ENVIRONMENT WAIKATO

Memorandum

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TO S Bannock

FROM N Selvarajah

SUBJECT **Buxton Farm Irrigation - Assessment of Environmental effects**

This memo has been prepared from the information obtained from the following sources:

1. Anchor Hautapu Buxton Farm Wastewater Irrigation Project prepared by Anchor Products, December 1993.
2. Information supplied by H Waters (Anchor Products, Hautapu) on the following dates: 30 March 1994, 6 April 1994 and 6 May 1994.
3. MIRINZ report for DRI on denitrification rates from dairy factory waste applied onto pasture, February 1990.
4. Environment Waikato databases.
5. Other references (see reference section).

WASTE WATER IRRIGATION TO LAND

This memo assesses the reliability of the prediction of the effects of the proposed land disposal of waste water produced from the Anchor Products dairy factory at Hautapu on the soil, ground water and surface water resources adjacent to Buxton farm, and this memo develops environmental indicators and monitoring programmes for the key waste water characteristics.

The keys issues are identified as (a) hydraulic loading (b) nutrient loading (c) sodium build-up (d) soil pH and (e) truck application of waste water.

Hydraulic loading

Objective: *Maintaining a hydraulic loading which does not enhance nutrient leaching, surface ponding and surface runoff.* <u>Average daily volume of effluent:</u>
The volume of waste water applied onto land can vary greatly and hence use of an average annual or daily value can often be misleading. The waste water application rate can also vary substantially, generally greater during spring and summer. In the spring waste water will be sprayed for a maximum of 8 hours over a 48 hour period hence approximately 50 mm is applied per application.

Assumption:
Number of days irrigated = 275 days

(1) Fixed-spray area:

Data on hydraulic loading:
Maximum application rate = 6 mm/hour
Area available = 45 ha
Proposed volume of irrigation = 900 m^3/day
Annual loading = 270000 m^3
Volume sprayed per area = 6000 m^3/ha/year
Depth of application = 600 mm/year
Application per dose = 50 mm

(2) Truck-spray:

Data on hydraulic loading:
Area available = 70 ha
Proposed volume of irrigation = 300 m^3/day
Annual loading = 90000 m^3
Volume sprayed per area = 1285 m^3/ha/year
Depth of application = 117 mm/year

Infiltration:

Te Kowhai silt loam, Bruntwood silt loam, and Horotiu sandy loam are identified as the major soil types in the land disposal area. The Te Kowhai silt loam is a poorly drained gley soil and is unsuitable for effluent irrigation (Wells, 1973). Consequently, the proposed application rate (6 mm/hour) is likely to cause surface ponding on Te Kowhai soil under saturated conditions. Proper land disposal systems should not allow any surface ponding. Frequent surface ponding from irrigated waste water enriched with high carbonaceous material can cause anoxic conditions in soil, which is detrimental for soil and pasture. The application rate recommended and widely used for most soil types is 5 mm/hour (MAFF, Welsh Office Agriculture Department, 1991). The proposed maximum irrigation application rate by Anchor Products is 6 mm/hour. Although this rate appears to be suitable for most New Zealand soil types for most time of the year, it is recommended that irrigation should not be performed on Te Kowhai soil under saturated conditions. The Horotiu sandy loam is well drained whilst the Bruntwood silt loam is moderately well drained and both are considered suitable for effluent irrigation at the proposed rate of application.

Net hydraulic loading:

It appears from the past records of Bardowie Farm that soils receive little or no irrigation during May, June and July which coincides with the typical regional non-milking season. From long-term rainfall records (1905 to 1980) available at Ruakura (NZMS, 1983), average rainfall during the balance of the year is estimated as 836 mm, which is 69% of the average annual rainfall. According to this estimation, the daily rainfall equates to 3 mm/day. The average evapotranspiration rate (ET) for the irrigation period is approximately 2.4 mm/day (pan evaporation data obtained from NZMS (1983) have been reduced by a factor of 0.73 according to Finkelstein (1973)). These data indicate that there is a rainwater surplus of 170 mm/year or 0.6 mm/day during the irrigation period which in turn demonstrates that any additional hydraulic loading through land application of effluent will contribute to the recharge of shallow aquifers beneath the farm. This additional hydraulic loading in the fixed-spray area is 600 mm/year.

Table 1. Estimation of net hydraulic loading for the irrigation period (275 days)

	Daily	Annual
Av. rainfall	3.0 mm	835 mm
Av. ET	2.4 mm	665 mm

Application rate	2.2 mm	600 mm
Net hydraulic loading	2.8 mm	770 mm

It must be emphasised that since the irrigation is intended to be carried out daily during the entire proposed irrigation period (275 days), it is appropriate to assess the 'actual' daily hydraulic loading. It has been estimated that out of 275 days, 92 days will receive > 1 mm/day rainfall (NZMS, 1983) and hence a large proportion of 835 mm rainfall is distributed during 34% of the irrigation period.

Use of precipitation index (PI):

Precipitation index has often been used to minimise or avoid any potential surface runoff or ponding of effluent applied onto land.

$$PI = (0.2 \times R_4) + (0.5 \times R_3) + (1.0 \times R_2) + (1.5 \times R_1)$$

where R_1, R_2, R_3 and R_4 is the rainfall (mm) on the previous 4 days respectively.

During wet periods PI can be used effectively to manage net hydraulic loading. The conventional engineering approach to waste water irrigation is to use land as a 'filtering system' hence it encourages greater hydraulic loading on well drained soils. Thus the PI for well drained soil is taken to be several folds higher than that for poorly drained soils. Such an approach accounts for surface runoff, but ignores nutrient leaching from top soil. Nutrient leaching is a dynamic and cumulative process which increases with hydraulic loading. For a given hydraulic load the extent of leaching varies according to the soil type, soil moisture conditions and the nutrient content of irrigation water (Scotter, 1993). Irrigating waste waters have more deleterious effects on the receiving environment than irrigating pure water because dissolved nutrients can move with waste water in the soil profile.

When waste water containing nutrients is irrigated onto dry soil the nutrients are absorbed into small soil pores and the potential nutrient leaching is reduced even if there is a high rainfall following irrigation. However, when waste water is applied onto wet soil, the nutrients are absorbed mainly in large pores resulting in a high leaching potential (Tillman *et al*., 1991). Thus a high rainfall event following irrigation can leach most of the nutrients that are located in the macropores. It is emphasised here that proper use of PI will only prevent surface runoff, but it does not guarantee minimal leaching loss. This is because PI considers only the preceding rainfall for 4 days and it does not account for post irrigation rainfall. Consequently, any good waste water irrigation practice should adopt conservative hydraulic loading rates. Irrigation should be planned according to the season and the ability for soils to assimilate the applied nutrients.

The proposed irrigation rate is 50 mm over a two day period. Assuming a maximum soil pore volume of 50%, the leaching depth will be 100 mm (i.e. only 50 mm depth is available in every 100 mm soil column for the water to occupy). If the top 100 mm soil is fully saturated then the leaching depth will be 200 mm (i.e. assuming little or no irrigated water is held in the 100 mm depth saturated soil column and the balance of the 100 mm dry soil column has 50% pore volume). However, generally most soils have a pore volume of 25% and the leaching depth will be much greater (i.e. with a 50 mm irrigation application water will travel 200 mm and 400 mm under dry and wet soil conditions respectively).

Any waste water irrigation administered on grazed pasture should attempt to confine the applied waste water nutrients and the existing soil nutrients within the top 200 mm soil where most pasture roots are located. Plant uptake of nutrients is used as the major nutrient removal mechanism and hence nutrient leaching below the root zone has a greater potential to contaminate ground water. Considering an ET of 5 mm for two days and the proposed 50 mm hydraulic loading for two days will result in 45 mm net hydraulic loading. If the soil is unsaturated, this loading will result in 180 mm leaching depth (at 25% pore volume). Thus the proposed hydraulic loading is acceptable when little or no rainfall is received prior to irrigation. Under wet conditions, however, such a rate of application can cause nitrate leaching. It is recommended that either the rate of application should be halved (i.e. 25 mm per dose) or a PI of 20 should be used during August, September and October.

Table 1 clearly shows that there is a substantial amount of hydraulic loading occurring on an annual basis (770 mm/year). Such a high hydraulic loading is one of the driving forces for leaching losses of nitrate. Nitrate has a greater potential to be reduced to gaseous forms in the top soil due to the presence of high organic carbon and bacteria. High hydraulic loadings reduce this potential for nitrate treatment in soil. When irrigation water contains nitrate the problem is accentuated because nitrate moves with soil water. The waste water proposed for irrigation contains 27% of N as nitrate (average concentration of 35.8 g/m^3). The level of total-N or nitrate-N can vary greatly over an year. The maximum nitrate level recorded in the waste water stream was 116.8 g/m^3. At this level combined with high hydraulic loadings, a substantial amount of nitrate leaching will occur. Considering the irrigated area will be used for grazing further nitrate leaching will occur from urine voided by dairy cows.

It becomes clear that hydraulic loading is an integral part of effective land treatment systems. Thus every effort should be made to minimise the volume of waste water produced in the factory.

Nutrient loading

Objective: *Avoid or minimise soil and water contamination whilst maintaining or enhancing soil and pasture quality*.

The waste water generated at Anchor Products is a good source of essential plant nutrients. It contains a considerable amount of macronutrients such as N, P, K, Ca, Mg, and S. Thus land disposal of this waste water is considered very useful for pasture production. The waste water also contains a substantial amount of Na and the land disposal of this element is addressed in the latter part of the discussion.

Nitrogen

1. Nitrate contamination

The presence of nitrate in ground water provides an indication of ground water contamination. According to the New Zealand drinking water standards the maximum acceptable level for nitrate-N is 10 g/m^3 (Board of Health, 1989). Bottle fed infants less than 6 months old consuming water containing nitrate reported to have developed a disease called methaemoglobinaemia (`blue baby' syndrome). Overseas studies report many such cases with several cases resulting in death (Winton et al., 1974). To date, no cases have been reported in New Zealand, although methaemoglobinaemia is not classified as notifiable disease by the New Zealand Health Department. However, the symptoms for the Sudden Infant Death Syndrome ('cot death') are similar to that of `blue baby' syndrome, implying that there may have been methaemoglobinaemia cases in New Zealand which have never been noticed. In adults consumption of drinking water with high nitrate levels have been linked to gastric cancer and hypertension cases (quoted by Burden, 1982).

Apart from being a potential health hazard, due to subsurface flow of ground water into streams or rivers, nitrate in ground water can pollute waterways causing algal blooms and may subsequently affect aquatic life such as fish. Many waterways in the region are used for recreation and unwanted algal growths can affect the revenue gained by tourism. High nitrate flow into the sea combined with P availability has also been considered as one of the main factors for toxic algal blooms reported frequently around the globe and recently in New Zealand. Moreover, if the environment is degraded, unnecessary trade barriers can be imposed by overseas trading partners on the export of food products from New Zealand. Currently, many European trading partners are spending billions of dollars in the management of their environment, hence the high cost of production. In New Zealand the cost of production is relatively low, principally because there is an `environmental subsidy' attached to the total cost of production (i.e. the cost of environmental degradation is not considered in the production of export food products). Many European trading partners believe that countries which trade with the EC should maintain similar environmental standards, hence a 'realistic' cost of production. It should also be emphasised that New Zealand has a good marketing potential because of its clean and green image overseas. Every effort should be made to maintain this image because once such an image is lost it is difficult to regain. One of the major problems with nitrate is that contaminated ground water is difficult to clean up.

2. Nitrogen in grazed pasture system

Efficient N management is very important in soils receiving effluent with a high N content. Poor N management will lead to substantial ground water pollution. When the input exceeds the output of N, a surplus of N in soils occurs and hence potential for leaching loss of applied N. It is essential to use N transformation models to predict the fate of applied N. A proper model will consider the important N transformation processes in the system. Once the model is derived a loading rate can be determined. A pasture system with zero grazing which is frequently referred to as 'cut and carry' is easy to manage and requires only a simple N model since crop uptake is the major N removal mechanism. For example, in order to produce 16000 kg dry matter per ha with 4% N will require 640 kg/ha/year. Assuming that the soil has very low levels of organic-N, for a pure ryegrass pasture system approximately 650 kg N/ha/year can be applied in several split doses throughout the growing season, causing little or no ground water pollution. However, under a grazed pasture system N ingested by animals is recycled through animal excreta without being transferred offsite as in a `cut and carry' system. Consequently, the conventional N loading rate determination based mainly on the amount of crop uptake and N removal in animal products is considered as inappropriate under a grazed system. Moreover, under a grazed pasture system, whilst high soil N build-up leads to high nitrate leaching losses, high N content in pasture leads to greater N ingestion by grazing animals and consequently higher excreta-N loss through urine (Jarvis et al., 1989). It has been well documented that the presence of grazing animals is the driving force for nitrate leaching in soil (Selvarajah, 1994). This is because cow urine spots contain up to 1000 kg N/ha. Although it is well known that increasing N application results in increased dry matter production, the resultant increased stocking rate or high plant N content can lead to greater N loss through leaching from the system.

3. Assessment of proposed nitrogen balance

(i) Products removal of N

According to the information provided by Anchor Products the anticipated milk fat production at Buxton Farm at a N application rate of 600 kg N/ha/year will be 526 kg/ha/year. It has been estimated that milk production and replacement stock will remove 63 and 10 kg N/ha/year respectively. Thus the total removal will be 73 kg N/ha/year. Considering the high input of N, this estimation appears to be accurate. It becomes clear that the amount of N removed through dairy production is relatively small in the entire N flow in a grazed system (approximately 10% of the herbage-N consumed).

(ii) Ammonia volatilisation

Ammonia volatilisation occurs when ammonical-N is present in soil at excessive levels. Losses sustained can vary according to the environmental conditions (rainfall, temperature, and soil moisture), agronomic factors (fertiliser-N application, liming and presence of grazing animals), soil types and presence of plant cover. It has been characterised that Anchor Products waste contains only protein-N and nitrate-N. There is no information available on the levels of ammoniacal-N present. Assuming that protein and nitrate are the only forms of N present in the waste water, the potential for instantaneous ammonia loss will be zero. The extreme pH values provided for the waste water suggest that at times pH levels reach up to 11. Under such conditions some protein-N can be hydrolysed into ammoniacal-N form. However, considering the carbonaceous nature of the waste water the potential for ammonia loss can be suppressed through rapid immobilisation process where ammoniacal-N is used for biosynthesis by heterotrophic bacteria. Such a process requires only ammoniacal-N form, and nitrate-N form is not consumed by these bacteria for immobilisation process (Wickramasinghe *et al*., 1985).

In the long term, however, ammoniacal-N can be released from mineralisation of applied protein and the urine voided by cows in which only urine patches have greater potential for ammonia loss. A recent study on ammonia loss from urea-N applied to a wide range of soil types in New Zealand demonstrated that volcanic ashes have very low potential for ammonia loss (Selvarajah *et al*., 1993). Moreover, volatilisation can be completely suppressed during an irrigation or rainfall event due to urea-N and ammonical-N leaching (Selvarajah, 1991). The presence of pasture cover can absorb a substantial amount of ammonia volatilised (Lockyer and Whitehead, 1987). Under Waikato field conditions and the proposed irrigation conditions all the above factors favour very low ammonia volatilisation. Extrapolating the field ammonia loss from urea broadcast to pasture under Canterbury spring conditions using micrometerological methods, my estimation of ammonia loss for the proposed pastoral system will be up to 5% of the urine-N deposited. If 730 kg N/ha/year is assumed as herbage-N intake by cows, after the removal of products the remaining N will be animal excreta (i.e. 657 kg N/ha/year). Assuming 15 kg/ha/year of this excreta is deposited in the milk shed (see the section on transfer of N to non-productive areas) the remaining 642 kg N/ha/year will contain 450 kg N/ha/year as urea-N (approximately 70% of the excreta is urea-N). An ammonia loss of 5% of 450 kg will be 22.5 kg N/ha/year. The ammonia loss is estimated to be 25 kg N/ha/year and this estimate is considered to be appropriate under the given conditions.

(iii) Denitrification in soil

Denitrification can occur through chemical and biological processes during which nitrite-N or nitrate-N is reduced to gaseous forms of N (nitrous oxide or dinitrogen). Unlike biodenitrification, the chemodenitrification process does not depend directly on microorganisms and occurs only when *nitrite-N* accumulates in high amounts. Many papers indicate that nitrite accumulation is rarely noticed in most soils and hence chemodenitrification is considered as minimal under most conditions (Chalk and Smith, 1983). Since biodentrification is the major pathway for nitrous oxide or nitrogen loss from the system, in this memo biodenitrification is referred to as denitrification.

The denitrification process requires four essential factors, meaning that in the absence of one of these factors there will be no denitrification loss. These factors are (a) availability of nitrate (b) absence of oxygen i.e. anaerobic conditions (c) an electron donor (e.g. available organic carbon) and (d) denitrifying bacteria. Other factors that can influence the extent of the denitrification process are moisture and temperature. Apart from moisture, temperature is one of the key environmental factors regulating the extent of denitrification losses. Consequently, denitrification losses are low at night and during cold seasons. Thus caution must be taken in extrapolating day time denitrification losses for the entire day and in extrapolating summer/spring measurements for autumn/winter conditions.

The sources of nitrate under the proposed irrigation practice will be nitrate in waste water and nitrate released from protein applied through waste water irrigation, plant decay, and urine and dung deposited by animals. The amount of nitrate in waste varies greatly, minimum and maximum being 0.69 and 116.8 g/m^3 respectively. The estimated nitrate application rate is 186 kg N/ha/year according to the Bardowie data. Currently, Anchor Products is proposing to reduce the use of nitric acid in the factory and this can have a substantial effect on nitrate levels in waste water.

Losses of N through denitrification has been predicted by Anchor Products as 233 kg N/ha/year for Buxton farm site. This amounts to 39% of the applied N which is considered to be very high for the system proposed. The study conducted at the Bardowie irrigation site using Anchor Products dairy factory waste water at a higher N loading rate (1490 kg N/ha) by Russell and Lindsay (1990) showed that only 110 kg/ha was attributed to denitrification loss. This is only approximately 8% of the applied N. The study was conducted during the day time and gaseous samples were collected soon after the irrigation. Thus even an 8% of applied N loss can be an overestimation. The authors also observed that the gaseous losses dropped to background levels within 24 hours and that the losses recorded during a cold season were much lower. Russell and Lindsay (1990) also noted the relatively higher denitrification losses sustained during dairy factory waste water irrigation onto an alkaline soil (pH 7.0) at Bardowie farm compared with meat processing plant effluent irrigation onto an acid soil (pH 4.9). This difference is due to the greater soil pH, a longer irrigation event, a greater C:N ratio and the presence of dairy cows at the Bardowie site. The soil pH for the Buxton farm site is 6.0 and the predicted denitrification losses could be much lower than at the Bardowie site.

The following reasons strongly suggest that the Anchor Products estimate of denitrification loss for Buxton farm (233 kg N/ha/year) is an overestimate:

1. On a percent loss of applied N basis the estimated loss of N through denitrification should be 48 kg N/ha/year (8% of 600 kg N). It is well known that most gaseous losses are directly related to the level of their sources applied per unit area.

2. The 8% loss estimated by Russell and Lindsay (1990) could be lower considering the diurnal fluctuation of denitrification losses.

3. Soil pH for the Buxton farm site (6.0) is much lower than that of Bardowie (7.0) and hence there is less denitrification potential at Buxton.

4. The use of nitric acid will be further reduced which will reduce the level of nitrate in the waste water which will in turn reduce the potential for denitrification substantially.

5. Although high rainfall and irrigation can enhance denitrification processes by saturating the soil, similar conditions can also result in substantial amount of nitrate leaching below the zone of denitrification (i.e. top soil). High rainfall and irrigation can also leach urea-N from urine patches below the same zone, reducing the denitrification potential. Under such conditions the rate limiting factor will be the absence of nitrate in the zone of denitrification. Consequently, the estimate made on the basis of the number of rain days (i.e. 120 kg N/ha/year) is misleading.

6. The Anchor Products reports also indicate that the soil will act as a bioreactor and hence there may be rapid denitrification loss from the applied nitrate in the waste water. The results from the work by Russell and Lindsay (1990) suggest that the rate of N loss is not comparable with that of industrial bioreactors. For example, the peak emission rate of nitrous oxide gas observed by Russell and Lindsay (1990) was 55 g N_2O-N/ha/hour whilst the rate of loss measured in a water treatment bioreactor was 400-500 g NO_3/m^3/hour (Eppler and Eppler, 1988). Considering an irrigation application rate of 25 mm/day the amount of dairy factory effluent applied will be 250 m^3/ha/day. Thus the rate of denitrification loss from dairy factory waste water using soil as a `bioreactor' will be 0.2 g N_2O-N/m^3/hour. The reasons for such large difference between the systems are:

(a) Industrial bioreactors use a readily available carbon source (e.g. in the case of water treatment a suitable alcohol such as ethanol) whereas the carbon source in the dairy factory waste water (lactose) is relatively poor in releasing carbon readily for bacteria consumption. This is because the chemical structure of lactose is relatively complex (two aromatic rings, $C_{12}H_{22}O_{11}.H_2O$) compared to a simple carbon source such as ethanol (simple aliphatic, C_2H_5OH). Lactose can eventually breakdown into simple carbon compounds which requires a considerable time.

(b) Industrial bioreactor often remove oxygen by vacuum degassing which would create a full anaerobic condition. The soil medium is porous and hence only provide partial anoxic conditions even under saturated conditions. Moreover, rain water contains a substantial amount of dissolved oxygen and this is not conducive for denitrification.

(c) Industrial bioreactors often use higher temperatures to achieve greater denitrification losses.

(d) Most industrial bioreactors can also regulate the pH of the medium.

(iv) Denitrification in ground water

It has been indicated in the report by Anchor Products that there will be denitrification occurring in the ground water environment. No ground water studies have been undertaken thus far to assess the extent of denitrification in ground water. Moreover, accurate field measurements of denitrification losses are technically difficult to achieve. From the available data, a shallow aquifer (4 m depth) with a nitrate concentration of 3.8 g/m^3, and comparable with ground water beneath Buxton farm denitrified <0.014 mg N/L/day (Fontes *et al*., 1991). Considering the annual hydraulic loading of 770 mm at Buxton farm, the amount of water required for denitrification treatment would be 7700 m^3/ha. Assuming a denitrification rate of 0.01 mg N/L/day the amount of N denitrified for the irrigation period (275 days) will be 22 kg N/ha/year. This could be a substantial overestimation because the Fontes *et al.* (1991) ground water temperature was 27-31.9 ^{o}C whilst that of Buxton Farm would be 14-16 ^{o}C. Since the temperature is directly related to the denitrification rate, it is estimated that only 11 kg N/ha/year could be denitrified under New Zealand conditions. A recent paper by Selvarajah *et al*. (1994) indicated that in the Hamilton Basin where dairy farming and cropping are the major land uses, the mechanism for ground water nitrate decrease is through dilution from rain water recharge. In this environment ground water nitrate typically peaks during late autumn or early winter and decreases during late winter when the ground water reaches peak levels. The process is dynamic and the excess ground water flows into streams or rivers. These authors have shown that the only significant ground water denitrification was observed in the presence of reduced iron (Fe^{2+}) in ground water (autotrophic denitrification). Such waters have little or no nitrate. As a rule of thumb, Waikato bore waters containing >0.2 g/m^3 Fe^{2+} have <1 g/m^3 nitrate-N. It is not clear at this stage whether Buxton farm ground water has an iron content > 0.2 g Fe^{2+}/m^3, however, ground water beneath Buxton farm is likely to have little or no reduced iron considering the high levels of nitrate found.

(v) Denitrification due to the presence of animals

It is difficult to separate the denitrification losses from the irrigated effluent from that of urine spots. Generally, irrigation of effluent is carried out soon after a grazing cycle and hence the measurements made by Russell and Lindsay (1991) may have fully or partly included the denitrification losses due to the presence of animals. Sherlock *et al*. (1992) estimated that from intensively grazed New Zealand pasture up to 10 kg N/ha/year of denitrification can occur. As pointed out earlier, the potential for denitrification loss from urine spots can be reduced due to the irrigation practices at Bardowie or Buxton (leaching below the zone of denitrification) in relation to conventional dairy farming practices where little or no irrigation is used.

It is concluded that denitrification losses have been overestimated by Anchor Products, and with the available information, my estimation of total denitrification loss at Buxton farm is up to 70 kg N/ha/year (considering a denitrification loss of 48 kg N/ha/year from soil due to effluent irrigation, 11 kg/ha/year from ground water and 10 kg N/ha/year from the presence of animals). It must be emphasised that overestimation of the N loss process will lead to excessive N build-up in soil and the subsequent leaching losses. Considering the complexity of N transformation dynamics, from a resource management point of view it is suitable to use conservative estimates rather than overestimations.

(vi) Transfer to non-productive areas

The Anchor Products report estimated that 50 kg N/ha/year will be transferred to non-productive areas. It must be emphasised that tracks and races are part of the farm system. Nitrogen transferred from grazed areas onto these non-productive areas have poor removal mechanisms and hence are susceptible for accumulation and leaching. On the other hand, the N transferred to the dairy shed can be treated separately if dairy shed effluent is applied at the recommended rate by EW (150 kg N/ha/year) onto a non-irrigated area. The amount of N transferred to the dairy shed will be approximately 15 kg/ha/year (assuming N excreted in the dairy shed is 20 g/cow/day for a 270 days of milking and 255 cows in a 100 ha grazed area).

(vii) Leaching losses under conventional dairy system

Most Hamilton Basin soils have a high nitrifying capacity (oxidation of ammonium to nitrate) due in part to their volcanic origin. This high nitrifying capacity emphasises the requirement for stringent hydraulic management for these soils; mismanagement can lead to severe nitrate leaching losses which will result in ground water nitrate elevation. There have been several studies conducted on the extent of leaching under various farming practices. The majority of these studies have used lysimeters for the estimation of leaching losses. Actual field studies should examine the ground water to obtain an accurate assessment of the extent of leaching. One such estimate performed in the Hamilton Basin area showed that under ample rainfall conditions the leaching of nitrate from farmlands could be up to 60 kg N/ha/year (Selvarajah *et al*., 1994). The study area is used predominantly for maize cropping and dairying. Cropping involves cultivation of soil and this could leach a substantial amount of nitrate. Thus the above leaching estimate (60 kg N/ha/year) could be considered as an overestimate for conventional dairy farming in the Waikato region (clover-ryegrass pasture with little or no input of fertiliser-N and high input of phosphorus).

Table 2. Nitrogen balance

Nitrogen transformation processes	Proposed	Amended	Recommended
	Input 600 kg N/ha/year		Input 300 kg N/ha/year
Products (milk + maintenance)	73	73	73
Ammonia volatilisation	25	25	25
Denitrification (effluent)	233	60	50
Denitrification (excreta)		10	10
Transfer to non-productive areas	50	Not applicable	Not applicable
Transfer to dairy shed	-	15	15

Leaching loss under clover based pasture systems	-	60[a]	60[a]
Total N losses	381	243	233
Nitrogen available for leaching	219	357[b]	67[b]
(a+b)Predicted nitrate leaching	219	417	127

According to Table 2 it is clear that from the proposed application rate of 600 kg N/ha/year the estimate for net leaching will be 417 kg N/ha/year. Thus it is concluded that the proposed rate of N application by Anchor Products is likely to cause excessive nitrate leaching and ground water contamination. From the available information, 300 kg N/ha/year application rate appears to have considerably less leaching than that of the proposed application rate. It also appears that a high application rate such as 600 kg N/ha/year has been proposed on the basis of an 'apparent' high denitrification loss from the system. From the existing information such a rate of denitrification loss is considered to be a gross overestimate. Considering the difficulty in predicting such complex and dynamic N transformation processes in soil and water for a specific site, such as Buxton farm, it is environmentally safer to adopt conservative N loading rates. Ideally the applicant should have performed some work on N transformation processes for the site without speculating the N loss processes.

4. Bardowie farm - state of the environment

Many Anchor Products reports submitted in relation to the Buxton farm consent frequently refer to the Bardowie farm irrigation project. The farm size is 140 ha with a herd of 300 and similar soil types as that at Buxton. Average annual loading of N is 1200 kg N/ha which is applied onto an area of 110 ha. Figure 1 shows mean water levels and ground water levels for 8 piezometers beneath the site. As illustrated the nitrate levels in ground water have increased during the last decade. Within just 3 seasons of waste water application nitrate levels increased from 10 to 40 g/m^3. Nitrate levels attained a peak of 70 g/m^3 following 1990/1991 season. There is no obvious seasonal pattern during the steady increase of nitrate levels until 1987/88 season. Since 1987/88 season, peak nitrate levels are usually attained during the February-March period. The annual N loading does not appear to have a direct influence on either the peak nitrate levels ($r = 0.09$; not significant) or average nitrate levels during an irrigation season ($r = 0.18$; not significant). For example, a high total-N loading (155 t/year) during the 1988/89 season corresponds with a nitrate peak of 58 g/m^3 whilst at a loading of 127 t/year the peak nitrate level was 68 g/m^3 during the 1990/91 season. The reduction in nitrate levels during each season is attributed to dilution through recharge.

Apart from the ground water contamination beneath the farm, the Bardowie irrigation practice had also caused pollution outside the farm. For example, at the boundary of the disposal site, 3 piezometers not used in Figure 1 had nitrate levels of 63, 68 and 77 g/m^3 respectively in December 1993. Moreover, the already contaminated Mangaone stream (>7 g/m^3 upstream) adjacent to the disposal site is further contaminated (>20 g/m^3) through the contaminated ground water draining into the stream. An estimated 13 tonnes of ground water nitrate-N enters the stream every year through this pathway from the Bardowie farm.

It must be emphasised that Anchor Products has been actively involved in N loading minimisation in the waste water through installing better recycling facilities and reduction in nitric acid use. Although waste reduction is expected to reduce nitrate leaching at Bardowie farm, the evidence available to date shows no *statistically* significant reduction in nitrate leaching despite the apparent reduction in peak nitrate levels in Figure 1. Moreover, the low rainfall received during 1992/93 can also be attributed to the low nitrate peak for this season. Considering the complexity involved in the release of mineral N from the *residual* organic-N, and seasonal variation, it is too early to see the effect of reduced N loading on nitrate leaching. It may take a few more years to see an actual effect, however, the N balancing suggests that there will be a reduction in the extent of nitrate leaching at Bardowie farm. These observations clearly demonstrate that there is a need for soil monitoring for N accumulation for any N based waste water applied onto land. Regular monitoring will provide information on the soils' ability to assimilate the applied-N.

5. Farm N management strategies

Farm management should be aware of the high annual N application rates through waste water irrigation and hence take account of other N inputs. Paddocks which receive waste water from Anchor Products should not be used for other forms of N application. This includes dairy-shed effluent irrigation either directly or indirectly from effluent storage facilities or oxidation ponds, fertiliser-N application, receiving and using N based waste water from other waste water sources (except for Anchor Products) and using stock feed (e.g. silage, hay or concentrates) brought from other farms or suppliers unless there is an acute shortage of stock feed.

It should be verified that the existing pond capacity is adequate to receive waste from 255 cows. Moreover, an irrigation programme is required for the disposal of dairy shed effluent from the pond system. Currently, Environment Waikato allows 150 kg N ha^{-1} loading for dairy shed effluent. The land area required depends on the size of the herd. For example, a herd size of 255 requires approximately 5 ha for dairy shed effluent irrigation assuming a milking period of 270 days. If the irrigation of dairy shed effluent is carried out throughout the year, only a temporary holding system such as is currently available is necessary as a contingency measure for pump failure or wet weather conditions.

Another vital N management practice is the control over cultivation practices. Since ploughing during warm periods is considered as a major source of ground water nitrate (Francis et al., 1993), any form of cultivation should not be performed on the irrigated land. If ploughing should be performed for the reestablishment of the grass cover or maize cropping, it should be performed during dry weather in June or July to minimise mineralisation from soil organic-N and subsequent leaching of nitrate. Since the irrigation is not performed during these months this period appears the best time for any cultivation.

6. Interaction of hydraulic and N loading

According to the hydraulic loading of 50 mm per application, the amount of N loading per application will be 65 kg/ha. This estimate has been made from the average effluent total N content of 131 g/m^3. Considering the instantaneous N loading, this loading rate is considered to be agronomically acceptable. At this rate of application each paddock will be irrigated at least 5 times during the season. As suggested earlier, at 25 mm/dose irrigation can be performed 10 times a year per paddock. Alternatively, using PI a higher PI can be used with a lower application rate as long as the net hydraulic loading remains constant (i.e. 50 mm) (e.g. Table 3). If irrigation has to be performed when PI > 20 mm, hydraulic loading can be estimated by subtracting PI from net hydraulic loading.

Table 3. Different combination of net hydraulic loading parameters

PI	Hydraulic loading	Net Hydraulic loading
25 mm	25 mm/application	50 mm/application
30 mm	20 mm/application	50 mm/application
40 mm	10 mm/application	50 mm/application

Combining a higher PI (> 25 mm) with lower irrigation application rate will help to reduce the loading on the disposal area during wet weather conditions.

Soil conditions and sodium levels

Soil test results in the proposal clearly show that there is an excessive amount of phosphorus (P) and sodium (Na) present and an optimum level of calcium (Ca), magnesium (Mg) and potassium (K) at the Bardowie farm site. Consequently, for pasture production there is no more land application of these nutrients required for a few seasons. In the case of soil build-up of Ca, P, K and Mg there is generally no adverse effect on soil fertility, plant and animal health or ground water quality. Several years of P build-up in soil can eventually cause P leaching. However, the three soil types at Buxton farm are classified as yellow brown loams which have one of the highest P retention capacities among New Zealand soil types.

According to the proposed waste water volume application (1200 m^3/day) the annual loading rate of Na at Buxton farm will be 122 tonnes. On an area basis this will be approximately 2000 kg Na/ha/year in the fixed-spray area and 435 kg Na/ha/year in the truck-irrigation area. Excessive land application of Na is deleterious for soils with a high clay content. High Na levels in soil will destroy soil structure which is essential for soil aeration and drainage. When clay minerals are dispersed by Na they clog soil pores causing poor drainage. The success of the proposed irrigation system depends mainly on good soil drainage conditions. Although yellow brown loams are less affected by high soil Na levels than many other New Zealand soils, caution must be taken in applying such large quantities of Na. The mass loading of Na can outweigh any benefit that is obtained by having other cations such as K, Mg and Ca. It must also be noted that Na can be more deleterious to soil structure when applied with waste water which has a pH > 9.0. Due to presence of high Na levels it is important to keep the waste water pH below 8.5 throughout the irrigation period. As a soil amendment practice, application of high amounts of calcium can leach excessive Na from soil. Lime ($CaCO_3$) is a cheap source of calcium and can be used to leach Na. However, since lime can also cause elevation of soil pH, it is discouraged as a source of calcium (see below). Gypsum ($CaSO_4$) is the most suitable amendment chemical under the given conditions and will not elevate soil pH and supplies additional sulphur for pasture growth. It is recommended that gypsum should be applied annually to avoid any deleterious effects caused by Na and excessive accumulation of Na.

The major Na based chemical that is used at Hautapu dairy factory is caustic soda (NaOH). It is recommended that alternative non-Na based chemicals should be used as much as possible. For example, potassium hydroxide (KOH) is a good substitute for NaOH. Every effort should be taken to recycle the use of NaOH without discharging into the waste water stream.

The extremely variable pH levels of waste water applied can cause some long term soil problems along with the problem caused by Na- pH interaction. Bardowie farm soil pH levels have increased by a unit within a decade of waste water application (from 6.2 (1982) to 7.1 (1992)). At pH 7.0 certain micronutrients (e.g. copper, selenium) that are essential for plant and animal health will be deficient. This is a farm management problem and can be solved by providing a supplementary diet containing trace elements.

Truck application of waste water

It has been reported by Anchor Products that truck application of waste water will be performed onto a 70 ha of Buxton farm. This area is different from that of fixed-spray area (45 ha) in several ways (i.e. very high water table (0.1 m) with predominantly Bruntwood series soil type). High level of Na application combined with trucking can cause severe compaction and poor permeability. Trucking should be minimised as much as possible by using long high powered spray guns in most areas.

Recommendations and Monitoring

Hydraulic loading:

(a) Every effort should be taken to minimise waste water generation in the factory.

(b) The **net** hydraulic loading should not exceed 50 mm and irrigation should be performed in combination with the PI value (e.g. PI (20 mm) + hydraulic loading (30 mm)).

(c) Considering the high N loading, a 15 day irrigation cycle should be used.

(d) No surface ponding or surface runoff should be apparent during the entire irrigation operation.

(e) A daily record of waste water flow should be maintained.

(f) A daily record of irrigated waste water flow and area irrigated should be kept.

(g) A daily record of rainfall should be kept.

(h) Trucking should be avoided as much as possible and a high powered long spray gun can be used in the back of the farm.

Nutrient management:

(a) Nitrogen loading should not exceed 300 kg N/ha/year.

(b) Dairy shed effluent should not be applied onto the waste water irrigation area.

(c) Fertiliser N use or other N based waste water should not be applied in areas which receive 300 kg N/ha/year through waste water irrigation.

(d) Stock should not be fed with stock feed from external sources (e.g. silage, hay, concentrates) other than the pasture from the irrigated area which receives 300 kg N/ha/year waste water irrigation.

(e) Ploughing irrigated areas should be permitted only during dry weather in June or July.

(f) When new chemicals are introduced into the waste water stream, EW should be informed.

(g) The proposed Na loading rate should be reduced either through the use of substitute chemicals (e.g KOH for NaOH) or more efficient recycling of waste water.

(h) An appropriate amount of gypsum should be applied annually.

(i) The irrigation water should be characterised for the following properties on composite samples:

(a) daily- pH, BOD, TKN and nitrate-N

(b) monthly- Na, Ca, Mg, K and TP.

Ground water quality monitoring:

(a) Three piezometers are required at the boundary of Fencourt Road in addition to the existing piezometer sites.

(b) Piezometer and bore water samples should be monitored on a monthly basis for ground water level, pH, conductivity, nitrate-N, TKN, nitrite-N, ammoniacal-N, sodium, total-P and dissolved organic carbon.

Surface water monitoring:

(a) Proper sampling sites (possibly using sites monitored previously) should be established with the assistance of EW technical staff for upstream and downstream samplings.

(b) Surface water should be monitored for the following on a monthly basis: flow rate, pH, conductivity, nitrate-N, TKN,ammoniacal-N, total-P and BOD.

Soil testing:

(a) Soil should be tested for the following characteristics annually at the end of April: infiltration rate, pH, TKN, ammoniacal-N, nitrate-N, organic-C, calcium, sulphate, total-P, sodium, potassium and magnesium.
A composite sample of 3 sampling sites for each soil type should be obtained. Each sampling site should comprise 3 sampling locations 0-20, 20-60 and 60-100 cm cores.

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