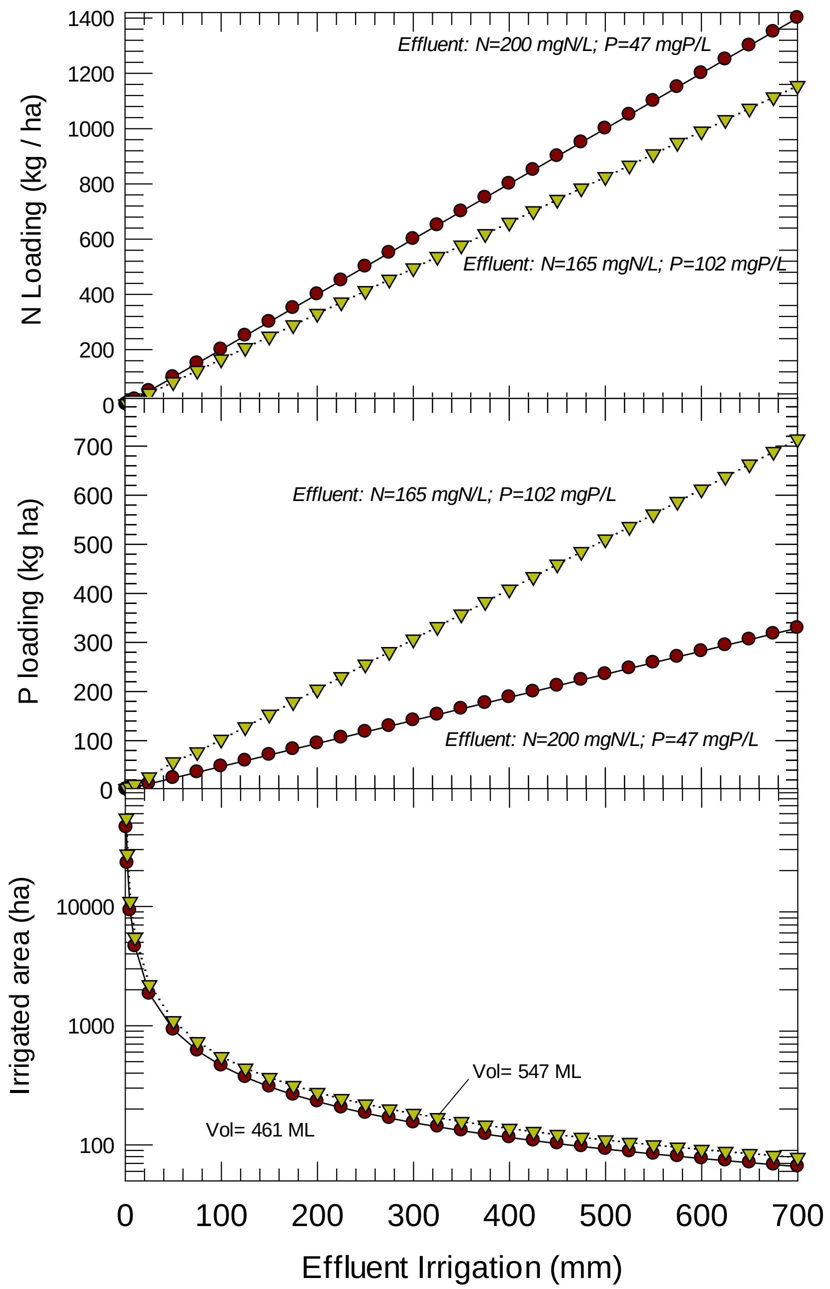

Figure 10. Relationship between N and P loading (kg/ha) and wastewater irrigation (mm) with different chemical compositions.

Nutrient Mass Balances

Based on the current wastewater irrigation strategy at Bega, the loading rate for nitrogen is 306 kg/ha each year. Of this amount, approximately 200 to 250 kg/ha could be exported from the site by adopting cropping system (Figure 11). Storage of nitrogen in the soil was low, and 20 to 80 kg/ha was predicted to leach below the crop root zone each year.

For phosphorus, about 75 kg/ha was applied each year and 40 to 60 kg/ha was exported in biomass leaving an excess of phosphorus in the soil of 10 to 30 kg/ha each year. The soil has the potential to store phosphorus, and based on published retention data (50 mg P sorbed per kg of soil; Meyers *et al.* 1999) around 700 kg/ha of phosphorus can be stored in the top metre of soil. This estimate assumes an average soil bulk density of 1400 kg/m^3.

Assuming the net loading each year of phosphorus is 10 to 30 kg/ha, and then using the equation below, the time to fully load the soil profile is estimated to vary from 23 to 70 years.

Management options that lower the net loading, such as reducing the phosphorus application rate will increase the years before phosphorus retention capacity of the soil profile is saturated. Ideally, the nutrients should be applied at a loading rate that can be used by the plants and not rely on storing phosphorus in the soil.

The general equation for calculating phosphorus retention is:

Total P retention (kg/ha) = P retained (mg/kg soil) * BD (kg/m^3) * Soil Depth (m) / 100

In order to do these calculations more accurately it is important to measure the sorption and desorption isotherm for the soil.

Uptake of Nutrients and Salt by Crops

Figure 11 presents the predicted crop biomass and crop uptake of nitrogen, phosphorus and potassium for the wheat, maize and wheat-maize double cropping system (referred to as "Rotation") under an irrigated application of wastewater of 153 mm/yr. Figure 12 presents the same information for an application of double the amount of wastewater - 306 mm/yr. The average biomass and ranges for both application rates are provided in Table 2.

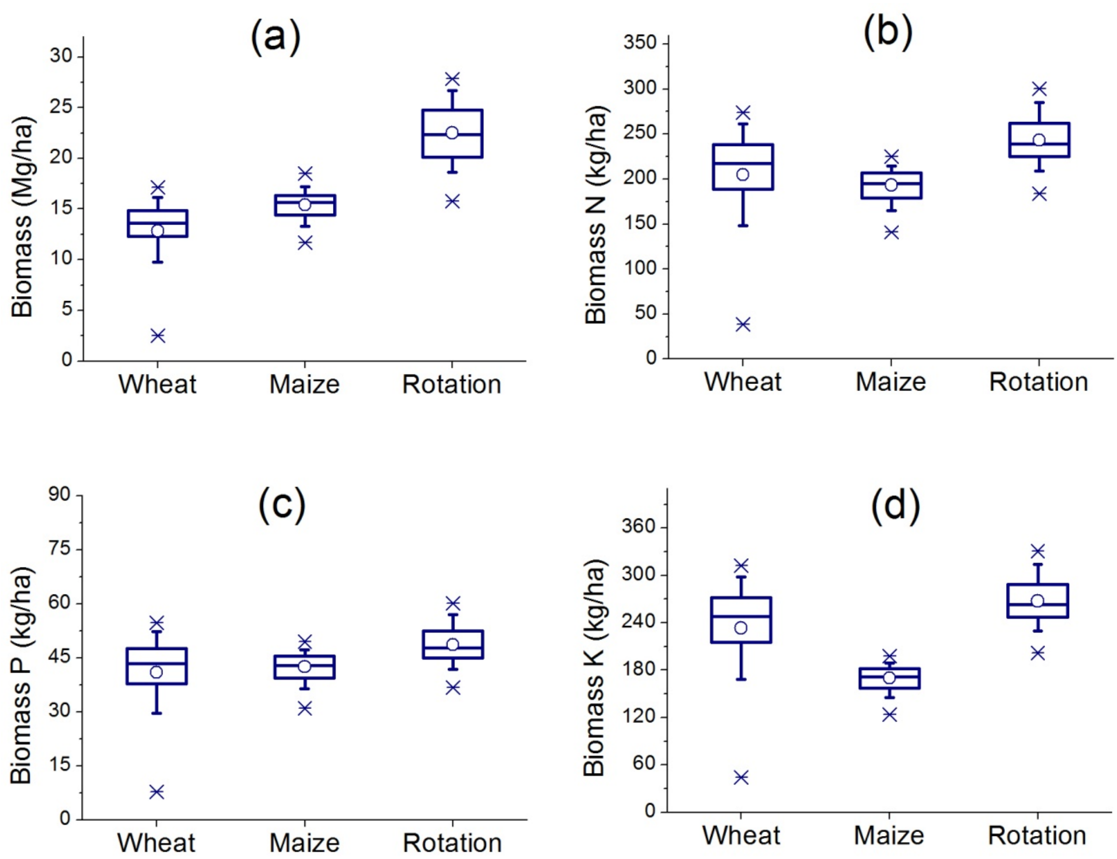

Figure 11. Predicted crop biomass (a), crop uptake of (b) **n**itrogen (N), (c) **p**hosphor**us** (P) and (d) potassium (K) for wheat, maize and wheat-maize double cropping system under average wastewater application of 153 mm per year. The N, P and K loading are 306, 72 and 536 kg ha^{-1} year^{-1}.

The crop uptake of nitrogen, phosphorus and potassium was much lower in the wheat-maize rotation cropping system compared to the sum of that in single wheat and maize systems. This was mainly due to the limited nitrogen contained in the 153 mm of wastewater.

When the application rate was doubled to 306 mm of wastewater per year (to explore if nitrogen was limiting plant production and the uptake of other nutrients during the rotation-cropping system), the average crop uptake of nitrogen, phosphorus and potassium increased; the recovery was equivalent to 60.8% of the nitrogen added, 57.8% of the phosphorus added and 52.3% of the potassium added in the wastewater (see Figure 12).

The simulations demonstrate that with more nitrogen, crop growth and nutrient uptake were enhanced, creating an opportunity to recover more phosphorus and potassium in the dairy wastewater for a wheat-maize rotation that is not deficient of nitrogen.

Table 2. Predicted average crop biomass and crop uptake of nitrogen, phosphorus and potassium for wheat, maize and wheat-maize double cropping system as average and range.

Crop and wastewater application rate		**Biomass Average and range**		**Nitrogen Average and range**		**Phosphorus Average and range**		**Potassium Average and range**	
Crop	mm/yr	Mg/ha		kg/ha		kg/ha		kg/ha	
Single wheat	153	13	2.5 - 17	205	39 - 274	41	7.8 - 55	233	44 - 312
Single maize	153	15	12 - 19	193	141 - 225	42	31 - 50	170	124 - 198
Wheat-maize rotation	153	23	16 - 28	243	184 - 301	49	37 - 60	268	202 - 330
	306	27	17 - 33	329	-	65	-	356	

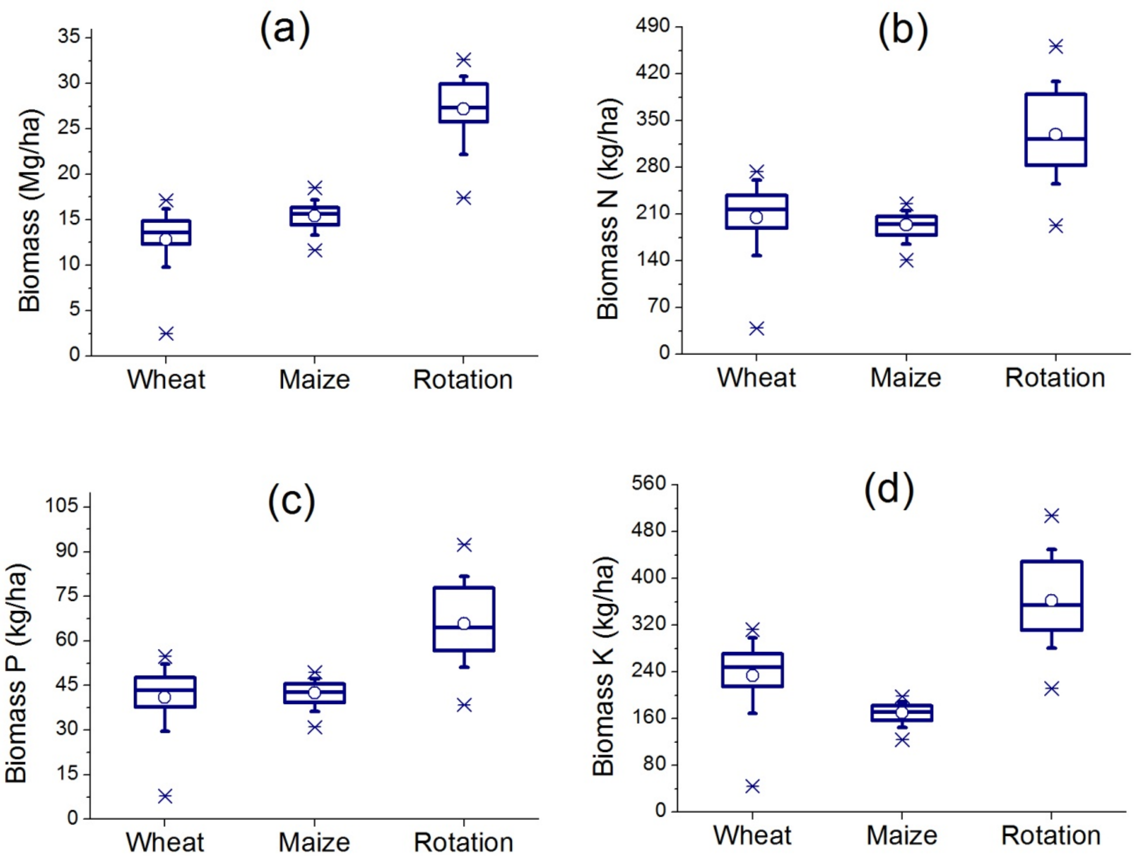

Figure 12. Predicted crop biomass (a), crop uptake of (b) Nitrogen (N), (c) Phosphorus (P) and (d) potassium (K) for wheat and maize when 306 mm of wastewater was applied each year or a rotation (wheat and maize) when the wastewater application was set at 306 mm per year. The N, P and K loading are 612, 144 and 1071 kg ha^{-1} $year^{-1}$.

Chloride balance

Figure 14 presents the simulated annual chloride balance. Annual addition of chloride was 767 kg/ha, calculated from 153 mm of wastewater applied at a chloride concentration of 501 mg/l. The amount of chloride leached increased in the first ten years of irrigation. The long-term (53 years) average of chloride leaching per year was equal to the annual addition of 767 kg/ha, regardless of the plant systems used. This would appear to be because very little of the added chloride is taken up by the crops.

The effect of applying wastewater of 25 to 153 mm on chloride leaching (averaged for all pasture and cropping systems) is shown in Figure 13. In these simulations, no fresh water was added. In general, for all irrigation applications, the amount of chloride added to the soil is leached. Increasing the irrigation amount increased the amount of chloride added and the amount leached beyond the root zone.

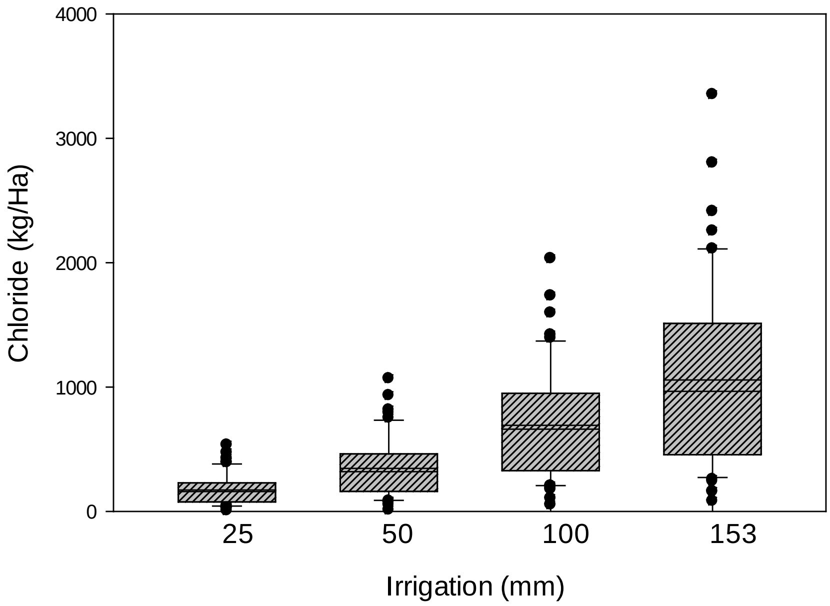

Figure 13. Predicted Chloride (Cl; kg/ha) leaching for the different pasture or crop options from 1961 to 2012.

Chloride leaching also showed significant inter-annual variability that was consistent with the variability in drainage (Figure 15). The temporal pattern shows that during dry years the flux of water beyond the root zone was low, as was the flux of chloride. In subsequent years, the chloride that had accumulated in the soil profile was leached when wetter conditions returned. Although not shown, when extra irrigation with fresh water was applied, the salt applied as part of the wastewater irrigation (traced by the chloride) was leached within the year when it was applied ($P<0.1$). The simulations demonstrate that there is adequate leaching at the site and salt does not accumulate in the soil profile. This is consistent with the soil data shown in Figure 3 and Figure 4.

The long-term sustainability of an irrigation area is underpinned by leaching. If leaching did not occur, the soils would become too saline for plant growth.

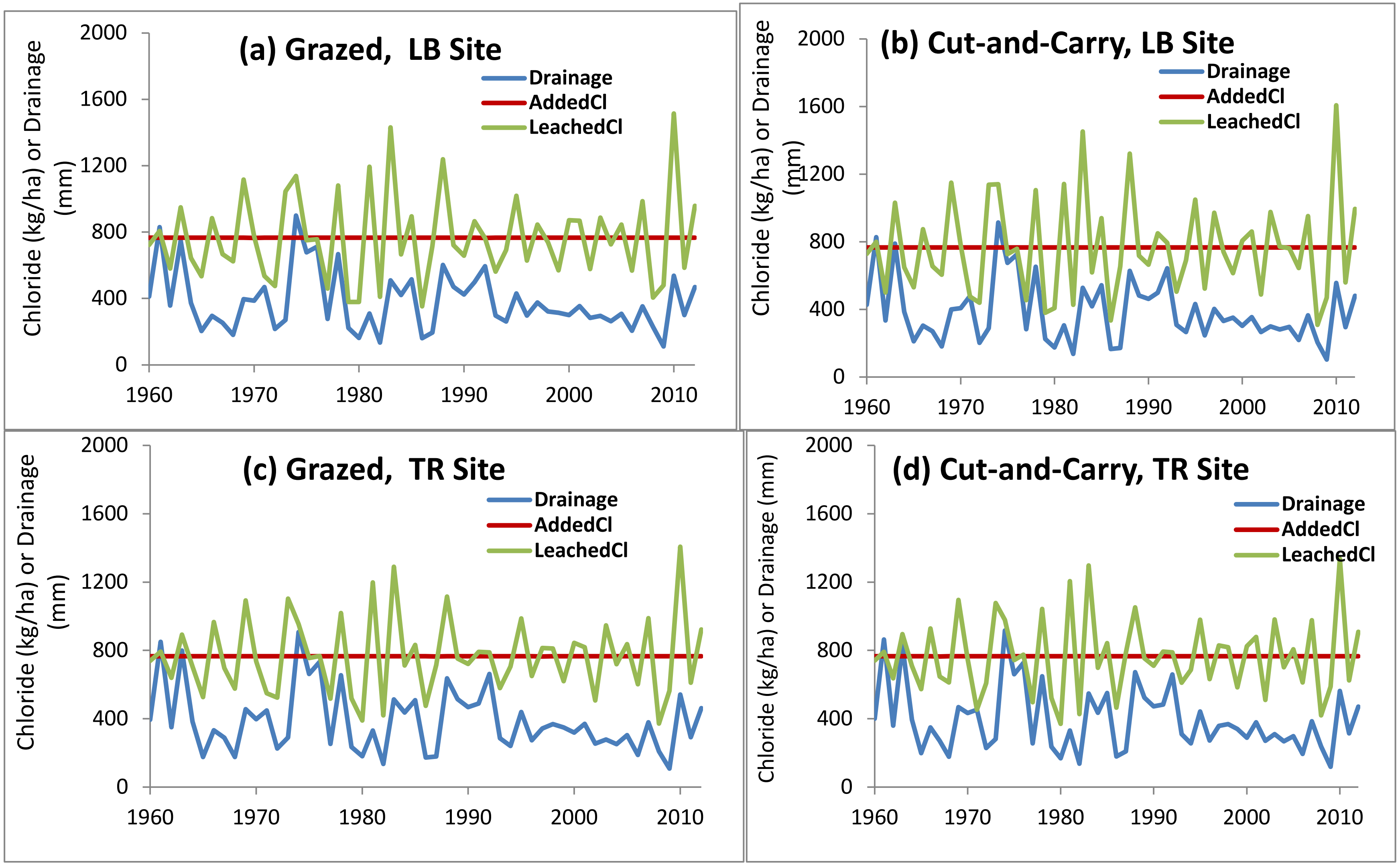

Figure 14. Predicted chloride balance for the irrigated pasture at two sites (LB – Lower Brogo and TR - Towamba River) and with two management systems (Grazed or Cut-and-Carry) from 1960 to 2012.

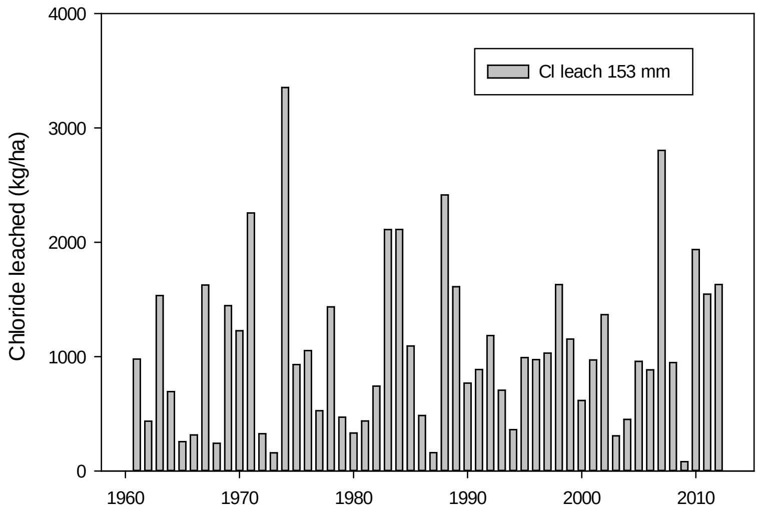

Figure 15. Predicted temporal pattern of Chloride leaching for production system irrigated with 153 mm of wastewater.

Monovalent salts (sodium and potassium)

The current wastewater irrigation strategy at Bega applied 511 kg/ha of sodium and 535 kg/ha of potassium each year. The concentrations of sodium and potassium were 334 and 350 mg/l, respectively (Table 1). Because little sodium salt is exported, the salt must be managed by leaching to prevent salt accumulation in the soil profile.

Bega Cheese is making changes to the factory over the coming years that are expected to change the chemistry of the wastewater (*Per. Com.* Bega Cheese). In particular, the new concentration of potassium is estimated to increase to around 600 mg/l.

If this wastewater were applied at a reduced amount of 50 mm over 1000 ha, the loading of potassium would be 300 kg/ha. Under this scenario where only 50 mm of wastewater is applied, the average potassium removal in the crops is about 120 kg/ha each year (range 100 -134), whereas removal in the pasture could be as high as 320 kg/ha each year from a **Cut-and-Carry** pasture management system. When extra freshwater is applied, there is only a slight increase in potassium removal. In the above reduced application scenario, the potassium in the wastewater is balanced by export through a **Cut-and-Carry** system, provided the biomass is not added back to the site in animal feed. In contrast, for the cropping system, inputs are greater than the potassium that can be exported from the site.

Studies reported in the literature have focused on the impact of exchangeable sodium on soil water salinity[5]. The effect of potassium on soil hydraulic properties has not traditionally been given much consideration. This is mainly because sodium concentrations in salt-affected soils and groundwaters are usually much higher than those of potassium, but there are also historic scientific reasons. In Australia, we have been heavily influenced by salinity research in the US[6] where most of the wastewater irrigation guidelines focus on sodium.

Caution is needed in wastewater reuse, as there is a trend to replace sodium with potassium salts, which may not be helping salinity mitigation. There is emerging research showing that both sodium and potassium should be considered when evaluating the impact of monovalent salts on soil.

[5] The following literature cover this area in detail: Quirk and Schofield, 1955; Bresler *et al*., 1982; Shainberg and Shalhevet, 1984; Sumner, 1993; Sumner and Naidu, 1998; Oster and Jayawardane, 1998; Levy, 2012).

[6] Handbook 60 (U.S. Salinity Laboratory Staff, 1954) concluded 60 years ago: "exchangeable K has only a slight or no adverse effect upon the physical properties of soils … (Fig. 1)". The figure displays the ratio of air permeability to water permeability as a function of exchangeable sodium percentage (ESP) and exchangeable potassium percentage (EPP). This ratio increases exponentially with ESP, whereas for EPP there is no increase observed for three of the seven soils examined, while the increase is small for the other four.

Using the concentrations of sodium and potassium from Table 1 (Na 334 mg/l; K 350 mg/l) and expressing potassium as the equivalent monovalent sodium using the equations below, the concentration becomes 450 mg/l. This is equivalent to a sodium load of 690 kg/ha each year when 153 mm of wastewater is applied.

The impact of sodium and potassium on soil water salinity can be determined as follows:

$$\text{CROSS} = (\text{Na} + a\ \text{K})/[(\text{Ca} + b\ \text{Mg})/2]^{0.5}$$

$$= \text{SAR}^* + a\ \text{PAR}^*$$

If the parameters for the coefficients are based on the relative dispersion potential of potassium (K) relative to sodium (Na), and the relative flocculation potential of magnesium (Mg) relative to calcium (Ca), the resulting equation is (Reneggasamy and Marchuk, 2011):

$$\text{CROSS}_f = (\text{Na} + 0.56\ \text{K})/[(\text{Ca} + 0.60\ \text{Mg})/2]^{0.5}$$

Smith, Oster and Sposito (2014) further developed this work and derived the optimised equation:

$$\text{CROSSopt} = \text{SAR}^* + 0.335\ (\pm\ 0.038)\ \text{PAR}^*$$

These equations represent the effect of K on clay dispersion is about one-third to about one-half of that of Na depending on whether one chooses to select the optimised coefficients or those proposed by Rengasamy and Marchuk (2011).

4. Technology Options

Current wastewater treatment process

Bega's current wastewater treatment process is summarised in Figure 16. Bega screens wastewater from the plant with final BOD levels of 1,500-3,000 mg/L. There is no further treatment to reduce BOD and odour was identified as an issue. The greatest contributor to BOD levels is cream followed by whey then butter. Gypsum is also applied to help manage the impact of sodium on soil dispersion. Energy production was explored, but not viewed as high priority as it has not been seen to be core business.

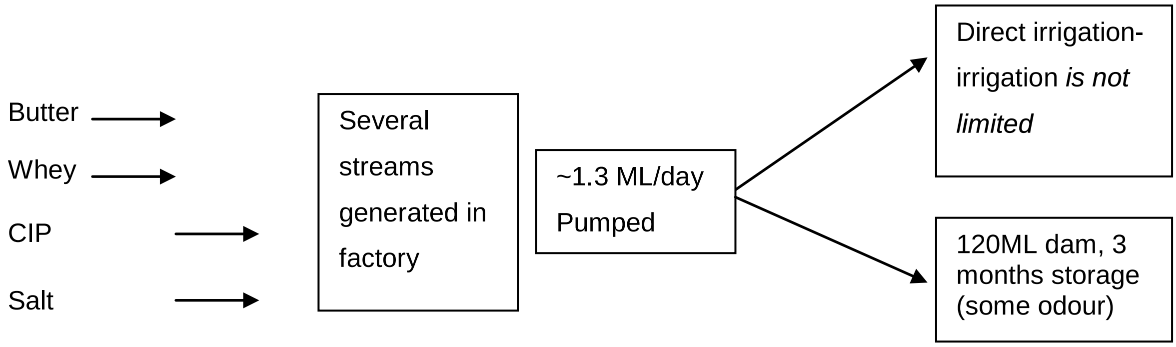

Figure 16. Summary of the current wastewater treatment plant at Bega.

The APSIM model highlights the fact that chloride and other salts contained in the wastewaters, which are not taken up by pasture plants, are leached from the soil profile. Phosphorus is also retained in the soil profile – at around 10 to 30 kg net loading per hectare each year – which would give the soil profile an estimated irrigation life from 23 to 70 years. Reducing the salt and phosphorus application rate will increase the longevity of the site. Current wastewater treatment processes at Bega are not sufficient to address the long term Na and P concerns. Odours associated with wastewater storage over greater periods of time have also been identified as an issue not addressed by the current wastewater treatment plant.

As part of this case study, the project team has proposed three technology options for low, medium and high cost approaches to further encourage water recycling, as shown in Figure 17. It is important to note that each of these options will have to be evaluated against the required regulatory framework and value proposition tool as demonstrated using real data from Bega before any final decision can be made. An understanding of the views and future plans of surrounding farms would also increase the chance of successful investment into treatment technologies.

Low cost option

The main focus of this water treatment option is the removal of phosphorus from the factory effluent. The phosphorus removal process proposed incorporates technology developed at CSIRO to sustainably capture phosphate by reacting soluble phosphate in the effluent with calcium salts. The product from this reaction is calcium phosphate which will settle and be removed as sludge for beneficial use as a fertiliser. Current trials on dairy effluent elsewhere in the project suggest that this material is comprised of 54-68% hydroxylapatite ($Ca_5(PO_4)_3OH$) and 32-46% calcium carbonate, with a Ca: P ratio of approximately 3:1. The method proposed for Bega will be slightly different to current trials as sodium carbonate will not be required for removal of residual calcium. The operational cost for P recovery with this method is anticipated to be $16 ± 5 /kg P recovered. Depending on the final dilution factor as well as sodium this may not be problematic. As this method does not remove sodium but adds calcium, it is expected that the SAR will improve as given in the following equation: $SAR = [Na]/([Ca]+[Mg])^{1/2}$. Dilution to manage sodium and potassium will then be required to tailor water quality to the final crop application.

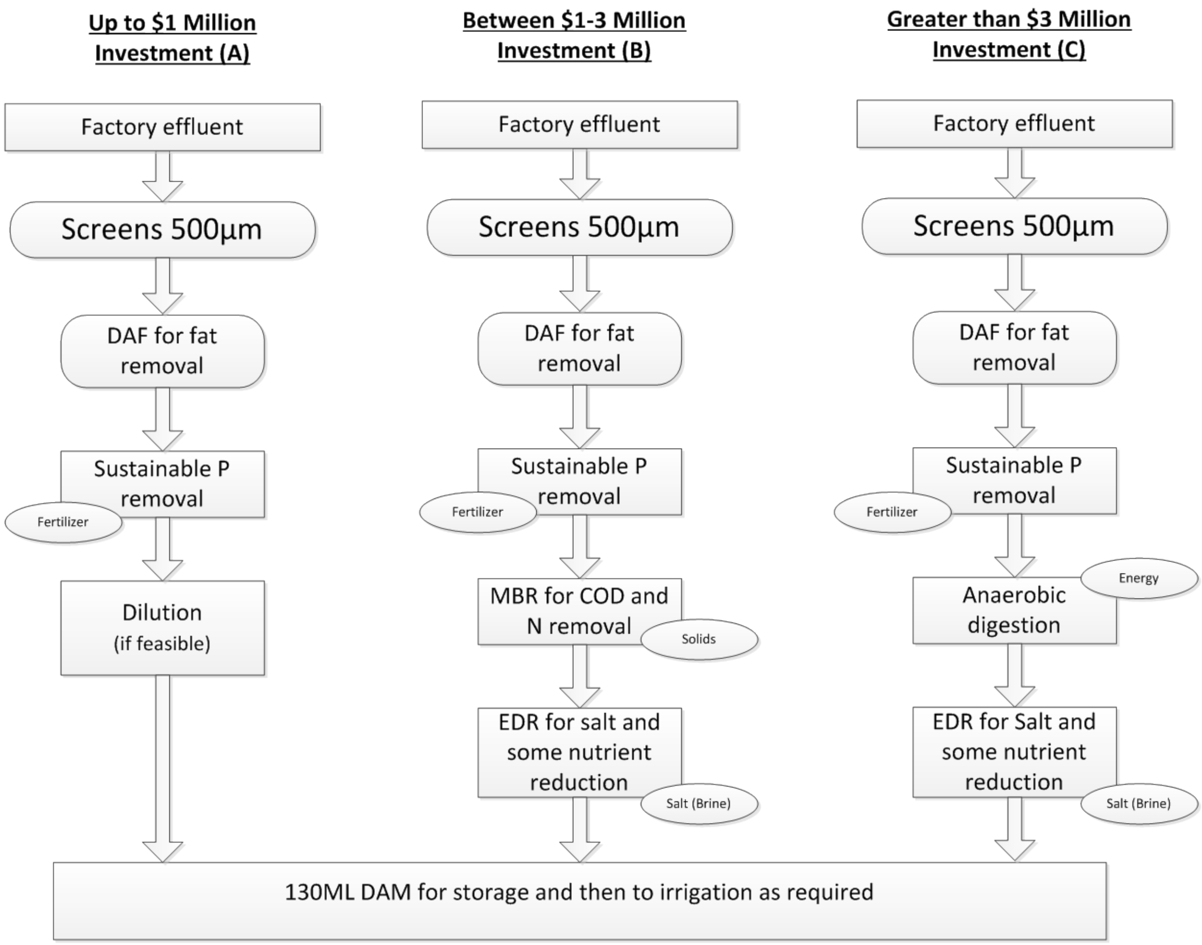

Figure 17. Technology options for a more sustainable wastewater recycling practice at Bega.

Medium cost option

In addition to P removal, the mid-cost technology option proposes to remove COD and nitrogen by treating the effluent in a membrane bioreactor (MBR). As a well being a proven biological process, MBRs have been reliably used to remove carbon and nitrogen from a variety of industrial and municipal effluents. MBRs produce a high quality effluent via aerobic digestion and microfiltration processes. A biosolids waste stream is also produced which will require disposal or reuse; possible reuse opportunities include incorporation of this material into organic mulch. After this treatment stage, the effluent will pass through an electrodialysis process (EDR) to remove monovalent ions, namely Na^+, Cl^- and K^+. By using monovalent selective membranes, beneficial ions such as Ca, Mg, PO_4 etc will be retained in the effluent for irrigation. The operating cost of EDR is around 15-20 c/kL. Blending would not be required under this scenario as EDR will lower salts to a level suitable for irrigation. A waste brine or retentate stream will also be generated which may be disposed of or recycled (at a cost) depending on requirements. As part of the meat sector work, CSIRO has developed a fact sheet which outlines potential reuse options.

High cost option

The difference between the mid- and high-cost options is the inclusion of an anaerobic MBR that would allow significant reduction in COD and allow an option for energy recovery. While anaerobic MBR is a proven technology, the associated infrastructure for biogas handling and capture increase the cost. Energy recovery for in-house electricity or heat production will help offset some of these additional costs, and there may be options to co-digest manure-rich feeds from surrounding farms. Typical payback periods for energy recovery processes are several years. Typically, COD levels warranting investment in anaerobic digestion would exceed 5000-10000 mg/L.

5. Demonstration of the Value Proposition Tool

The following document provides a mock example to demonstrate the use of the value proposition tool. The following scenarios are not intended to reflect practice at Bega Cheese and do not provide recommendations for investment options. The demonstration illustrates the type of analysis that the tool is capable of and may provide a starting point for analysis of actual options.

Option 1. Dilution to reduce effluent concentration for irrigation

This option assumed no additional treatment and assumed that the effluent would be diluted and used for irrigation. Table 3 provides a summary of the assumed data for the purpose of the demonstration. The actual volume of water for dilution will depend upon factors such as the annual rainfall. The type of cropping system may also require addition nutrients.

Table 3. Summary of Assumed Data for Option 1.

Variable	Value	Comment
Interest rate	12%	
Period of analysis	10 years	
Volume of effluent for irrigation	922 ML/year	This includes an effluent volume of 461 ML and an additional 461 ML for dilution. The unit cost of water was assumed to be $2.50/kL. The annual amount of water required will vary depending upon rainfall.
Areas of land for irrigation	460 Hectares	The land is assumed to be leased at a cost of $400-800 per hectare per year.

Option 2. Treatment to reduce effluent nutrients and salt concentration for irrigation

This option (Table 4) assumes that effluent will be treated to a level that does not require dilution. This introduces a capital and operating cost for equipment but reduces the costs for water for dilution as well as the area needed for irrigation. Additional costs may also include sludge disposal but have not been included in this analysis.

Table 4. Summary of Assumed Data for Option 2.

Variable	Value	Comment
Interest rate	12%	
Period of analysis	10 years	
Volume of effluent for irrigation	461 ML/year	
Capital cost	$2-3 million	
Operating	$100 000-150 000	Assumed to be 5% of capital
Areas of land for irrigation	230 Hectares	The land is assumed to be leased at a cost of $400-800 per hectare per year.

Analysis

Option 1 results in a Present Value (PV) cost of about $10 million over the period of analysis. Most of the cost was due to the water required for the assumed dilution of the wastewater. The annual operating costs were about $1.4 million per year and the assumed water for dilution accounted for about $1.15 million per year. This analysis is a reflection of the assumed unit rates and dilution required. However, it highlights that the analysis can bring to light technical factors that need further attention. The 95% confidence interval was $9.9-10.3 million. The small range for the confidence interval reflects that the combined uncertainty did not consider uncertainty in the price for water. This, along with the amount of water for dilution, is a factor that needs to be explored in a sensitivity analysis.

Figure 18 illustrates the results for Option 2. The 'most likely' cost for the system for the assumed data was a Present Value of about $4.4 million over the period of analysis. This includes a capital cost of about $2.5 million and operating costs of about $1.9 million. The 95% confidence interval for the PV is from about $3.8-4.9 million. The confidence interval for the PV is a reflection of the uncertainty in the data. For example, based only on the assumed uncertainty in the data, it appears that option 2 is significantly less costly than option 1 (ie. there is no overlap in their confidence intervals).

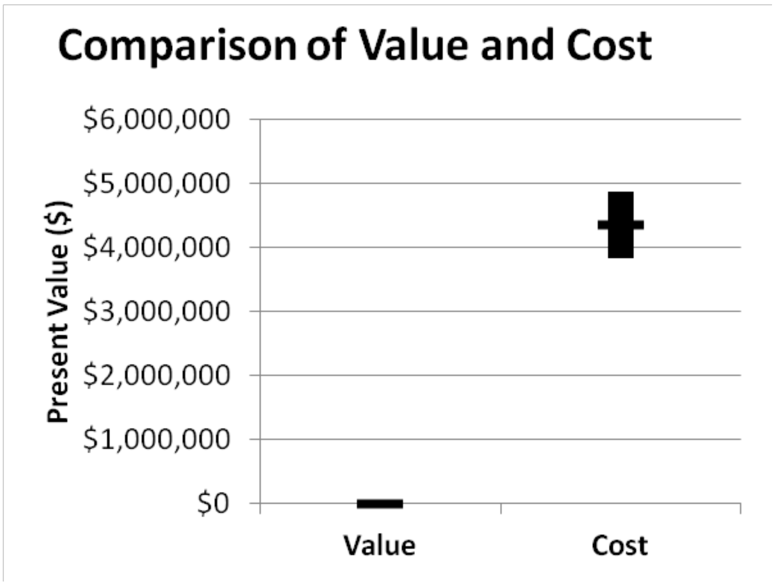

Figure 18. Summary of Present Value for Option 2.

6. Regulatory Framework

Bega Cheese is investigating the potential to recycle wastewater produced within their plant with an aim to improve water sustainability and reduce their water use footprint. There are a range of reuse options potentially available for Bega, however, at this point in time, the company has elected to continue to investigate the potential of using their wastewater for irrigation purposes. This assessment predominantly uses the relevant recycling guidelines and the associated treatment requirements for wastewater to be utilised for irrigation purposes. The assessment also provides some information on possible alternative reuse options for the Bega wastewater should irrigation not be required or if it is decided to utilise the wastewater for other non-potable, or indeed potable, purposes.

The ability to recycle wastewater produced by the dairy industry, either externally for irrigation of green spaces, or within the factory is reliant on following appropriate guidelines and meeting a number of treatment and control requirements. One of the most important of these requirements is the protection of human health and the environment achieved through the use of a risk management approach being the optimal way to address any potential issues. This can be facilitated through a system such as an appropriate Hazard Analysis and Critical Control Point system (HACCP).

This assessment specifies the guidelines that need to be considered in order for the wastewater produced within the Bega Cheese factory to be effectively utilised for the desired irrigation purposes. The Australian Guidelines for Water Recycling (AGWR) provide a reference for the supply, use and regulation of recycled water programs, offering guidance on safely and sustainably recycling water from sources such as effluent and greywater, which would otherwise be wasted (NRMMC, EPHC, AHMC, 2006). The other major source is the NSW Department of Environment and Conservation (DEC) -incorporating the EPA - Environmental Guidelines for the Use of Effluent by Irrigation which also provides information which can be applied during the design and implementation of effluent irrigation systems, and which may also be of great value when meeting any specified environmental requirements (DEC, 2004). Each of these guidelines is a useful tool in their own right, but should not to be considered to be regulatory or mandatory tools.

With regards to uses other than for irrigation purposes, there is a national regulatory framework that incorporates federal and state regulatory agencies, dairy farmers, dairy companies and Dairy Australia. However, there is still a distinct lack of clarity surrounding the content of these regulations with very general descriptions such as ‘fit for purpose’ describing the proper use of water. Greater clarity and specificity in the regulations is necessary in order to make them easier to interpret and implement to assist the uptake of recycled water in the dairy processing factories. There are also additional restrictions on the use of recycled water if products are to be exported internationally.

Guidelines

For this study, as the current preferred method for the recycling of Bega Cheese’s wastewater is the irrigation of pastures, the most relevant guidelines for this assessment are found within Phase 1 of the AGWR (NRMMC, EPHC, AHMC, 2006) and the NSW EPA Environmental Guidelines for the Use of Effluent by Irrigation (DEC, 2004), which were consulted for information relevant to water reuse and recycling within the dairy industry. As no recycling is planned within the Bega Cheese plant, the food regulations and standards such as those produced by Food Standards Australia are not relevant for this assessment. Also, as there is no possibility for the recycled water to contact food materials, only the non-potable uses within the AGWR (NRMMC, EPHC, AHMC, 2006) and the NSW EPA Environmental Guidelines for the Use of Effluent by Irrigation (DEC, 2004) were used as a source of guidance for this assessment. The assessment was then divided into regulations pertaining to health and to the environment, as well as examining the implications of recycling the water externally for dairy farm irrigation. Additional information on regulations specific to the recycling and reuse of wastewater within the dairy itself are also briefly discussed. For example, recycled water has been utilised by the Shoalhaven Council REMS project for both dairy pasture irrigation and dairy wash down since 2002 under these guidelines (Shoalhaven City Council 2014). If using recycled water is considered for uses such as a cooling make up or as a boiler feed source, it is recommended that reference to the relevant standards such as the Australian Standards for Cooling Towers.

States and Territories have the discretion to enforce adherence to water recycling legally binding Acts, and whilst they do not represent mandatory standards, Phase 1 of the Australian Guidelines for Water Recycling are intended to be an authoritative reference providing guidance on how best to support sustainable and beneficial recycling of wastewater sources. , . Their primary focus is of the advantages of recycling water that would have traditionally been wasted, into a usable product. This product can then be provided as an additional water source for a variety of purposes, such as irrigation, thereby reducing the pressure on Australia's limited freshwater resources that would ordinarily be used for such purposes. While they do not deal specifically with industrial wastewaters, it is indicated that the general approach of the guidelines can indeed be applied to such wastewater sources (NRMMC, EPHC, AHMC, 2006).

A key aspect of these guidelines is that they utilise a risk management framework in order to identify and deal with risks in a proactive way, rather than relying on post-treatment testing and subsequently responding if and when issues arise. This risk management approach enables interested parties to implement the concept of identifying and producing recycled water of a quality that is 'fit for purpose' – the water must be of a quality that is acceptable for the purpose it is intended. In addition to this concept, the guidelines offer more flexibility in that they do not include a recycled water classification system. This again allows the quality of the recycled water produced to vary, depending on the intended end use. For example, the risk management system will determine the pathogen removal requirements of a recycled water source depending on whether it will be used for irrigation of food products such as salad crops or for irrigation of green spaces and pasture (NRMMC, EPHC, AHMC, 2006).

As with the AGWR, the NSW EPA Environmental Guidelines for the Use of Effluent by Irrigation (DEC, 2004) are an informative, educational and advisory tool and are not mandatory or regulatory. They have resulted from lengthy and detailed discussion with industry and government, and incorporate relevant national guidelines, principles and potential statutory requirements. As a result of this consultation, the NSW EPA Environmental Guidelines for the Use of Effluent by Irrigation encompass the broad framework, principles and objectives that require attention when implementing an effluent irrigation system (DEC, 2004). However, guidelines and information specific to each industry and site should be read in conjunction with these guidelines, and may require consultation prior to their application, as suggested within the guidelines themselves. Essentially, the guidelines provide information which can be applied during the design and implementation of effluent irrigation systems, and which may also be of great value when meeting any specified environmental requirements. In effect, the Environmental Guidelines for the Use of Effluent by Irrigation aim to support all parties involved in the implementation of effluent irrigation systems in order to attain the best environmental result for each individual site at minimal cost.

Overall, specifics within the two sets of guidelines relating to the level of treatment required when recycling dairy factory wastewater for effluent irrigation systems are unclear. It is anticipated that treatment types and levels will vary according to the contaminants required to be removed and the soil profiles and other site characteristics of the proposed irrigation sites. As expected, the sources of the wastewater will dictate what the potential contaminants will be: for example, bottle wash water and whey produced during the processing of dairy products would be anticipated to be reasonably free of microbial contaminants. The risks from exposure to the raw wastewater would be minimal as the pasteurisation and other dairy food production processes would result in the expected absence of microbial pathogens. Instead, the main focus should be on the removal of unwanted contaminants such as salt, cations, anions, phosphorous, nitrogen and the Chemical Oxygen Demand (COD). As well as determining the risk from microorganisms, the recycled water may also contain other contaminants such as cleaning chemicals used for cleaning equipment etc that can be present in the wastewater and would need to be removed prior to any potable reuse.

Statutory requirements

As stated in the national guidelines, an effluent irrigation system must *'comply with the requirements of the Environment Protection Authority (EPA), Department of Energy, Utilities and Sustainability (for local government sewerage effluent reuse schemes) or local council, and other relevant authorities in the planning and designing stages'* (Sections 6; Appendix 5) (NRMMC, EPHC, AHMC, 2006). The NSW Environmental Guidelines for the Use of Effluent by Irrigation also state that there are a number of statutory requirements, approvals and obligations that may be required to be met prior to the implementation of effluent irrigation (DEC, 2004). These include, but are not limited to: sewerage schemes managed by the local government and the protection of drinking water supplies, as set out in the Local Government Act 1993; the National Parks and Wildlife Act 1974 for any activities within national parks; the Threatened Species Conservation Act 1995 for activities which may impact on threatened species, populations or ecological communities; NSW Water Industry Competition Act 2006 (WICA); and the Water Industry Competition Amendment (Review) Bill 2014.

The specific statutory requirements relevant for dairy effluent irrigation sites, such as the one assessed here for Bega Cheese, will depend on a multitude of factors such as location, ecological reports, soil profile and potential risks to both the environment and public health. As such, all requirements should be considered on a case-by-case basis, and the relevant regulatory agencies should be consulted as early as possible in order to clarify requirements in the planning and design stages, and most definitely prior to the implementation of an effluent irrigation system.

Proposed options for utilising wastewater for irrigation

Bega Cheese currently supplies local farmers with wastewater from their dairy processing factory, to be used for irrigation purposes. This system benefits both Bega Cheese and the farmers in a number of ways. Primarily, Bega Cheese has assisted the farmers in securing access to water for irrigation, and in turn, the farmers have aided Bega Cheese by providing a functional and productive way to manage their wastewater. The nutrients contained within the treated wastewater may also be considered of value as fertilisers and soil conditioners, thereby potentially reducing the need for the addition of fertilisers where recycled water is applied. While this has the benefit of reducing expenses associated with waste discharge licence, there are still environmental impacts associated with this use of wastewater which need to be assessed and potentially addressed. Heaven *et al* (2012) found that the application of wastewater from dairy factories can be relatively benign to the receiving farms, green spaces, parkland and gardens, and any associated downstream environments. However, it was noted that an understanding of the potential sources of contaminants and their possible impacts on irrigation sites and associated environments is important.

The provision of wastewater of suitable quality to external parties has great potential, though it is important that Bega Cheese ensures that the quality of the water provided fits within any environmental constraints to ensure that there are no adverse environmental impacts. As specified in introduction of this section, the AGWR and the NSW EPA Environmental Guidelines for the Use of Effluent by Irrigation are the most appropriate starting points for any environmental assessment around the reuse of the Bega Cheese wastewater (NRMMC, EPHC, AHMC, 2006; DEC, 2004). In both sets of guidelines, the use of recycled water externally for purposes such as for irrigation requires the water to be of a quality deemed 'fit for purpose' that will not cause an adverse impact on the receiving environment. The environmental issues of greatest interest are the presence and concentration of various nutrients such as sodium, phosphorous and nitrogen, and other factors including salinity and Biological Oxygen Demand (BOD).

Comparison of water quality issues for Bega Cheese

Salinity

Salinity levels of the raw wastewater of Bega Cheese were assessed using the information supplied from the measurement of the salinity of the soil at 0 cm depth, the point of application of the raw wastewater to the irrigation site, as no information on the salinity (as TDS or EC units) of the actual wastewater were provided. The surrogate of salinity at the soil surface was found to be in the region of 60 - 220 µS/cm (EC). This value is well within the critical limits of 700 µS/cm set up by the AGWR section on reuse for irrigation purposes (NRMMC, EPHC, AHMC, 2006). If this was the only measure of salinity, it would indicate that no further treatment of the wastewater would be required in order for an acceptable use for irrigation purposes. Annual soil sampling undertaken by Bega Cheese, however, indicates that there has been an increase in soil salinity in profile at the sites irrigated with their wastewater, while the control sites showed no increase in salinity (Figure 3 in Section 2 of this report). This indicates that the potential accumulation of salt in the soil profile can be a concern. This demonstrates that assessments of proposed recycling of wastewater should not only consider the recommended electrical conductivity limits set in guidelines, but also must consider issues such as loading rates and soil type in an overall environmental assessment. A failure to do so could have a serious negative long-term impact on pastures receiving wastewater as an irrigation source.

As demonstrated by the APSIM assessment in Section 2, there has been an accumulation and possible leaching of salt through the soil profile with limited knowledge of the fate of this salt. This means that it is likely that a reduction in salinity levels in the Bega wastewater would need to be monitored and appropriate action is likely to be necessary to be taken to remove or dilute the salt content of the Bega wastewater prior to use to meet local environmental standards.

Sodium

Sodium can also have an impact on some soil types (particularly in soils high in clay) and cause sodicity issues. This is especially important when sodium levels are high relative to calcium and magnesium levels. Sodium levels in the raw Bega wastewater were found to be on average 334 mg/L, which is considered a high value in relation of the guidelines and further removal or dilution of the wastewater would be necessary to render it useful for irrigation purposes. This is a potentially significant environmental issue that may need to be investigated further to cover requirements within environmental regulations approval. This would need to be part of any discussions with potential third party users of the wastewater and a potential consideration regarding appropriate uses or site assessment of sodium impacts on the soil.

Nitrogen and Phosphorous

Nitrogen and phosphorous in wastewater have the potential of being useful as a fertiliser source. The AGWR do consider the use of these nutrients in the wastewater in place of, or in combination with, the use of commercial fertilisers. The amount of substitution will depend on the type of plants receiving the recycled water, the concentration of the nutrients in the water, and the amount of water required for different crop types (NRMMC, EPHC, AHMC, 2006).

Nitrogen concentrations in the Bega wastewater average approximately 200 mg/L. This is a high level as average concentrations in recycled water are generally found to be around 12 mg/L, occasionally as high as 50 mg/L (based on the assessment of wastewater sources such as human effluent). The outcomes of the APSIM modeling in Section 2 above have also indicated that there is high potential for leaching of nitrogen past the root zone of the pastures. Based on the recommended nitrogen concentrations in the guidelines and the outcomes from the APSIM modeling, as the nitrogen concentrations in the Bega Cheese wastewater are much higher, the wastewater will need to be treated to reduce nitrogen concentrations to avoid polluting the environment through excess application of nitrogen.

Similarly to nitrogen, the total phosphorous concentrations in the Bega wastewater average 47 mg/L, which again is high when compared to the range of 5-10 mg/L specified in the AGWR (NRMMC, EPHC, AHMC, 2006). Like with the issue for nitrogen, there is a high risk of overloading the soils from the Bega wastewater and the reduction of phosphate will be likely to be necessary through treatment. Treatment may only be needed to achieve a phosphorous concentration that mean that farmers receiving the recycled water product would have no need to add additional phosphorous fertiliser to their irrigated land and pastures but the chance of environmental pollution through leaching or run off of excess phosphorous is prevented.

Although the AGWR and the NSW EPA Environmental Guidelines for the Use of Effluent by Irrigation each provide information regarding acceptable levels of nutrients found within recycled water, they also note that site and soil profiles will clarify the specific levels that are acceptable for each nutrient in question (DEC, 2004). While the AGWR focus on the levels of nutrients that are deemed acceptable in recycled water irrigation applications, the Environmental Guidelines for the Use of Effluent by Irrigation also refer to nutrient loading as a factor. The Environmental Guidelines for the Use of Effluent by Irrigation state in Section 4.3 that *‘under most conditions, the rate of nutrient application would need to be predicted using a nutrient balance before any scheme commences’* (DEC, 2004).

A qualitative measure of consequence or impact (using Table 4.4 page 133 of the AGWR) suggests that the current raw Bega Cheese wastewater quality should have minor to moderate environmental impact, depending on the soil profile of the irrigation sites, with continued monitoring a requirement. If the treatment options suggested by the CSIRO assessment are also taken into consideration, then any further removal of nutrients achieved through enhanced treatment will reduce any potential impacts even further. The outcomes of the APSIM modelling indicate that there is excessive nutrient loading of some of the nutrients investigated. These results demonstrate that the guidelines are a useful starting point for a general assessment of water recycling potential, issues such as loading rates and impacts on local soil conditions needed to be assessed at a local scale.

Another point for consideration is that, while the studied potential treatment options will reduce the nutrient concentrations, it is likely that salinity concentrations will remain virtually unchanged. If there is a need to further reduce the salinity, a higher level of treatment such as nanofiltration or Reverse Osmosis (RO) would need to be considered. Similarly, there also remains a need to assess if any more sodium issues exist outside of the general salinity issues (in particular soil sodicity issues). This strongly depends on where the water is used and the soil profile at that location. Again, more detailed investigations of receiving sites would be required to determine if any additional treatment of the wastewater would be required prior to use for irrigation.

An assumption has also been made that there are no toxic chemicals (organics, boron or copper) as the wastewater has generally come from processing food components. The potential exceptions to this are cleaning agents added to the recycled water through cleaning activities in the plant - these may contain chemicals that may impact the growth or health of plants irrigated with the wastewater. If it was determined that such chemicals were present, then treatment methods would need to be assessed for their ability to remove these problem chemicals.

Potential alternative non-potable uses for the Bega Cheese recycled water

While Bega Cheese has plans to continue to recycle its wastewater as an irrigation source, a small assessment was also undertaken to investigate what would be required should there be an identified need to utilise the wastewater for other purposes within the Cheese manufacturing processes to reduce Bega Cheese's water footprint. Such needs could include an increase in the cost of supply of a potable water source, a lack of sufficient water supply due to drought or other external forces, or insufficient water supply to enable expansion of the processing plant.

The potential alternative options for use of recycled water within dairy factories are varied, as are the requirements for differing levels of water quality depending on the end use. A number of these options may involve direct contact with food, such as uses in the processing of milk and dairy products, or for the washing of equipment and surfaces where there is the potential for contact with food products. In these instances recycled water of potable quality is required according to the Food Standards provided by Food Standards Australia (FSANZ Food Safety Standards Australia New Zealand). The quality of this water must be closely managed using a HACCP plan to ensure it does not have the potential to contaminate milk.

For use within the plant where there is no potential contact with food products (e.g. for use in plate coolers, cooling towers, heating) the water must be of a standard that is deemed 'fit for purpose', as dictated by the Food Standards. This means that the water does not necessarily need to be of potable quality, but must be of a quality sufficient to not cause any health, environmental or process risks. This level of quality can vary, depending on the use, the potential for contaminants in the water, and the potential for contact with people and environments that may be at risk.

The use of recycled water externally but still within the dairy itself, such as for yard washing and irrigation, requires water quality of a level deemed 'fit for purpose' as determined by the Food Standards and the AGWR. For example, yards and sheds can be washed using plate cooler water diverted into wash down or storage tanks with minimal treatment. Similarly, pre-cooler water can be reused for both washing and irrigation, warm water from the plate cooler and final machine rinse can be reused and/or recycled and final rinse water can be reused for the first rinse of the wash after the next milking. Additionally, yard wash water can be recycled and reused many times, for both yard washing and irrigation, with the use of suitable storage and any appropriate treatment to remove gross pollutants.

Risks to be considered

Key risks to be considered with regards to recycling water within the dairy factory are primarily potential health issues relating to non-potable recycled water, and the presence, type and number of microbial pathogens. Another issue requiring consideration is the potential for community members to be exposed to any pathogens that may be present in the recycled water. The AGWR, and therefore State regulations, provide considerable information on controlling pathogens in recycled water and reducing exposure.

However, given the nature of the dairy factory, it is assumed that the risk of contamination by human pathogens can be considered minimal (assuming usual hygiene practices are maintained around the water treatment processes). Additionally, pasteurisation and food production processes will ensure that the wastewater produced during dairy processing is free of pathogens. There is, however, the potential for contamination by spoilage microbes due to the generally non-sterile fittings used in the construction of the plants. An additional concern may be of the presence of cleaning chemicals used within the dairy, and what potential effects the reuse/recycling process will have on their concentration.

Additionally, any applications that are for purposes that can create a spray drift (eg, cooling towers), have the potential to pose risks from *Legionella* to the plant workers and closely neighbouring communities around the factory if the water is not treated to a sufficient quality for these purposes. Therefore there is a need to control the BOD and nutrients to ensure that there is limited potential for growth of *Legionella* in these systems.

For any off-site recycling options, the people most at risk would depend on the potential for exposure to the recycled water. This would depend strongly on the application method of the water. Potential examples include farm irrigation, green space irrigation (parks and gardens), dust suppression and third pipe use in suburbs and buildings. Similar to the potential issues with internal use, the major health risk for this recycled water would be bacterial pathogens capable of regrowing in the water (predominantly opportunistic pathogens such as *Legionella* and *Aeromonas*). Control of the regrowth issue for opportunistic pathogens would be through the level of treatment of the wastewater prior to the supply of the water to a third party. Additional treatment such as disinfection, particularly if disinfection is through UV, would remove any problem bacteria from the wastewater prior to supply for external recycling. This extra treatment would cover any health regulations pertaining to irrigation of recycled water. The only other issue that would be required to be demonstrated to the health regulators is the length of storage and the potential for the regrowth of nuisance microorganisms during storage. The additional use of chlorination also can be used to prevent regrowth of nuisance microorganisms. Dairy factories should also ensure that third party users of the supplied recycled water are fully aware that they are responsible for ensuring that the location, manner and timing of use of the recycled water are appropriate and fit for purpose.

With regards to chemicals present within the recycled water, it is assumed that any chemicals used within the dairy are cleared for safe usage and covered under the Standards. It is important to note that recycling water may potentially increase concentrations of nutrients, farm chemicals and cleaning chemicals, therefore recycled water quality should be monitored closely to ensure that it is indeed fit for its intended use. Also of importance to note is that detergents designed for use within Australian dairies have not been registered for reuse purposes and consequently it is unclear as to whether they are in fact suitable for reuse applications (http://www.dairyingfortomorrow.com - 'Water in the Dairy' InfoSheet C1).

Summary and Recommendations

An assessment of the current recycling practices of Bega Cheese has determined that the principal guidelines of importance are the sections on non-potable use and environmental considerations in the Australian Guidelines for Water Recycling and the NSW EPA Environmental Guidelines for the Use of Effluent by Irrigation. Consultation with these guidelines suggest that the salinity of the wastewater fits within the guidelines, however the concentration of nitrogen and phosphorous are higher than the recommended limits in the guidelines.

Both sets of guidelines indicate that an assessment to determine the impact of local conditions and soils is important when recycling wastewater for irrigation purposes. A comparison with the outcomes of the APSIM modelling has shown that there are potential impacts from salinity, nitrogen and phosphorous through overloading of the pastures and leaching past the soil root zones with potential environmental impacts.

It is therefore recommended that the wastewater be treated to reduce the nitrogen and phosphorous to concentrations that are of use as a fertiliser source but not to the excess to be an environmental hazard and that the salinity in the water be controlled through treatment or controlled application rates to the pastures.

7. Conclusions

APSIM modelling showed that:

- In Bega the potential evapo-transpiration significantly exceeded rainfall in most months during the year and in most of the years. Irrigation with fresh water is needed to grow pasture or crops to achieve their potential productivity.
- The annual plant water requirement is much higher than the current average wastewater irrigation of 153 mm, determined by the volume of wastewater available from the factory. In all years, it was possible to apply this average wastewater of 153 mm for irrigation. On average, about 650 mm of irrigation (wastewater plus fresh water) is needed to maximise the biomass production (equivalent to 6.5 ML/ha).
- A **Grazed** pasture management system would result in significant leaching of nitrogen (as nitrate-N), but a **Cut-and-Carry** system would significantly reduce the amount of nitrogen leached. More frequent biomass cutting could lead to higher pasture production, greater nitrogen removal and less nitrogen leaching. If the ultimate aim is to maximise milk production and use the plant biomass as feed on site, expansion of cropping land areas may be needed to achieve sustainable nutrient cycling. However, chloride and other salts contained in the wastewaters, which are not taken up by pasture plant, are leached from the soil profile.
- Phosphorus is retained in the soil profile – around 10 to 30 kg net loading per hectare each year – which would give the soil profile an estimated irrigation life from 23 to 70 years. Reducing the phosphorus application rate will increase the longevity of the site.

Technology options for treating wastewater to reduce the nutrient and salt loadings:

Three treatment options of varying complexity were identified. These are:

- Screening → fat removal → P removal → Dilution
- Screening → fat removal → P removal → Membrane Bio Reactor(MBR) → Salt removal
- Screening → fat removal → P removal → Anaerobic digestion → Salt removal

Approximate capital costs for these options are estimated to be in the range $1 to $3M.

Value proposition

The usefulness of the value proposition tool was demonstrated for making investment decisions for different scenarios when wastewater is used for irrigation.

Regulatory framework

- A comparison of the Australian Guidelines for Water Recycling and NSW EPA Guidelines with the water quality parameters indicates that the salt concentration in the wastewater fits within the recommended limits but the nitrogen and phosphorous concentrations are higher than the recommended limits.
- A comparison of the guideline assessment of potential environmental impact and the outcomes from the APSIM modelling demonstrate that the guidelines must be used as an initial guide only and that more in depth local investigations determining long term impacts taking into account issues such as loading rates and soil conditions are also important.

8. Recommendations

- The nutrient balance in the current effluent irrigation system at Bega Cheese needs to be improved and different options should be considered to reduce the nutrient load in the soil when wastewater is used for irrigation. Options to consider are:
  - Treating or diluting the effluent to match the loading to crop nutrient demand (200 kg N/ha, 50 kg P/ha)
  - Increasing the area of irrigation (by 40-225% depending on the volume of wastewater used in irrigation)
  - Adoption of suitable pasture / cropping systems.
- As all these options will have cost implications, a value proposition should be developed to choose the best option. The tool developed by the CSIRO team may help Bega Cheese to develop value propositions for different wastewater treatment and irrigation options to assist investment decisions to be made.
- The Australian Guidelines for Water Recycling and NSW EPA Guidelines should be referred to when developing strategies in using the wastewater for irrigation at Bega Cheese.
- The APSIM model predictions for nutrient and salt uptake by crops and their accumulation in the soil should be validated with actual soil data.

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