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NITROGEN LOADING RATE FOR DAIRY PASTURE SYSTEMS IN THE WAIKATO REGION

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This report was prepared for the Environmental Planning Section, and considers proposed changes to Environment Waikato's Transitional Regional Plan - 1 Dairy Shed Effluent. The report was prepared after submissions were received on the proposed plan.

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1 INTRODUCTION

The document "Proposed Changes to Environment Waikato's Transitional Regional Plan - 1 Dairy Shed Effluent" includes regional rules for land application systems. A number of submissions have been received on these rules. In particular the following aspects of the proposed rules have been questioned:

(i) annual effluent loading rate;
(ii) effluent application rate per dose;
(iii) application of sludge to land; and
(iv) effluent storage requirements.

2 NITROGEN LOADING RATE FOR DAIRY PASTURE SYSTEMS IN THE WAIKATO REGION

2.1 SUBMISSIONS

Various concerns have been raised about nitrogen (N) in effluent. It has been indicated that the annual N loading rate stated in the rules (150 kg N ha^{-1} y^{-1}) is too low. One recommendation has been made to raise the loading rate to 400 kg N ha^{-1} y^{-1}. Questions were raised about the applicability of the evidence used in the rationale to determine the annual N loading rate several submissions indicated that the rationale lacks scientific rigour. It has also been emphasised that the rationale to determine the loading rate is critical in establishing the credibility of a safe loading rate.

Several submissions noted that the area required for effluent irrigation is too high (200 m^2 cow^{-1}) and a minimum area of 50 m^2 cow^{-1} was recommended. Concerns have been raised about rules giving no consideration on the loading rates for potassium and phosphorus (P) in the effluent. It has been stated that the rate of effluent application on land is based only on N loading and that at this rate of application the loading of potassium (K) is too high and it will cause magnesium (Mg) deficiency in soil.

2.2 NITROGEN TRANSFORMATIONS IN CLOVER-BASED DAIRY PASTURE SYSTEMS

Soil N is considered to be the most prominent essential nutrient for crop growth. Nitrogen occupies a unique position among the major nutrients, because plants require N in relatively large amounts, whereas it occurs only in trace amounts in soil parent materials. Surface soils (up to 20 cm depth) contain about 0.2% N, mainly in the form of organic N. Microorganisms break down organic N to form mineral N (ammonium and nitrate). Mineral N is used for plant growth.

Continuous farming can lead to depletion of soil N. A common practice is to apply manure or fertiliser that can supply sufficient N to meet crop requirements. Agronomy scientists have demonstrated that crop yield per land area can be increased many fold by using appropriate fertiliser management techniques. Consequently, intensive farming practices (e.g. fertiliser usage, high stocking rates) have become prevalent in New Zealand. Environmental awareness has changed substantially, with a well documented and increased awareness of the impact of intensive farming practices on environmental quality (e.g. elevated nitrate levels in the water bodies, algal blooms and acid rain). Currently scientists are examining ways to minimise environmental pollution caused by farming practices without affecting farm production.

Major pathways of N transformation in a grazed pasture system are identified as: plant uptake and clover N fixation; N losses from excreta through ammonia volatilisation, leaching and denitrification; transfer of excretal N to unproductive areas (raceways and dairy shed); and removal of N through milk production.

2.2.1 Plant uptake

New Zealand dairy pasture systems comprise mainly a mixture of ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.). The extent of plant uptake of N is influenced by pasture growth rate which is influenced by soil moisture, temperature and extent of grazing. Generally peak pasture growth and greater uptake of N occurs during spring, whilst the lowest uptake of N occurs during winter. Pasture performance is measured in terms of dry matter (DM) production. In most cases, increases in DM production are apparent for N application rates up to 550-650 kg N ha^{-1} y^{-1} - after which rate the yield decreases (Ryden, 1984). At high N application rates pasture begins to accumulate nitrogen. Nitrogen accumulates in plants mainly in the form of protein. In addition to protein, nitrate can also accumulate in plants if there is excessive nitrate present in soils (Appendix 1) (Jarvis *et al.,* 1989).

Compared with many other regions in New Zealand, Waikato has optimal conditions for pasture growth. Soils of the lowland plains and fertile soils derived from volcanic parent materials combined with typically warm, humid summers and mild winters to ensure that Waikato soils are among the most productive in the country. Pasture uptake of N is approximately 520 kg N ha^{-1} yr^{-1} in the Waikato region assuming that average pasture production is 13000 kg DM ha^{-1} and assuming a high N content of pasture of about 4% on a dry weight basis.

2.2.2 Clover fixation of N

The ability of clover to fix atmospheric dinitrogen gas (N_2) in the form of organic N in association with a symbiotic bacteria (*Rhizobium spp*.) in the form of organic-N is referred to as symbiotic N fixation. Clover stolons and roots decompose and contribute to the soil organic-N reserve. The amount of N fixed per land area is influenced mainly by the size of the clover population and type of cultivar, soil moisture and temperature conditions, and the presence of soil mineral-N (Ledgard and Steele, 1992). Increased fertiliser-N can also reduce clover performance through reduction in clover N fixation and growth (Ledgard, 1989).

The most widely used cultivar has been *Huia,* which has been used for a number of years. Recently, some new cultivars (e.g. *Pitau and Kopu*) have been introduced. Ledgard *et al.* (1990) showed that amount of N fixed by *Aran, Kopu, Pitau* and resident clovers averaged 280 kg N ha^{-1} y^{-1} whilst that of *Huia* amounted 224 kg N ha^{-1} y^{-1} when established on a Horotiu sandy loam. These values have been obtained from 2 y old cultivars and it is believed that when clover is well established it is capable of fixing greater amount of N.

In grazed pasture, clover performance can also be affected by urine voided onto grass (Ball *et al.,* 1979). However, it has been estimated that about 248 kg N ha^{-1} y^{-1} can be fixed by clover in an intensively grazed dairy pasture system in the Manawatu area (Field and Ball, 1982). The response of clover is not quantified for dairy shed effluent applied onto clover-based pasture. However, an indirect assessment of clover N fixation on a Waikato soil (Te Kowhai silt loam) applied with a weekly dose of fresh dairy shed effluent (total application of 511 kg ha^{-1}) for 8 months showed that clover can fix about 241 kg N ha"[1] (Barkle *et al.,* 1993). Using this information, it is assumed that under zero N fertiliser use, on average, Waikato soils will be able to receive a minimum of 200 kg N ha^{-1} y^{-1} through clover N fixation from an established clover-ryegrass pasture.

2.2.3 Nitrogen losses from excreta

Dairy cows excrete a large proportion of N that is ingested. The amount of N consumed and excreted depends mainly on the N content of pasture; the higher the N content, the greater the excretion of N (Appendix 2) (Jarvis *et al.,* 1989). It has been estimated that up to 14% of the N ingested is used for milk production (Field and Ball, 1982) and the balance of the N is excreted, out of which about 60% is urine-N and 40% is dung-N for animals fed on a clover-ryegrass mixture (with zero N application) (Jarvis *et al.,* 1989).

2.2.3.1 Ammonia volatilisation

About 75% of urine-N is in the form of urea (Doak, 1952). When urine is deposited onto soil, urea-N is hydrolysed to form ammoniacal N (ammonia (NH_3) and ammonium (NH_4^+)). The ammonia form of N is very alkaline, causing the release of ammonia gas from the soil surface.

Urea + water —urease→ ammoniacal-N + carbon dioxide [1]

Volatilisation rate peaks within 3 days of urination. Volatilisation can continue for 2-3 weeks at a slower rate. During rainfall or an irrigation event, the volatilisation process is arrested and urea-N is leached below the surface and it will continue to hydrolyse and produce ammoniacal-N. If the intensity of the rainfall or irrigation is very high, urea-N is leached below the rhizosphere. This occurs because urea is very mobile in soil. It must be noted that ammonia volatilisation is greater from urine voided onto soil than a urea solution which has similar strength of urea-N applied onto soil. It has been demonstrated that the presence of hippuric acid increases the potential for ammonia loss from urine (Whitehead *et al.,* 1989).

Depending on the plant density, a proportion of the ammonia volatilised from the soil surface can be absorbed by plants through stomatal openings. The greater the plant density (height and population per area), the higher the absorption (Hoult and McGarity, 1987). Urea-N deposited onto plant cover is also hydrolysed rapidly and the ammonia produced is either absorbed by plants or volatilised to the atmosphere.

It becomes clear that the volatilisation process of urea-N voided during a urination event is complex. The extent of ammonia loss is influenced by several factors. Urea-N concentration, micrometeorological conditions, presence of plants, soil type and soil moisture are the major factors. Field trials conducted on a wide range of New Zealand soils under controlled conditions clearly demonstrate that the amount of ammonia loss from surface applied urea can vary greatly (Selvarajah, *et al.*, 1993). The same trials show that the major soil characteristic that controls the amount of ammonia volatilised from urea-N is the capacity for soils to resist an alkalinity build-up during the urea hydrolysis process, **not** the soil acidity as has generally been reported in the literature. The pathway of ammonia volatilised in a pasture system is also complex. Consequently, it is difficult to estimate the annual ammonia flux value for the Waikato region. However, from the available information in New Zealand on the extent of ammonia volatilisation from cattle urine voided onto pasture (Ball *et al.,* 1979; Carran *et al.,* 1982; Ball and Keeney, 1983) and the volatilisation potential studies on agricultural soils (Selvarajah *et al.,* 1993) it is estimated that on average about 20% of urine-N can be volatilised annually from Waikato soils.

Ammonia is also volatilised from dung at much slower rates than that from urine, hence the relative potential for N loss from dung through the volatilisation process is small (Ryden *et al.,* 1987). Approximately 3-8% of the dung-N is likely to volatilise under a range of Manawatu conditions (Sugimoto and Ball, 1989). This loss is only 1-3% of the total N excreted.

2.2.3.2 Leaching

It has been estimated that urea-N is voided at the rate of 800 kg N ha^{-1} during each urination event (Doak, 1952). If 20% of this amount is volatilised, 640 kg N ha^{-1} will remain in the soil system. Due to the ammonia build-up in soil the organic carbon present in soil can be hydrolysed to more labile forms. This is favourable for biomass growth and consequently a large proportion of the ammoniacal-N produced can be immobilised by the microbes. Trials performed on urea show that about 15% of the urea-N can be rapidly assimilated as ammonium and immobilised by microbes within 2 weeks of urea-N application onto the soil surface (Selvarajah, 1991). Microbial immobilisation of ammonium is a dynamic process and it continues until labile carbon (Okereke and Meints, 1985) or ammonium become deficient in the environment (Wickramasinghe *et al.,* 1985). Ammonium released from urea-N can also be taken up by plants. Under unsaturated conditions most of the remaining ammonium is oxidised (nitrified) to form nitrate.

After the hydrolysis process converts urea-N in urine into ammoniacal-N, it takes about two weeks for nitrate to appear in the soil. Among the mineral-N species, nitrate-N (NO_3^--N) has greater leaching potential than ammonium, because the ammonium ion (NH_4^+-N) is positively charged and hence adsorbed onto the cation exchange sites of clay and organic particles.

Unlike highly weathered tropical soils, New Zealand temperate soils have few or no anion exchange sites. Consequently, the nitrate form of N is very mobile in soil and can be leached below the rhizosphere during high rainfall or irrigation. The potential for soil N leaching increases when nitrate is generated in soil in excess of the amount required by plants. Often the conditions are not conducive for plant uptake of N in the urine patch because the high concentration of ammonia retards plant growth and under dry conditions may result in death of vegetation. Consequently the potential of nitrate to leach is very high in the urine patch.

Most Waikato soils contain allophanic minerals which are known to enhance the nitrification process (Baber, 1978). Apparently, the presence of allophanic minerals is more important for the nitrification process than the actual number of nitrifiers found in the environment (Sarathchandra, 1978). Thus Waikato soils have a greater potential for generating nitrate than other New Zealand soils. In the Waikato, moisture deficits are often experienced during

December, January, February and March, whilst recharge usually occurs during the balance of the year. Due to prevailing dry conditions nitrate tends to accumulate in the surface soil during summer. The summer conditions are favourable for high ammonia volatilisation losses from urine patches which can reduce the accumulation of N in soil. Despite such reduction, due to poor plant N uptake and reduced leaching the potential for nitrate to accumulate over the summer period is very high. Ground water samples collected in the Hamilton Basin clearly demonstrate that there is high influx of nitrate into shallow aquifers during the onset of the recharge period (Marshall, 1986). The nitrification rate slows down during winter, but nitrification is not completely inhibited by the cold conditions. The microbial species (nitrifiers) that oxidise ammonium to nitrate form in temperate soils are capable of nitrifying under cold soil conditions. Evidently, nitrate production has been observed in moist soils stored under refrigerated conditions (Selvarajah *et al.,* 1986).

Steele (1982) estimated that about 110 kg N ha^{-1} y^{-1} is leached in a dairy farm in the Waikato region. Ground water studies performed in the Hamilton Basin from 1981 to 1985 on some selected bores at 5-10 m deep had 12.1 g m^{-3} nitrate-N and those greater than 10 m had 5.7 g m^{-3} nitrate-N (Marshall, 1986). An estimation made from the above studies on the basis of an annual loading in a 5 m thick aquifer indicates that approximately 100 kg nitrate-N ha^{-1} y^{-1} could leach annually in Hamilton Basin under worst conditions (i.e. high soil nitrate accumulation over the summer followed by heavy recharge) (Selvarajah *et al.,* in prep.). Considering the high potential for leaching in the Waikato region (high rainfall coupled with greater nitrification rates), an estimated 100 kg N ha^{-1} is considered as the maximum annual leaching loss rate for the Waikato region.

2.2.3.3 Denitrification

Denitrification is a process where nitrate-N is reduced to nitrous oxide (N_2O) and/or dinitrogen (N_2) under reduced or anaerobic conditions. It has been a general practice to measure the amount of denitrification from the soil surface (topsoil). Sherlock *et al.* (1992) estimated that from intensively grazed New Zealand dairy pasture up to 10 kg N ha^{-1} y^{-1} of denitrification can occur. However, the extent of denitrification below the soil surface and in shallow ground water aquifers is several times greater than denitrification from the soil surface. Barkle *et al.* (1993) found that after a regular application of dairy shed effluent on a poorly drained soil (Te Kowhai silt loam) with an established pasture and perched water table, a substantial amount of dairy shed effluent-N applied onto pasture was unaccounted for (354-361 kg N ha^{-1}). These authors suspected that the applied N unaccounted for must have either been denitrified or stored as organic-N. Their results also showed that there was little or no ammoniacal-N present in the topsoil. These observations suggest that the ammoniacal-N in the dairy shed effluent is nitrified rapidly in the topsoil and either leached and subsequently denitrified or denitrified *in situ.* It is worth noting that the leachate obtained from these soil cores contained a substantial amount of iron.

Under reduced conditions many Waikato soils generate considerable amounts of the reduced form of iron (Fe^{2+}) that can also act as an effective electron donor, which is one of the main prerequisites for denitrification process. It has become a general rule of thumb that ground water aquifers which contain significant levels of iron (>0.3 g m^{-3}) will contain very little or no nitrate (Selvarajah *et al.,* in prep.). Considering the large number of ground water aquifers in the Waikato region with high iron levels, it is reasonable to assume that subsurface denitrification is one of the most important N removal mechanisms in certain parts of the Waikato region. However, from the point of view of N balancing in a dairy pasture system, the estimation of the subsurface denitrification is less important because the N budgeting only requires the extent of leaching loss of nitrate from the rhizosphere, not the fate of leached nitrate from the soil-plant system. Thus only the surface denitrification loss is considered for N balancing, which is estimated as 10 kg ha^{-1} y^{-1}.

2.2.3.4 Nitrogen removal through milk production

In the Waikato region 'factory milk supply' is generally produced from about mid-August to mid-May. 'Town milk supply' is carried out throughout the year. Most dairy farms in the Waikato region cater for 'factory milk supply' and thus the average milking duration for the Waikato region is considered as approximately 270 days. Farms that produce 'town milk supply' comprise a very small proportion of the total dairy farms in the region and hence not considered in determining an N budget for dairy pasture.

Milk production per given area depends mainly on the breed of cow, stocking rate, and pasture production. In the Waikato region there are a large number of Holstein-Friesian herds which produce low fat low protein milk. The crossbred cows (e.g. Holstein-Friesian x Jersey) produce more milk fat and protein than the pure breeds (Dairy Statistics, 1992-1993). On average, dairy farms in the Waikato region produce 388 kg milk fat ha^{-1} y^{-1} and 300 kg milk protein ha^{-1}. The calculated amount of N removed from the system is 46 kg N ha^{-1} y^{-1}. Approximately, 20% of the milking herd are 2 y old cows and unlike > 3 y old cows they use substantial amount of N for body growth. On the other hand, 2 y old cows produce about 15 kg milk protein less than the 3 y olds per milking season. The amount of N used for milk production and body maintenance is estimated as approximately 55 kg N ha^{-1} y^{-1}.

2.2.3.5 Nitrogen transfer to unproductive areas

Insufficient information is available on the amount of excreta-N that is transferred to non-pasture areas. Excreta can be deposited in substantial amounts in dairy sheds, raceways and camping areas (e.g. around water troughs). The amount of excreta deposited depends mainly on the length of time animals spend in these areas. For example it was estimated that the amount of time spent in the dairy and collecting yard is 2 h and hence about 8% of the excreta is deposited during milking time (Vanderholm, 1984). The length of time spent in the dairy shed varies greatly depending on the management practices. For example, data obtained from a Taranaki Regional Council (TRC) Technical Report (1990) showed that for a herd size of approximately 200 (n = 6) the time spent in the milking area was in the range of 60-180 min per milking. Assuming that the length of time spent in the milking area is directly related to the amount excreted, the range of excreta loss is estimated as 8-25% per day. It has been assumed that the amount of excreta deposited in the milking area is the same in the morning and afternoon. However, more excreta is generally deposited in the morning than in the afternoon. It is also suspected that certain milking management practices can have a profound effect on animal behaviour which in turn can influence the amount of excreta generated in the dairy shed. On the other hand, no accurate estimates have been made on the amount of excreta transfer to raceways and watering areas. Depending on the herd management, animals can spend a substantial amount of time in raceways (e.g. transfer of herds for milking or grazing) and hence a high amount of excreta deposited in the raceways.

Field and Ball (1982) estimated that the transfer of N to non-pasture areas as 32 kg N ha^{-1} y^{-1}. This figure appears to be very low compared with the greater amount and range of time spent by animals in non-pasture areas. It has been estimated that about 8% of the excreta is transferred to dairy sheds and a similar amount may be transferred onto raceways and camping areas collectively.

2.2.3.6 Other N pathways

Other N pathways are immobilisation of mineral-N, mineralisation of organic-N, surface runoff of N, and wet and dry deposition from the atmosphere. None of these pathways are considered in developing an N budget for dairy pasture system for the following reasons:

(i) Immobilisation/mineralisation turnover:

Plants require a continuous supply of mineral-N for growth. Apart from the mineral-N derived from urine patches, the soil organic-N pool supplies a substantial quantity of mineral-N. Soil organic-N is the largest pool of N in soil (up to 6000 kg ha^{-1} in 20 cm topsoil), hence it is difficult to notice any accumulation or depletion occurring in the organic-N pool. The dynamics of organic-N changes in soil is poorly understood. Under New Zealand conditions there may be a depletion of mineralisable organic-N reserve in soil during spring and early summer, however, a clover-based dairy pasture system is capable of replenishing it during cold months of the year (Field and Ball, 1982). Consequently, it is assumed that there is little or no change in net annual N turnover.

(ii) Surface runoff:

Surface runoff can occur during a high rainfall. The potential for surface runoff is greater for dung-N rather than urine-N. Urine-N is likely to leach into soil profile during a high rainfall. Surface runoff of dung-N increases with the increasing slope, rainfall intensity and soil compaction and decreasing density of vegetative cover.

Currently there is no information available on surface runoff of N in a dairy pasture system. Pastoral lands with moderate to steep slopes in the Waikato region are used mainly for sheep and beef farming (e.g. Waitomo, Coromandel, Taupo and Franklin areas). Most dairy farms are located in the lowlands of the Waikato region and hence the potential for surface runoff loss of N is considered minimal in a dairy pasture system in the Waikato region.

(iii) Wet and dry deposition from the atmosphere:

There is insufficient information available on this N pathway. In Europe ammonia gas is considered as an atmospheric pollutant (Williams, 1992). It is produced mainly from livestock farming where animals are housed permanently (piggeries) or temporarily (dairy). The main source of ammonia is from the waste produced from these farms. In New Zealand the main source of ammonia is grazed pasture. Although the ammonia volatilisation loss can be quantified for New Zealand (360000 tonnes y^{-1}) on the assumption of 25% loss from urine-N and 5% loss from dung-N (Hedley *et al.*, 1990), it is difficult to quantify the return of this volatilised ammonia back to the New Zealand pasture lands. An estimate made on the basis of the above figure of ammonia loss from pastures indicates that about 14 kg N ha^{-1} should return on the entire New Zealand land area. This figure is considered to be a conservative estimate of the return of volatilised ammonia, because the estimate does not take into account other sources of ammonia (e.g poultry, piggery, meat industry, industrial and municipal areas). Under New Zealand conditions, such predicted values of N deposition do not occur because of prevailing wind directions and turbulence. Total N measurements for rainwater at Ruakura, Hamilton indicate that the amount of N through wet deposition is very small (2 kg ha^{-1} y^{-1}) (Barkle *et al.*, 1993). Thus the input of N to a dairy pasture system through atmospheric deposition is considered negligible for the Waikato region.

2.3 NITROGEN BUDGET FOR CLOVER-BASED DAIRY PASTURE SYSTEMS IN THE WAIKATO REGION

Determining an N budget for any grazed pasture systems is a difficult task due to the interaction between pasture, soil and grazing animals. Various attempts have been made in the past to develop an N flow model for the Manawatu (Field and Ball, 1982) and the U.K. (Ryden, 1984; Jarvis, 1993) grazed pastures. Jarvis (1993) summarised, "although there are data from experimental systems, a total comprehension of flows is not yet possible". There can also be a substantial variation in soil, pasture and climatic conditions and farm management practices. It must be emphasised that the objective of the current section is not to identify and estimate the entire N flow pathways for the Waikato region. The aim is to estimate the net N balance for grazed pasture system in the Waikato. The current section uses the discussion in Section 2.2 and the information collected from selected dairy farmers, P Journeoux (MAF Policy, Ruakura), Dairy Statistics (Livestock Improvement 1991/92) and Field Officers (Environment Waikato) as a base for estimating the N budget.

Stocking rates in the Waikato region can vary greatly, but are typically from 2.0 to 3.5 cows ha^{-1}. Milk production also varies from about 300-700 kg milk fat ha^{-1}. However, most dairy farms in the Waikato produce above average milk and have above average stocking rates. The annual estimate for the consumption of plant-N and the excreta-N flows are illustrated in Figure 1. Note that the amount of N deposited in dairy sheds and raceways and camping areas is 2 x 37.2 kg ha^{-1} y^{-1} (rounded up to 76 kg ha ^{1} y'^{1}).

2.3.1 Assumptions

Average annual dry matter consumption in the Waikato region	= 13000 kg N ha-1
Nitrogen in clover-based pasture (dry weight basis)	= 4%
Average annual milk fat production	= 388 kg ha^{-1}
Average annual milk protein production	= 300 kg ha^{-1}
Stocking rate	= 2.7 cows ha^{-1}
Loss of N in raceways & camping areas	= 8% of total N excreted
Loss of N in dairy shed	= 8% of total N excreted
Average milking period	= 270 d

Nitrogen input through wet or dry deposition is negligible.
Surface runoff losses of N in dairy farms are negligible.
Calves are not considered in the N balance estimations.

Table 1. Nitrogen balance for grazed clover-based pasture systems in the Waikato region

Nitrogen transformation processes	Input (kg N ha^{-1} y^{-1})	Output (kg N ha^{-1} y^{-1})
Clover N fixation	200	-
Products (milk + maintenance)	-	55
Ammonia volatilisation	-	35
Leaching	-	100
Raceways	-	38
Dairy shed	-	38
Denitrification	-	10
TOTAL	200	276

DEFICIT = INPUT-OUTPUT = -76 kg N ha^{-1} y^{-1}

2.4 EFFECT OF DIFFERENT N LOADING RATES ON THE ENVIRONMENT

It becomes very clear that an intensively managed clover-based dairy pasture system with zero fertiliser N input will result in N deficit. The main reason for net deficit occurring in the system is the large amount of plant protein-N ingested (520 kg N ha^{-1} y^{-1}) is excreted (465 kg N ha^{-1} y^{-1}) (Figure 1). A substantial proportion of the excreta-N is urine-N (231 kg ha^{-1} y^{-1} onto pasture) and excreted mainly in the form of urea (about 75%) and the potential for loss of N either through ammonia volatilisation or leaching (urea-N and/or nitrate-N) is very high.

As indicated in the N budget, a large proportion of the soil N is leached below the rhizosphere in the Waikato region. Baber's (1978) ground water studies performed in the Hamilton Basin emphasised that the main source of ground water nitrate in the Waikato region is from clover-based intensively grazed farm lands. His studies were performed in the early 1970s during which period dairy farmers in the Waikato region used little or no N fertiliser. He demonstrated that about 30% of the bores tested in the Hamilton Basin had nitrate levels above the World Health Organisation (WHO) limit (10 g NO_3-N m^{-3}) and the maximum level recorded was 58 g NO_3-N m^{-3}.

It has often been suspected that increasing fertiliser N use is the main cause for nitrate level increases in the environment. It must be emphasised here that when used with sufficient spread of doses in small application rates, the use of fertiliser N can result in increased farm productivity (e.g. Roberts and Thomson, 1990). Increased rates of N application can be used in 'cut and carry' pasture systems (e.g. hay and silage production) with little or no impact on the environment. Studies performed in the U.K. clearly demonstrated that when managed carefully, large amounts of fertiliser N (420 kg N ha^{-1} y^{-1}) could be used on cut ryegrass with little leaching of N. However, when grazed the leaching losses of N were substantial -resulting in losses up to 6 times greater than the cut grass system (Ryden *et al.*, 1984). This paper and several other papers have clearly demonstrated that the main cause for nitrogen loss from the dairy pasture system is the presence of animals (Field and Ball, 1982; Ryden, 1984). Ball and Field (1989) concluded "clover-based pastures suffer chronic shortages of nitrogen, *no matter how well they are managed"*. There will be a net N deficit in a New Zealand grazed dairy pasture system regardless of the type of pasture used.

The 'driving force' of the N depletion in dairy pasture systems is the urinary excretion of nitrogen ingested by animals. When animals are fed on pasture that receives high fertiliser N the amount of N ingested increases with increasing levels of N excreted in urine but with little change in dung-N (Appendix 2) (Jarvis *et al.*, 1989).

As stated in Section 2.2.1, increasing fertiliser N application will increase pasture yield, however, it will also increase plant N content. Thus fertiliser N must be applied at rates that do not trigger accumulation of N in plants. The most sustainable way of applying N to dairy pastures is to balance the deficit in the system. However, if greater dry matter production per area is required, N loading should exceed the deficit, but this N loading will result in increased loss of N from the system.

What dictates the mechanism of urinary excretion of N? In ruminant animals, when N is ingested it is transformed into ammonia and amino acids through microbial breakdown. Whilst amino acids are absorbed in the small intestine for protein synthesis in animals, ammonia can be either converted into urea or recycled in the system. When intake of N exceeds that of the required level, the net N loss to ammonia exceeds conservation of N in the system. The excess level of ammonia produced in the rumen not only increases the urea output in urine, but triggers greater metabolisable energy use for recycle of ammonia produced or synthesis of ammonia into urea. Since clovers contain a higher amino acid content than grass, a greater amount of N is absorbed in the digestive system and consequently plant protein losses as ammonia are greater in animals fed with grass (Waghorn and Barry, 1987). The unabsorbed amino acids and plant protein (mainly clover protein) can escape through faeces (dung-N).

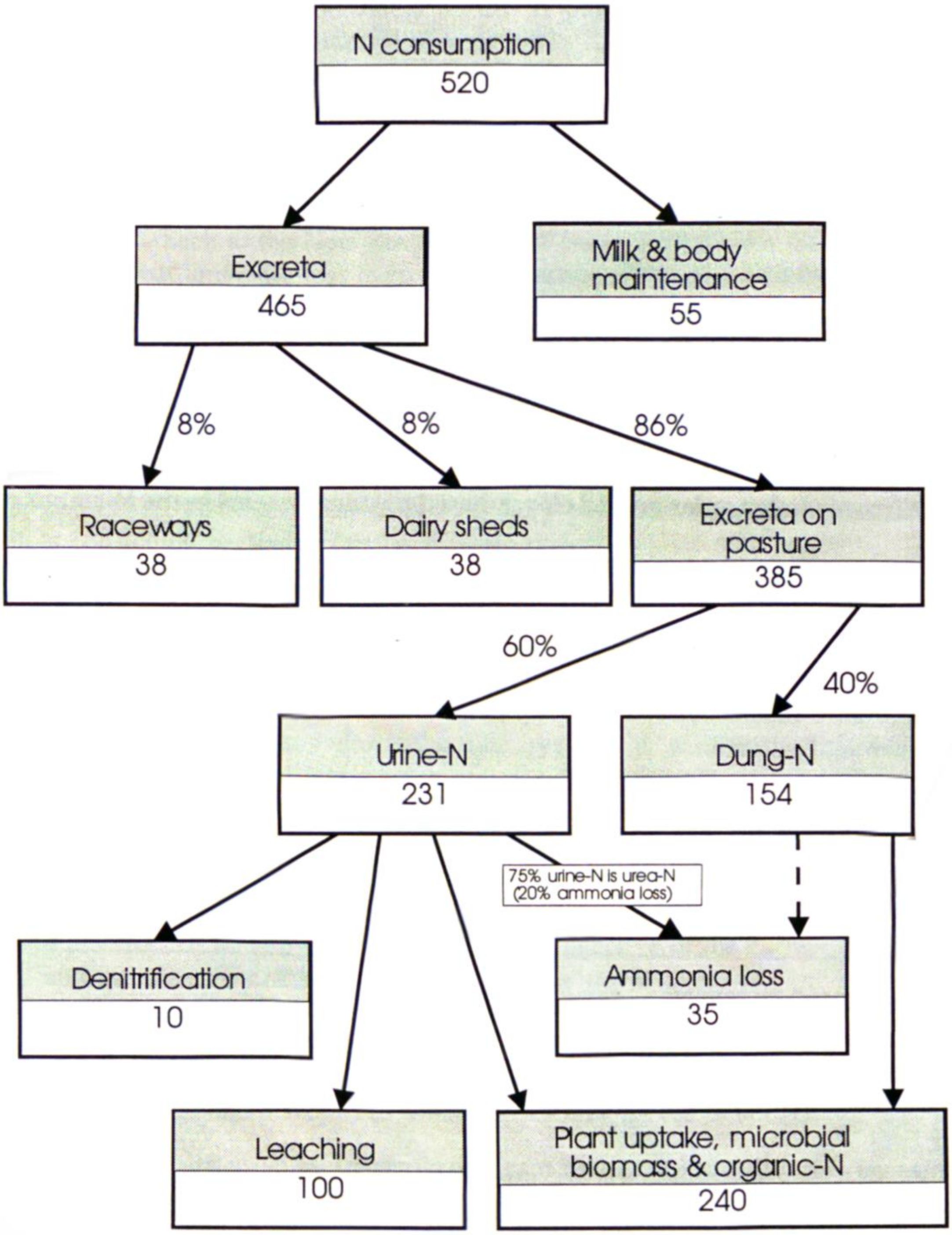
About 45% of New Zealand dairy farms are located in the Waikato region and about one third of the land in the Waikato region is used for intensive dairy pasture production. Consequently, the Waikato regional economy depends heavily on dairy farming. Dairy farming in the Waikato is also of national importance since about 50% of the country's dairy products are produced in the Waikato region. The current trend towards an increasing number of herds and herd size in the region corresponds with increasing returns from dairy farming. The best practicable option is to reduce or minimise any adverse effects of dairy farming practices on the environment with little or no impact on the economy.

Plant breeders and animal nutritionists must develop cultivars of pasture which will increase the efficiency of the absorption of plant N and reduce excretion of N through urine in ruminants. Deep rooted pasture species are another option which will extend root systems into the soil profile for nitrate and other nutrients and will reduce the potential leaching loss of soil N and increase the stability of plants on light soils (J Crush, pers. comm.).

2.5 NITROGEN IN DAIRY SHED EFFLUENT

Dairy shed effluent is produced in the morning and afternoon during the milking season. Generally cows excrete a greater amount of excreta in dairy sheds in the morning than in the afternoon. Dairy shed effluent contains animal excreta, water used for cleaning the floor, milking equipments and milk vats, detergents and soil transferred by animals. Most farms have little or no provision for storm water diversion (collected in the dairy shed area) and this water can runoff with dairy shed effluent.

Figure 1. Fate of N ingested by cows in a dairy pasture system in the Waikato Region (kg N ha^{-1})



2.5.1 Factors influencing effluent quality

Dairy shed management:

Washing practices in dairy sheds vary greatly. Some farms do not wash the yard after the afternoon milking and leave it for the following morning. Certain farms have tipping barrels installed in the milking shed yard that splash water on the yard to keep the floor moist and to wash down some excreta.

Detergents are used in the dairy shed mainly to wash milk plants. The extent and types of detergents used can vary greatly. The detergents used are either acidic or alkaline. Generally acidic detergents are used daily and the alkaline detergents are used either on a weekly or monthly basis. The amount of detergent used varies from about 150-300 mL d^{-1}. Depending on the amount and strength of the detergents used, acidic detergents can enhance the preservation of ammonia whilst alkaline conditions can accelerate the ammonia volatilisation process or urea-N excreted. Most raw effluents have elevated pH (8.5-8.9), mainly because of urea-N forming ammonia (Eq. [2]). Elevated effluent pH is the driving force for the ammonia volatilisation process or an effluent containing high ammoniacal-N and urea-N, which is the initial stage of the excreta-N loss process. Consequently, any chemical that affects the net pH of effluent can affect the ammonia loss process.

$$CO(NH_2)_{2(aq)} \text{ (Urea)} \rightarrow NH_{3(aq)} \overset{NH_{3(gas)}}{\uparrow} \text{ (Ammonia)} \rightarrow NH_4^+{}_{(aq)} \text{ (Ammonium)} \quad [2]$$

Effluent management:

Dairy shed effluent is managed differently by farmers. In the Waikato region about 30% of farms irrigate dairy shed effluent whilst the balance use pond or barrier ditch treatment systems to treat the effluent. Irrigation practices vary greatly. Effluent can be irrigated from the following sources:

(i) raw effluent from a sump containing a trip mechanism;
(ii) raw effluent stored in a temporary storage system for land application; and
(iii) holding ponds (holding ponds are either specifically designed to hold effluent for a given period or effluent pond systems that have been converted to function as holding systems).

The effluent obtained from all the above sources is referred to as dairy shed effluent and hence the quality of the effluent varies greatly. Raw dairy shed effluent contains readily mineralisable (urine-N) and slowly mineralisable (dung-N) N forms. Since a large proportion of readily mineralisable N is urea-N (approximately 45%), the potential for ammonia loss through volatilisation is also very high (see Eq. [2]). Consequently, a substantial proportion of ammonia released from urea can be lost from the effluent within two to three days following effluent collection. When the effluent is stored in holding ponds (anaerobic), N losses can be more severe due to organic-N breakdown into ammoniacal-N and the subsequent release of ammonia or nitrification followed by denitrification. There is insufficient information available on the changes in N content of effluent stored for a given time period.

Other factors:

Soil mineral-N availability can indirectly influence the amount of N excreted. Increased rates of N fertiliser use can increase plant uptake of N and result in increased consumption of plant N (Section 2.5). This can increase the amount of N excreted by grazing animals (Jarvis *et al.*, 1989). On the other hand, mineral-N levels in soil increase during spring and summer and hence increase the plant absorption of nitrogen. Goold (1980) showed that the N levels in dairy shed effluent fluctuated throughout the milking season following a bimodal pattern. Pasture composition can also regulate the amount of N excreted (see Section 2.4).

2.5.2 Nitrogen content of dairy shed effluent (g cow^{-1} d^{-1})

Although the N content of dairy shed effluent can vary greatly within and among farms it is essential to know the approximate level of N in effluent for the purpose of land application. There is insufficient information available on the content of N of raw or stored effluent.

Sample collection and preservation:

Sample collection and preservation is very critical in determining the N content. Collection of representative samples of raw effluent from a dairy shed is not an easy task. Samples collected from an effluent outlet during washing are true representatives because the N content can vary depending on the stage of the washing process. Ideally, the entire supply of the effluent should be collected in a container and representative samples can be obtained after mixing it thoroughly. In this manner the effluent volume can also be estimated, which is required for N concentration estimation. If the daily rate q N excreted is to be determined, both morning and afternoon samples should be collected. However, sample collection for N analysis for stored effluent is very easy (e.g. tank or holding ponds). Representative samples can be obtained after mixing the effluent thoroughly. Effluent samples contain free ammonia hence the use of acid preservative stabilise free ammonia and inhibit microbial activity.

Data on total-N content in dairy shed effluent:

The most widely used datum for dairy shed effluent N content is that of Vanderholm (1984), who uses an average value of 10.4 g cow^{-1} d^{-1} from a range of 6.8 to 19.0 g cow^{-1} d^{-1} (Table 2). A one-off survey has been performed to determine the daily production of effluent volume and N quantity for dairy sheds in the Waikato region. Samples were collected from 6 farms with herd size varying from 120 to 290 cows. Effluent was collected in tanks after the morning washings. Two farms had twice daily collection of effluent whilst the balance of the farms collected in the morning only. Samples were analysed for total-N using Kjeldahl method. The average amount of N produced was 12.2 g cow^{-1} d^{-1} and the average volume of effluent produced was 45 m^3 d^{-1} (Table 2).

Table 2. The quantity of effluent and N produced in dairy sheds

Source	Effluent volume (L cow^{-1} d^{-1})	Total-N levels (g m^{-3})	N cow^{-1} d^{-1}
Vanderholm (1984)	Range 20-90 Average 50	Range 100-325 Average 208	Range 6.8-19.0 Average 10.4
Environment Waikato	Range 30-55 Average 45	Range 136-455 Average 271	Range 9.0-14.7 Average 12.2

Further raw dairy shed effluent surveys are planned farms in the region. However, the quick survey results have shown that the values determined by Vanderholm (1984) are comparable with preliminary data collected by Environment Waikato. Since the effluent is applied at various stages of storage the N content of effluent can vary substantially. Stored effluent can sustain significant N losses during storage and thus a value of 10 g cow^{-1} d^{-1} is used as an average amount of N produced. The volume of effluent produced also can vary greatly. Since the quick survey samples were collected from farms that store effluent in tanks, it is suspected that waste minimisation could have reduced liberal use of water for washing. Farms that use larger storage facilities or irrigate directly from the yard are likely to use greater volumes of water and thus an average effluent volume of 50 L cow^{-1} d^{-1} is estimated.

2.6 ANNUAL N LOADING RATE FOR THE WAIKATO REGION

The main criteria considered for determining an annual N loading rate for dairy pasture systems are the impact of the loading rate on the environment and pasture production. According to the estimated annual N budget, the N deficit in a dairy pasture system in the Waikato region is 76 kg N ha^{-1} y^{-1} (Section 2.3.2). It must be emphasised that this is the *maximum* estimated N deficit in a clover-based pasture system under a worst case scenario (e.g. warm and humid climate), poor herd management (e.g. prolonged presence of animals in non-pasture areas) and light soils. Consequently, leaching and ammonia volatilisation losses and excreta transfer to unproductive areas (raceways, watering areas and dairy sheds) have all been estimated using maximum levels for dairy pasture systems in the region. Consequently, assuming that the average clover N fixation of 200 kg ha^{-1} y^{-1} remains constant throughout the year, the N balance in soil can vary greatly, from an excess N supply to a deficit of approximately 76 kg N ha^{-1} y^{-1}.

Recommendation for fertiliser N applications made for *grazed* pasture that are determined solely on the basis of plant uptake of N should be considered with caution. Although the dry matter production can be increased substantially by adding fertiliser N, the adverse effects on the environment may be very severe (Section 2.4). From the farming point of view application of excess fertiliser quantities is poor management of N. Good farming practices aim at minimising nutrient losses without decreasing farm productivity. In the case of N, it should be retained in the rhizosphere as long as possible without being lost to the atmosphere or below the rhizosphere. On the other hand, crop production without the presence of grazing animals (hay or silage making, wheat or barley production) can be managed with significant fertiliser N applications - with little or no impact on the environment (Section 2.4). In this case, the major N removal pathway is plant uptake of N and the fertiliser N recommendation can be made on the basis of crop requirements for N.

Effluent containing free ammonia (NH_3) and/or urea can sustain volatilisation losses when applied onto pasture. Dairy shed effluent contains a substantial proportion of free ammonia and urea depending on the duration of storage. Application rate recommendations for effluent that are based on nutrient loading must consider the loss pathway of the nutrient applied. Information available in the overseas literature on ammonia loss from surface applied farm effluent is plentiful (Beauchamp *et al.,* 1982; Ryden, 1984; Thompson *et al.,* 1987; Smith and Chambers, 1993). Very little or no information is available on the loss pathways of dairy shed effluent N surface applied onto pasture in New Zealand. Ammonia volatilisation from piggery effluent surface applied onto pasture has been estimated as 10% (20 kg N ha^{-1}) of the applied N (200 kg N ha^{-1}) for a Lismore silt loam under Canterbury conditions (Cameron and Rate, 1992). Piggery effluent contains greater levels of N (0.17% compared with 0.02% in dairy shed effluent) (Vanderholm, 1984) and a very high proportion of ammoniacal-N (about 85% of total-N) (Cameron and Rate, 1992) hence a greater ammonia volatilisation potential than dairy shed effluent. It has been estimated that trace amounts of ammonia are lost (5 kg ha^{-1}) from dairy shed effluent (collected from a storage tank) applied onto a pastoral soil (Te Kowhai silt loam) at very high rates (511 kg N ha^{-1}) (Barkle *et al.,* 1993). Thus it can be assumed that ammonia losses will be relatively small from a wide range of dairy shed effluent applied in the Waikato region.

Considering the worst case of N loss from grazed clover-based pasture systems in the Waikato region, a recommendation of 100 kg N ha^{-1} annual N loading rate is made for land application of dairy shed effluent. Since the N in the effluent is in both mineral and organic forms (with long-term and short-term mineralisable N) it is an ideal manure for land application. Unlike its mineral counterpart (fertiliser N), this manure is believed to take any 'shock' in the system caused by sudden demand for or 'flush' of mineral N due to seasonal changes, or other factors affecting the net mineralisation/immobilisation turnover. There is very little information on the long-term effects of dairy shed effluent application at rates such as 100 kg ha^{-1} y^{-1} on pasture performance and the environment. It must be emphasised here that only long-term research on land application of dairy shed effluent onto grazed clover-based pasture can reveal the transformation dynamics of soil N in a clover-based pasture system.

2.7 NITROGEN AND HYDRAULIC LOADING RATE PER APPLICATION (DOSE)

2.7.1 Nitrogen loading per application

It is important that the effluent applied onto land is treated as a manure or fertiliser rather than a 'waste'. The concept of 'land treatment' of dairy shed effluent should change to 'land application'. Despite the high content of organic-C, N, P and K in the dairy shed effluent, it is regarded as 'waste' by many farmers in New Zealand. Smith and Chambers (1993) recognise similar problem in the U.K. where farm effluent is regarded by the U.K. farmers as 'waste material' rather than a source of plant nutrients. The rate of application of effluent is important from the point of view of efficient use of nutrients and environmental effects.

Numerous N fertiliser trials have demonstrated that N applied in split-small doses result in greater crop yield than N applied in single-large doses. When N is applied in large doses that exceed plant uptake rates the potential for N loss is greater. This is mainly because plant response to applied N reduces above a threshold application rate (Roberts and Thomson, 1989). Although greater rates of N application can increase the DM production, the increase of kg DM per applied kg N will be lower at high rates of N application. This is simply referred to as 'N response' in kg DM kg"^{1} N. Several workers have suggested that the appropriate rate of N application for a single dose of fertiliser N is between 25 and 50 kg N ha^{-1} for good pasture response to applied N (O'Connor and Cumberland, 1973; Steel *et al.,* 1981; Roberts and Thomson, 1989).

Since dairy shed effluent contains both organic and inorganic (mineral) forms of N, it can be applied at greater rates than fertiliser N. However, considering the safe hydraulic loading per application (see Section 2.7.2) a rate of 50 kg N ha^{-1} is recommended.

2.7.2 Hydraulic loading

One of the additional benefits of using dairy shed effluent as a manure over solid N fertilisers is the large amount of water in the effluent (up to 99%). Farms can obtain greater pasture production during summer when soil moisture can restrict pasture performance. On the other hand, the recommendation made on the rate of effluent application must consider the deleterious effects of hydraulic loading on nutrient leaching (mainly from urine patches where N is often found at a concentration of up to 800 kg N ha^{-1}), subsequent ground water pollution, and surface runoff of the effluent into water bodies.

Hydraulic loading rates for a given time period must consider the infiltration rate of heavy soils. Heavy soils can receive up to 7 mm h^{-1} without causing any surface ponding or runoff (P Singleton, Landcare pers. comm.). However, MAFF, Welsh Office Agriculture Department (1991) recommend a rate of 5 mm ha^{-1} for farm waste application. Considering the greater suspended solids present in dairy farm effluent in the U.K., such a conservative rate of application appears reasonable, because the presence of high suspended solids can reduce infiltration rates by sealing the soil surface. For example, significant reduction of infiltration rates has been observed when soils were irrigated with meat processing plant effluent (suspended solids (SS) ranging from 1400 to 2200 mg L^{-1}) (Balks, 1991). In comparison, raw dairy shed effluent contains 2800-9300 mg SS L^{-1} (TRC Technical Report, 1990). Although dairy shed effluent contains a greater amount of SS, the effect of soil surface sealing can be different from that of a meat processing plant effluent.

One of the practical problems with the recommendation of hydraulic loading rates based only on soil infiltration rates is the compatibility of the effluent irrigation equipment. Effluent can be applied using: tankers, pot irrigators, travelling irrigators, spray guns and single sprinkler sprayers. Travelling irrigators are increasingly being used on dairy farms to irrigate dairy shed effluent. Although the capital cost is very high, it is a convenient and efficient irrigation system. The effluent pressure is important for the movement of a travelling irrigator. At low rates of application, travelling irrigators are likely to stall (G Barkle, Agricultural Engineering Institute, Ruakura, pers. comm.). Alternatively, such problem can be solved by increasing the effluent pressure and reducing the teeth setting, which will increase the travelling speed of the irrigator. The principal operational problem associated with increasing the travelling speed of the irrigators is the requirement for frequent shifting of the irrigator. However, it becomes clear that systems such as travelling irrigators can be manipulated to suit the soil and climatic conditions of the region.

Giffney (1984) recommends that for dilute effluent (e.g. dairy shed) a rate not exceeding 50 mm d^{-1} is a reasonable hydraulic loading under most conditions. The recommendation identifies dairy factory wastes as stronger effluent (high nutrient levels) than dairy shed effluent and recommends nutrient loading as the main criterion for selecting application rates for stronger effluent. Considering all these aspects, a maximum rate of application of 25 mm d^{-1} appears to be practically possible, which is also considered to have little or no adverse effect on the environment as long as there is no surface runoff of effluent into water bodies. This application rate also meets the N loading per dose requirement (Section 2.7.1) and thus is considered to be appropriate for using on grazed pastures in the Waikato region. It must be emphasised here that this rate is the maximum rate of effluent application per dose recommended, and farmers should use appropriate application rates to avoid surface runoff or ponding of effluent.

Farmers can apply effluent twice a year at the rate of 25 mm per application. For better nutrient management it is advisable to apply the second dose 3-4 months following the first application. However, considering the grazing cycle (7 days per paddock) and the length of time required for the pasture to be palatable for animals (3 weeks are required for better palatability), a minimum of 1 month is required for the subsequent and final application of effluent for the milking season.

2.8 MINIMUM LAND AREA REQUIRED FOR IRRIGATION

As a regulatory requirement for a permitted activity such as dairy shed effluent application on land, it is appropriate to provide the information on the amount of land area required for effluent irrigation practices. Such information will be helpful for resource users and regulatory authorities to effectively manage land application of dairy shed effluent effectively. From the practical point of view, it is convenient for farmers to confine effluent irrigation activities close to dairy sheds. Ideally effluent must be used on an entire farm area on a rotational basis, which will ensure a good distribution of organic matter. Although this practice is often impractical or uneconomic some farms have effluent spreaders that can distribute the effluent onto most of the farm.

Assumptions:

Herd size	= 200 cows
Average N in dairy shed effluent	= 10 g cow^{-1} d^{-1}
Average number of days milking	= 270 d milking $period^{-1}$
Annual effluent N application rate	= 100 kg N ha^{-1}

Calculations:

Total N excreted in dairy shed	= 2 kg N d^{-1}
Total N excreted per milking season	= 540 kg N d^{-1}
Total area required for effluent irrigation	= 5.4 ha
Area required per cow	= 270 m^2

Key for easy calculation: Number of milking days = Area required (m^2) per cow

2.9 PHOSPHORUS (P) AND POTASSIUM (K) IN DAIRY SHED EFFLUENT

Despite the variety of nutrients (e.g. P, K and S) found in dairy shed effluent in considerable amounts, questions have been raised in the submissions for the reasons for considering only N. The average amount of P and K found in dairy shed effluent is 1.76 g P and 8.0 g K cow^{-1} d^{-1} respectively. Annual loading of P and K in relation to N (@ 100 kg N ha^{-1}) is 17.6 kg P and 80 kg K respectively.

The following reasons are provided for not considering P and K as nutrients of concern:

a) It has been estimated that a substantial proportion of K and P can be lost from the system through milk production, and transfer of nutrients to unproductive areas annually (Hedley *et al.*, 1990).

b) For certain soil types (e.g. pumice), K excreted in urine can be leached in large quantities through macropores and lost from the pasture root system (Williams *et al.*, 1990).

c) A substantial amount of K can be fixed by certain clay minerals that are not readily available. This also applies to P where P can react with aluminoferric oxide and calcium minerals found in soils. The amount of aluminoferric oxides found is greater in allophanic soils and hence P fixation is greater in soils of volcanic origin. Phosphorus that reacts with soil minerals is not readily available for plants.

d) Since phosphorus tends to react with organic matter and soil minerals on surface soil, P has a greater potential for surface runoff loss than other nutrients (Hedley *et al.*, 1990).

Thus the application of P and K through effluent irrigation can only supply a proportion of P and K required per given grazed area. Moreover, P and K are not considered as ground water contaminants. Prolonged use of P fertilisers in luxurious amounts may result in P saturation in soil, and P may leach into ground water as reactive phosphorus. Phosphorus found in ground water can reach surface waters depending on the ground water flow directions. Phosphorus is considered as a pollutant in surface waters, because it can trigger algal blooms (Wilding *et al.*, 1977). It is likely that the amount of P applied through effluent irrigation will not accentuate the current P status of surface water.

There has been a concern in the submissions that excess K causes magnesium (Mg) deficiency in soil. Excretal K is present in urine in very high quantities and hence dairy shed effluent contain high levels of K. Consequently, dairy shed effluent applied onto pasture can enhance uptake of K in relation to other cations, which result in reduced Ca and Mg levels in plants (Lowe, 1993). Nevertheless, K in the effluent is unlikely to cause severe Mg or Ca deficiency either in plants or soil (assuming that dairy shed effluent is irrigated onto pasture at a rate of 80 kg K ha^{-1} y^{-1}). Goold (1980) demonstrated that dairy shed effluent applied on to Northland pastures at 156 kg N ha^{-1} y^{-1} for 4 milking seasons corresponded with a small but statistically insignificant increase in soil Ca and Mg levels.

It must be emphasised that it is not appropriate to expect dairy shed effluent to provide all essential nutrients in a balanced form. Good farming practices use nutrient supplements to correct plant or animal deficiency of nutrients. It is believed that the extent of K related problems are more related to urine patches than the use of highly diluted effluent due to intensive grazing practices. Moreover, since the potential key contaminant in dairy shed effluent is N, the purpose of the determination of safe effluent application rates is to prevent or minimise any potential leaching of nitrate-N into ground water. It is emphasised that the dairy shed effluent rules do not prevent farmers from maintaining the balance of essential nutrients (e.g. P, K, Mg and S) in relation to applied N.

2.10 RECOMMENDATIONS

1. The maximum annual effluent loading should be either 100 kg N ha''^{1} or 50 mm effluent y^{-1}.

2. The maximum rate of effluent application per dose should be 25 mm d^{-1} with a minimum return period of 1 month.

3. The minimum area required for irrigation of dairy shed effluent should be 270 m^2 cow^{-1}.

4. The loading of P and K need not be considered in the land application of dairy shed effluent.

3 SLUDGE

3.1 SUBMISSIONS

Several concerns have been raised about sludge application to land. It has been questioned whether the land application of sludge should meet the rules (s 3.3.1) specified for the land application of dairy shed effluent. It has been indicated that wet sludge contains greater levels of nutrients and hence should be applied at lower rates than dairy shed effluent. However, a contrary claim has been made that sludge can be applied onto crops or non-pasture areas at rates greater than the loading rate specified and that the reference to sludge is unnecessary because sludge is not a contaminant. It has also been pointed out that the minimum area (200 m: cow"[1]) requirement for sludge application is irrelevant and impossible to comply with.

3.2 WHAT IS SLUDGE?

Sludge is a term that is widely used in the industrial, municipal and agricultural waste management practices and hence has many definitions.

The Concise Oxford Dictionary (1983): "thick greasy mud; sewage; muddy or slushy sediment or deposit; accumulation of dirty oil, esp. in sump of internal combustion engine;"

Chambers Science and Technology Dictionary (1992): "A slime produced by the precipitation of solid matters from liquid sewage in sedimentation tanks".

NZ Land Treatment Collective (1992): "…the by-product of wastewater treatment performed to remove organic and inorganic solids, nutrients and pathogens. Sludges are separated from wastewaters by a combination of physical, chemical and biological in-plant processes. The sludge can be derived from wide variety of municipal or industrial sources".

Agricultural Waste Manual (NZAEI): "(1) The accumulated solids separated from liquid, such as water or wastewater during processing, or deposits on bottoms of streams or other bodies of water. (2) The precipitate resulting from chemical treatment, coagulation, or sedimentation of water or wastewater".

In the case of dairy shed effluent treatment, sludge refers to the solids separated from 'treated' liquid effluent and is collected at the bottom of the anaerobic, oxidation and barrier ditch systems. Unlike certain treated municipal and industrial sludges, sludge generated from dairy shed effluent treatment systems contains a substantial amount of nutrients and bacteria. A sludge derived from an anaerobic pond system (21 d following the end of a milking period) contained high amounts of total-N (1597 g N m^{-3}), total-P (173 g P m^{-3}), K (751 g K m^{-3}), Ca (532 g Ca m^{-3}), total-S (432 g S m^{-3}), faecal coliforms (660/100 mL) and *Bacillus subtilis* (2.2 x 10^7/100 mL) (Cameron *et al.*, 1993). Sludge contains high amounts of nutrients compared with dairy shed effluent mainly due to dewatering during sedimentation. Unlike raw dairy shed effluent, a large proportion of sludge contains solid materials.

Dairy shed effluent sludge is defined here as *"the slime or slush material that is collected in either anaerobic or aerobic treatment systems, where there is little or no potential for further treatment"*. In barrier ditch systems sludge can accumulate within one year, whilst in anaerobic and oxidation pond systems it can take 5-10 years.

3.3 LAND APPLICATION OF SLUDGE

Since desludging is performed very occasionally, the question of land application seldom arises. Sludge application can be performed at greater rates of nutrient loading than dairy shed effluent. The only contaminant of concern for land application of sludge is N. Compared to raw dairy shed effluent (45% of N is in rapidly mineralisable form, i.e. urea), sludge contains a substantial amount of organic-N. An estimate from the data obtained from Cameron *et al.* (1993) showed that only 10% of the organic-N is in the form of mineral-N. Kolenbrander (1981) estimated that about 40% of cattle slurry N is mineral fraction, and 30% is mineralisable within one year of land application, which indicates that 70% of the dairy shed effluent is mineralisable within one year. The total-N concentration in raw dairy shed effluent is approximately 500 g N m^{-3} (estimated from TRC Technical Report, 1990), thus 350 g N m^{-3} is mineralisable. It is believed that a substantial amount of organic-N in sludge is in a slowly mineralisable form, because most readily mineralisable organic-N would have been released within the time period provided for treatment. Thus if sludge is applied to land, despite the greater sludge-N levels, the rate and amount of mineral N release from sludge will be small compared to that of raw dairy shed effluent. Consequently, sludge can be applied onto grazed pasture at rates greater than 100 kg N ha^{-1} y^{-1}. Sludge can be applied at greater rates onto non-grazed pasture (hay or silage making or crops). Sludge is an excellent source of organic matter and hence can also be used on cultivated soils to increase the depleted soil organic matter.

Sludge must be applied onto the land thinly for rapid pasture recovery. Sludge applied at high rates can smother pasture and regrowth of pasture can be adversely affected. In some cases thick application can result in plant death. Generally, desludging is performed during dry periods of the year and hence the question of surface runoff seldom arises. However, care should be taken to avoid application of sludge on steep areas.

Although sludge has a high quantity of slowly mineralisable organic-N, it also has considerable amounts of P, K, Ca and S (see Section 3.2). In relation to the organic-N in sludge, these nutrients are in more readily mineralisable forms. In order to avoid high nutrient loading, either from N or other nutrients, it is advised that sludge should not be applied onto land that is used for dairy shed effluent irrigation.

3.4 RECOMMENDATIONS

1) Sludge is defined as *"the slime or slush material that is collected in either anaerobic or aerobic dairy shed effluent treatment systems, where there is little or no potential for further treatment"*.

2) Sludge is a contaminant and hence should be applied to land carefully.

3) Since sludge contains a high proportion of slowly mineralisable organic-N, it can be applied safely on pasture at rates greater than 100 kg N ha^{-1} y^{-1}. Sludge can be applied at greater rates onto cultivated soils (non-pasture areas).

4) Sludge should not be applied on to land that is used for dairy shed effluent application.

5) Research must be performed on the long-term effects of the use of sludge on pasture and crops.

4 THE NEED FOR AN EFFLUENT STORAGE SYSTEM

4.1 SUBMISSIONS

Numerous submissions have been made regarding effluent storage. It has been emphasised that storage systems are difficult to install and maintain in areas where the water table is high and that clay liners are inefficient for temporary storage of effluent (due to cracking). The cost of lining is considered to be a major disincentive for using a spray irrigation system. Moreover, solids are suspected to settle in storage systems and become difficult to remove when pumped. The use of aerobic ponds as a detention system has been questioned because the effluent pumped from an aerobic pond is believed to be a greater risk to nitrate pollution in ground water than irrigating raw effluent. It has been suggested that before introducing any controls on runoff, Environment Waikato needs to investigate procedures for rapid repair for system malfunction, the filtering ability of grass swards, the assimilative ability of receiving waters during high flow and some alternatives to storage.

It has also been stated that if rainfall causes surface runoff, under such conditions receiving waters could handle dairy shed effluent runoff with little impact. A recommendation was made that all references to 'non-sprayable periods' should be deleted from the rule and to rewrite a condition to avoid ponding or surface runoff of effluent into waterways.

4.2 STORAGE SYSTEM REQUIREMENTS

Land application of dairy shed effluent requires a pump, pipes, irrigators and effluent storage. As stated previously, effluent storage can be a sump, tank, spreaders or holding pond. The size and type of an effluent storage system primarily depend on the frequency of irrigation, herd size, type of irrigation and washing practices in the dairy shed. However, the design of an effluent system must also consider pump breakdown and non-sprayable periods. Generally, about 2-3 days are sufficient to repair the pump, and hence for a herd size of 200 cows an extra 30 m^3 emergency storage space is required. Alternatively, farms can install back-up pump system for emergency purpose.

4.2.1 Non-sprayable periods

The design of storage systems for non-sprayable periods is a difficult task. Effluent must not be sprayed during saturated conditions, which can cause surface runoff or ponding of sprayed effluent. The problem is accentuated when irrigation is performed during a high rainfall. Consequently the potential for the raw effluent to reach surface waters increases under such conditions. Although it has often been claimed that surface waters have greater assimilative capacity during high flow conditions, this claim requires further investigation. However, to reduce the risk of surface water pollution it is advisable to have some preventive measures rather than rely heavily on dilution effects.

One third of the Waikato regional land area is used for intensive dairy farming which includes the Hauraki lowlands, Hamilton Basin, Southern Waikato and Taupo/Reporoa areas. Generally the central and southern part of the region have well drained to moderately drained soils whilst the northern Hauraki lowlands are poorly drained. The poorly drained areas often have a high water table. The construction of underground storage tanks is difficult in these high water table areas due to tanks floating with a rising water table. Under these conditions storage systems can be constructed over the ground. There is a need for a back-up pumping system to cope with pump malfunctions.

Surface systems can be constructed using soil material. Since the storage systems are emptied frequently, they should be lined with synthetic liners regardless of the soil types and ground water hydrology at the location. Clay liners or natural soil sealing due to sludge sedimentation are not suitable for this purpose. It must be emphasised that storage systems are used for storage of effluent prior to irrigation, *not for treatment* of effluent.

It is believed that requiring an effluent storage facility with specific contingencies may not be the appropriate way of handling problems related to non-sprayable periods. It is difficult to specify storage requirements based on varying soil and climatic conditions. The best practicable option is to require farmers to manage effluent during wet periods, and to demonstrate no surface runoff or ponding during irrigation. Irrigation during wet weather or saturated soil conditions are unlikely to have adverse effects on ground water quality due to the composition and strength of the effluent. For example, a farm with a herd size of 200 cows will produce approximately 10 m^3 d^{-1} of effluent and 2 kg N d^{-1} (0.02% total-N with ammoniacal-N being the dominant mineral-N species).

4.2.2 The use of existing ponds as holding systems

A treatment pond system should be able to hold dairy shed effluent for several days (> 200 d for herd size of 200) thus an anaerobic pond system is sufficient to serve this purpose. In the case of a barrier ditch system, a 150 m long ditch will be able to hold approximately 300 m^3 effluent. A farm with a herd size of 200 cows will be able to hold effluent for 30 d per ditch. However, prolonged storage of effluent will result in nutrient break down and loss of valuable nutrients, mainly nitrogen. Moreover, prolonged storage of effluent can result in substantial accumulation of partially treated sludge which is difficult to pump. Thus effluent should not be held for more than 3-4 weeks in a holding pond.

If possible ponds should be backfilled with soil to reduce the existing size. Depth of anaerobic ponds can be reduced substantially. Synthetic liners should be installed in all pond systems converted into holding systems. Clay lining or sealing due to sludge accumulation are unsuitable for this purpose.

The use of an aerobic pond system as a holding system should be either discouraged or prohibited. Aerobic ponds and all but the first ditch in barrier ditch system should not be used for holding dairy shed effluent. Spraying effluent from oxidation ponds or the end of a barrier ditch system may accentuate nitrate leaching. Aerobic systems are capable of oxidising ammoniacal-N to nitrate-N form. Nitrate-N applied with effluent can leach rapidly into the soil profile. Nevertheless, most oxidation pond systems are either unable to retain the nitrate produced or do not nitrify at all. Evidence suggest that little or no nitrate is found in the effluent received from aerobic ponds (Hickey *et al.,* 1989; Grogan, 1990; TRC Technical Report, 1990).

4.3 RECOMMENDATIONS

1) It has been identified that storage requirements for land application of dairy shed effluent is necessary, however, the decision on this matter should be left to the discretion of the resource user as long as land application of effluent does not cause any surface runoff of effluent into waterways or ponding of effluent on land.

2) Conversion of existing dairy shed effluent treatment systems as holding systems should be encouraged, however, the use of aerobic pond systems or all but the first ditch in a barrier ditch system as holding systems should be either discouraged or prohibited.

3) Research should be conducted: (a) on the assimilative capacities of waterways during high flow; (b) on the design and construction of effluent storage for areas with a high water table; and (c) on the effect of dairy shed effluent irrigation on the environment under saturated conditions.

5 SUMMARY OF RECOMMENDATIONS

1. The maximum annual effluent loading should be either 100 kg N ha^{-1} or 50 mm effluent y^{-1}.

2. The maximum rate of effluent application per dose should be 25 mm d^{-1} with a minimum return period of 1 month.

3. The minimum area required for irrigation of dairy shed effluent should be 270 m^2 cow^{-1}.

4. The loading of P and K need not be considered in the land application of dairy shed effluent.

5. Sludge is a contaminant and hence should be applied to land carefully.

6. Sludge can be applied at rates greater than 100 kg N ha^{-1} y^{-1} onto pasture or cultivated soils (non-pasture areas).

7. Sludge should not be applied on to land that is used for dairy shed effluent application.

8. Storage requirements for land application of dairy shed effluent is necessary, however, the decision on this matter should be left to the discretion of the resource user as long as land application of effluent does not cause any surface runoff of effluent into waterways or ponding of effluent on land.

9. The use of aerobic pond systems or all but the first ditch in barrier ditch system as holding systems should be either discouraged or prohibited.

10. Research should be performed on: (a) long-term effects of dairy shed effluent use on grazed clover-based pasture and the environment; (b) long-term effects of the use of sludge on pasture and crops; (c) the assimilative capacities of waterways during high flow; and (d) the design and construction of effluent storage for areas with a high water table.

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APPENDIX 1

Effect of N management on N content of forage and faecal and urinary returns from yearling Friesian steers during a 2 year grazing period. Data are mean daily values for single animals given forage for a 5-day period from ryegrass swards receiving 420 (high N) or 210 (medium N) kg fertiliser N ha^{-1} per year or a grass/clover sward receiving no fertiliser N.

N content	May 1986				June 1987			
	Ryegrass				Ryegrass			
	High N	Medium N	Grass/ clover	S.E.* (12 d.f.)	High N	Mediu m N	Grass/ clover	S.E.* (12 d.f.)
Total N content of herbage (% dry matter)	3.93	2.60	2.67	0.075	3.24	2.20	2.26	0.114
NO_3^- - N content of herbage (% dry matter)	0.089	0.005	<0.005	-	0.089	0.002	<0.005	-

* S.E. = standard error of means for 5-day period.

Source : Jarvis **et al.**, 1989.

APPENDIX 2

The effects of N management on the consumption and excretion of N by housed yearling Friesian steers. Data are mean daily values for single animals over a 5-day period for 2 years; forage was provided from ryegrass swards receiving 420 (high N) or 210 (medium N) kg fertiliser N ha y^{-1} or a grass/clover sward receiving no fertiliser N.

N consumed or excreted	May 1986				June 1987			
	Ryegrass				Ryegrass			
	High N	Medium N	Grass/ clover	S.E.* (12 d.f.)	High N	Medium N	Grass/ clover	S.E.* (12 d.f.)
Herbage consumed (kg/animal/day)	5.22	6.19	5.23	0.231	6.13	5.49	5.05	0.238
N consumed (kg/animal/day)	0.20	0.16	0.14	0.005	0.20	0.12	0.11	0.006
Faeces excreted (kg/animal/day)	0.95	1.10	0.94	0.062	1.19	1.20	1.20	0.091
Urine excreted (kg/animal/day)	18.81	16.13	14.45	1.567	14.57	10.74	7.96	0.774
N excreted in faeces (kg/animal/day)	0.046	0.045	0.044	0.0025	0.047	0.043	0.046	0.0033
N excreted in urine (kg/animal/day)	0.145	0.068	0.065	0.0033	0.114	0.061	0.045	0.0039
Proportion of N consumed and returned in excreta	93.2	70.2	77.9	-	80.9	85.9	79.8	-

* S.E. = standard error of means for 5-day period.

Source : Jarvis **et al.**, 1989.