

Three decades of consenting and monitoring land treatment of industrial and municipal effluent – Are we on the right track in managing nitrogen contamination?

Selva Selvarajah

ENVIROKNOWLEDGE® Ltd, 3 Dunrobin Street, Dunedin, New Zealand
Corresponding author email: selvarajah@enviroknowledge.co.nz

ABSTRACT

To avoid direct discharges to water and to minimise adverse effects on *mauri* of water and surface and marine water quality, most regional councils promote land treatment systems to treat municipal and industrial effluent. Under the Resource Management Act (RMA) 1991, virtually all regional councils using varying regional rules require consents to discharge municipal and industrial effluent to land.

This paper focuses on the management of nitrogen (N) as a contaminant because it is one of the key components of the municipal and industrial effluent and has been a key water contaminant in New Zealand. In the first decade since the regional council formation in 1989, in the absence of appropriate nutrient/effluent models, regional authorities set effluent-N irrigation loading rates without N leaching limits and with some requiring groundwater nitrate monitoring. In the past decade, nutrient model such as Overseer® has been used extensively to set effluent-N loading and leaching rates. Consequently, much of the compliance/performance monitoring of N leaching from land treatment of effluent has been performed by using nutrient models such as Overseer®.

This paper assesses three decades of consenting, monitoring and the science of the land treatment systems in New Zealand for effectiveness in the context of N contamination management and provides way forward where appropriate.

Keywords: Industrial and municipal effluent, land treatment, groundwater, nitrate contamination, desktop N models, Overseer®

INTRODUCTION

Land treatment of municipal and industrial effluent is one of the best options to discharge and treat most effluents. I draw a distinction between ‘land disposal’ and ‘land treatment’ here. *Land disposal* is safe disposal of contaminants onto/into land with or without plant cover in a manner some contaminants enter water indirectly. *Land treatment* is using land with plant cover as a biological system to treat or assimilate the effluent contaminants to minimise indirect entry to water.

Since the enactment of the key historical and milestone environmental legislation in New Zealand, the Resource Management Act in 1991, many regional councils (i.e. regional environmental authorities) have been promoting land treatment systems to treat farm, industrial and municipal effluent. The main reasons have been land’s greater ability to treat effluent while retaining its productive purpose and to reduce the direct effluent discharge impacts on freshwater systems environmentally and on *mauri* (life force) culturally. As a first step, promoting farm effluent application to land was a sensible option for the regional

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councils since farm effluent had high nutrient value which was beneficial to pasture/crop production and the discharge of treated effluent from farm treatment pond systems had unacceptable levels of contaminants to sustain direct discharges to waterways (Hickey et al., 1989; Selvarajah, 1996a).

Under the RMA, Waikato Regional Council took the initial step to introduce farm dairy effluent land application *permitted activity* rule (activity which does not need a permit or consent) restricting effluent-N loading to 150 kg N/ha/year in 1994 based on a pioneering desktop nitrogen (N) model (Selvarajah, 1994a) which was later presented as a conference paper (Selvarajah, 1996b). Since then, there have been considerable research and monitoring on land treatment of farm dairy effluent under grazed pasture which had been compiled in peer reviewed literature reviews such as that of Houlbrooke et al. (2004), Wang et al. (2004) and Hawke and Summers (2006). To date 150 kg N/ha farm dairy effluent annual loading rate has been considered as sustainable under grazed dairy pasture system.

Unlike farm dairy effluent land treatment, the industrial and municipal effluent land treatment received less attention from the researchers to date with the exception of very few peer reviewed papers (Quin and Forsythe, 1978; Cameron et al., 2002 and Barton et al., 2005). Since much of the industrial and municipal effluent land discharges has been consented (allowed by consents/permits) activities, regional councils, consultants and hearing commissioners (commissioners appointed to hear and decide environmental permits under the RMA) have been left with little or no guidance to deal with effluent N loading or N leaching of land treatment to date.

Since the enactment of the RMA, numerous land treatment system permits to treat industrial and municipal effluent have been granted and monitored in New Zealand with wide ranging ad hoc approaches to controlling effluent-N loading and leaching by the regional authorities (which include hearing commissioners), consent holders and their consultants. This preliminary paper attempts a short review of the practices and their effectiveness to recommend a way forward.

CONSENTING AND MONITORING

Proper collation of the regional councils' consented historical data on the extent of land treatment for the past three decades demands considerable time and effort. Consequently, I have used only accessible data in this paper. In the 1980s when the Catchment Boards were the consenting authorities in New Zealand, in the absence of information on the effects of effluent-N loading onto land on water quality and the desire to divert poorly treated effluent from waterways, land was used as an effluent *disposal* system. During the above period, there was little or no concept of the land treatment system (LTS). An example of this was the Hautapu (Hamilton Basin) dairy factory site where effluent was irrigated to grazed pasture at 1200 kg N/ha/year loading rate in the 1980s under the Waikato Valley Authority consent granted in 1978 which triggered a significant groundwater nitrate-N contamination from in excess of 10 mg/L in 1982 which peaked in 1991 at 70 mg/L (Selvarajah et al., 1994).

Use of desktop N models

In the early 1990s, in the Waikato Region, the concept of LTS was recognised, in part, owing to heavy environmental pollutions caused by historical land *disposal* systems with unrestricted or high effluent-N loadings. Consequently, in the Waikato Region, similar to the desktop effluent-N models used for the regional farm dairy effluent rule, desktop effluent-N models were used to grant land treatment of municipal and industrial effluent consents (Table 1). Such models were based mainly on plant-N uptake, any N recycling by animal excreta and

leaching losses. Adverse effects monitoring consent conditions were also promoted with extensive groundwater nitrate monitoring requirements.

Table 1. Effluent-N loading recommended for municipal and industrial effluent LTSs in the Waikato Region in 1990s

Consent applicant	Effluent type	Land use	Recommended effluent-N and hydraulic loading rates	Reference
Wallace Corporation, Waitoa	Meatworks and rendering	Grazed dairy pasture	300 kg N/ha/year 24.8 mm/application	Selvarajah, 1994b
Hardy Martin Estates, Cooks Beach	Sewage	Forestry <i>Pinus radiata</i>	100 kg N/ha/year 20 mm/application	Selvarajah, 1994c
Anchor Products, Hautapu Buxton Farm	Dairy factory	Grazed dairy pasture	300 kg N/ha/year 30 mm/2 weeks	Selvarajah, 1994d
New Zealand Dairy Group of Companies, Lichfield	Dairy factory	Grazed dairy pasture	300 kg N/ha/year 50 mm/2 weeks	Selvarajah, 1994e
Taupo District Council	Municipal	Cut & carry pasture	640 kg N/ha/year 35 mm/week	Environment Waikato, 1994

The shift from the concept of ‘land disposal’ to ‘land treatment’ was not easy. There was considerable resistance from the permit holders against council’s (e.g. Waikato Region) lower effluent-N loading for consent recommendations at that time. Lower council recommended effluent-N loadings such as 300 kg/ha were considered as too conservative or onerous. Consequently, the consent hearing panels dealing with the consent applications granted consents with greater N loadings under grazed system (e.g. 400 kg N/ha) but substantially lower than the historical loadings. Despite the above resistance, the Hautapu site in Cambridge, New Zealand with historical high loading began a voluntary reduction in effluent-N loading from 1989/90. The shallow groundwater nitrate-N level reduction response was rapid to such a move. Between 1990 and 2000, 60% reduction in the effluent-N loading resulted in 50% reduction in groundwater nitrate-N level (Figure 1). This exercise was a clear demonstration of remedying historical shallow groundwater nitrate-N contamination by simply reducing the N-source effectively.

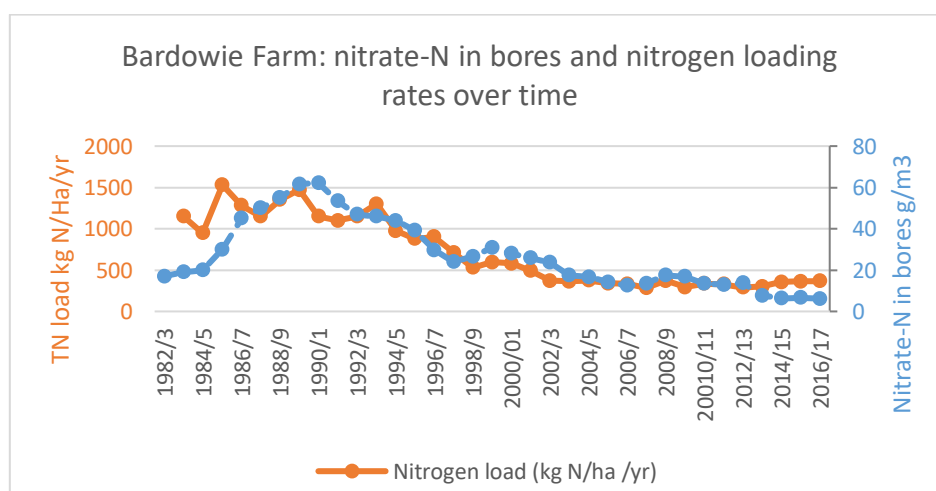


Figure 1. Effluent-N loading reduction resulting in corresponding groundwater nitrate-N level reduction (Murphy et al., 2018)

Use of Overseer®

Despite the industry based voluntary reduction and councils' permit reduction by using desktop N models in the 1990s, to date, there has been no clear guidance on sustainable effluent-N loading rate from the local and central governments. Unlike the farm dairy effluent discharge to land rule (allowed conditionally but without permits by most councils) with specific effluent-N loading rate, there have been no N loading rules on industrial or municipal effluent land treatment. The heavy shift of focus from point sources such as industrial/sewage discharges to non-point source pollution from farming activities in the early 2000s resulted in councils regulating catchment scale N management using regional rules (e.g. Variation to the Waikato Regional Plan: Lake Taupo Catchment, 2011). The above move in turn triggered nitrate leaching controls on farms in much of New Zealand as estimated by a nutrient management model such as Overseer®. As expected, around 2013 some councils extended nitrate leaching controls over consented LTSs using Overseer® to set effluent-N loading and to predict N leaching.

The practice has been expanded to even simple LTSs such as 'cut & carry' (crops are harvested without any livestock interaction) where plant-N uptake/removal would have been the most reliable indicator to manage effluent-N loading. However, it appears only few regional councils have been using Overseer® to consent LTSs. For example, in the Waikato Region, it was estimated there were 330 LTS consents with effluent-N loading restriction of 150-400 kg N/ha and in the recent years Overseer® has been used to restrict annual nitrate-N leaching rates (25-35 kg N/ha) and to monitor compliance (Kent Russell, Waikato Regional Council, pers comm). In contrast, Environment Bay of Plenty Council (EBoP) has 7 LTS consents and N loading (200-400 kg N/ha) is set without nitrate-N leaching limits and without the use of Overseer® but with nitrate-N monitoring in shallow groundwater (Marlene Bosch, EBoP, pers. Comm.).

With increasing desire to restrict catchment N loading to improve freshwater water quality, many councils have begun to restrict catchment scale nitrate-N leaching through land use/discharge rules, restricting annual nitrate-N leaching from various land uses in kg/ha. Under such circumstances, there has been no separate consideration to LTSs management hence LTSs consents are likely to be caught up with wider nitrate-N leaching rules. One such example is the 2013 Horizon Regional Council One Plan Rule 14-2 which required intensive farm nitrate-N discharges including LTSs to reduce nitrate-N leaching progressively within 20 years (e.g. from 70-140 kg N/ha after 20 years to 20-23 kg N/ha) as estimated by Overseer® version 6.0 (Brown, 2016). Is the use of Overseer® to restrict or monitor nitrate-N leaching in LTSs an acceptable or technically and legally defensible practice?

BRIEF SCIENCE OF INDUSTRIAL AND MUNICIPAL EFFLUENT-N APPLIED TO LAND TREATMENT SYSTEM

Before assessing consenting methods to control effluent-N loading and leaching in LTS including the use of Overseer® for the purpose, it is appropriate to understand the science of the industrial and municipal effluent LTSs. As stated before, there have been only few peer-reviewed nitrate leaching related land LTS trials involving municipal and industrial effluent in New Zealand. There must be considerable N leaching and groundwater nitrate data available from the consented sites from the regional councils, however, these require careful analyses and interpretation given much of the data has been collected to monitor the performance of the consent conditions rather than for the understanding of the N processes in soil and water.

The first step in understanding the science of the LTS is understanding the N content and composition and C content of the effluent. Why? The N species such as organic-N,

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ammoniacal-N ($\text{NH}_4^+\text{-N} + \text{NH}_3$) and nitrate-N react/being processed differently in the soil-plant systems and the effluent carbon (C) types and levels can dictate differing N processes and rates in soil. Much of the *municipal* effluent has been pre-treated before land treatment hence contains relatively high proportion of mineral-N (ammoniacal-N + nitrate-N) with low organic carbon and nitrogen. In contrast, often the *industrial* effluent has been applied without or minor pre-treatment hence has exceedingly high loading of organic-C (or BOD) and N. On the other hand, among the industrial effluents, in pre-treated effluents (e.g. meat works) much of the N is available in ammoniacal-N form with low levels of organic-N and little or no nitrate-N. What are the practical implications of the above differences in the effluent composition?

Industrial effluent

Cut and carry

Cut and carry system is the most straight forward LTS because it is less complex without involving grazing livestock and associated N recycling via urine and dung inputs. Despite its simplicity, differing effluent chemical compositions could trigger differing N processes in cut & carry soil-plant systems. For example, effluent applied to land with high organic loads can immobilise a high proportion of the applied ammoniacal-N because high applied dissolved organic-C can promote microbial assimilation (referred to as immobilisation) process in soil. This can be assessed in the field or laboratory by using ^{15}N tracer studies. Unfortunately, such studies have been sparse. One such pioneering New Zealand lysimeter cut and carry pasture study performed with dairy factory effluent (Table 2) at Lincoln University indicated 52 and 64% of the applied-N was immobilised or assimilated into organic-N form with effluent-N loading rate of 600 and 300 kg/ha respectively (Cameron et al., 2002). Note the higher immobilisation rate at lower effluent-N loading rate.

Table 2. Chemical properties of dairy factory effluent (Cameron et al., 2002)

Properties	Range	Average
pH	4.1-11.9	7.0
Nitrate-N (mg/L)	0.0-37.8	6.7
Ammoniacal-N (mg/L)	0.0-67.9	24.0
Organic-N (estimated) (mg/L)		127.3
Total-N (mg/L)	20-262	158
Organic-C (mg/L)	4329-4782	4555
C:N ratio	24.4-32.1	28.3
Na (mg/L)	20-161	85.3

I must emphasise that the above study was held on fresh Canterbury soil (i.e. not from a historical land treatment system but from a 10 year sheep grazing ryegrass-pasture soil) hence the extent of the immobilisation was expected to be much greater until the soil C and N attained an equilibrium following long-term effluent application. This is because typically, grazed pastoral soils without effluent application have a C:N ratio of 10:1 which favours net mineralisation (i.e. organic-N \rightarrow ammoniacal-N) and applying effluent with high C:N ratio of 28:1 and high ammoniacal-N (Table 2) can reverse the above flux (i.e. ammoniacal-N \rightarrow organic-N), thereby increasing the corresponding soil assimilation of mineral-N. I am not aware of any ^{15}N tracer studies performed on soils from consented and well-established LTS.

Judging by the substantial increase in microbial biomass and N mineralisation, nitrification and denitrification potentials in soils irrigated with dairy factory effluent for 22 years (Sparling et al., 2001), in the long-term, greater microbial activities can be expected from soils applied with high organic effluent loading. High N immobilisation means lower available mineral-N which in turn means lower N leaching losses. High available organic-C in

the effluent also means greater denitrification potentials for applied or residual nitrate-N. As expected, the Lincoln University study indicated a low average N leaching loss of 5.9-13.6 kg N/ha/year (Table 3) (0.9-4.5% of the 600 and 300/ha applied-N respectively without accounting for N leaching losses from controls) over a three year period and an estimated denitrification loss of up to 20% of the applied-N. Note the greater N leaching loss from the lower 300 effluent-N/ha loading rate. Also note the N leaching losses were greater in the 25 mm (water) control treatment (12.9 kg N/ha) compared to the 50 mm (water) control (4.2 kg N/ha) (Table 3). Judging by the detailed denitrification data in the paper, greater denitrification was sustained at the high effluent loading of 600 kg N/ha.

Table 3. Annual N leaching losses (Cameron et al., 2002)

Treatment	Year 1	Year 2	Year 3	Average
300 N (25 mm)	5.5	10.0	25.2	13.6
600 N (50 mm)	7.4	4.6	5.6	5.9
300 N + urine	65.1	123.3	93.8	94.0
400 N + urine	69.3	48.4	75.8	64.5
Control (25 mm)	4.7	7.0	27.1	12.9
Control (50 mm)	4.1	5.1	3.4	4.2

The above three year study also showed that pasture dry matter (DM) production was 13.8 and 12.9 t/ha/year and pasture removal of N was 304 and 285 kg/ha/year at 300 and 600 kg effluent-N/ha loading rates respectively. The lower plant removal of N in 600 kg/ha loading was attributed to high hydraulic loading (50 mm/3-weeks for 600 kg N/ha loading as against 25 mm/3-weeks for 300 kg N/ha loading) which resulted in effluent ponding and poor plant performance. I consider 50 mm/3-weeks as not high hydraulic loading between the relatively dry months of October and April under Canterbury conditions. Higher sodium (20-161 mg Na/L) loading at 50 mm application rate would have triggered soil pore clogging which in turn would have caused the effluent ponding. It is also noteworthy, despite the lower plant-N uptake, high N loading resulted in lower nitrate-N leaching of 5.9 kg/ha.

Grazed pasture

When simulated grazed pasture system was used by applying cow urine along with dairy factory effluent at 300 and 600 kg N/ha loading the above Lincoln University study found greater plant uptake of 489 and 644 kg/ha resulting in significantly greater DM yield of 19.9 and 24.2 t/ha/year respectively. The study also found under grazing conditions despite the high plant-N removal, both N loading rates sustained greater nitrate-N leaching (Table 3). However, under 600 kg N/ha lower leaching of 64.5 kg N/ha occurred compared to 94.0 kg N/ha from 300 kg N/ha loading. The study postulated greater *available* effluent-C (in this case lactose) applied at high N loading rate caused less leaching by high N immobilisation and denitrification.

Municipal effluent

To understand the science of the municipal effluent-N process in LTSs, I will use the peer reviewed papers from Quin et al. (1978) (from Templeton) and Barton et al. (2005) (from Waikato). The Templeton secondary treated effluent (Imhoff tanks followed by two ponds) border-dyke irrigation LTS (the first municipal land treatment system in New Zealand) studied under grazed pasture system by Quin and Forsythe (1978) had lower total-N with high proportion of ammoniacal-N and little or no nitrate-N (Table 4). The Waikato sewage pond effluent studied on four Waikato soils by Barton et al. (2005) under cut & carry pasture system had proportionally high organic-N but at lower level.

Table 4. Secondary treated municipal effluent properties (mg/L) and trial information (kg/ha) (¹Quin & Forsythe, 1978 and ²Barton et al., 2005)

Effluent properties and trial information	¹ Templeton	² Waikato
Plant management	Grazed pasture	Cut & carry
Leaching collection	Cups without suction	Barrel lysimeters
Soils	Templeton silt loam	4 soils (Allophanic, Gley, Pumice and Recent)
Hydraulic loading/application	80 mm (4 h flooding every month – 840 mm/year)	50 mm (10 mm/h)/week, except for the Gley soil at 2x25 mm/week (2100-2300 mm/year)
Effluent-N loading kg/ha/year	116	373-407
Total organic-C or BOD (mg/L)	Not measured	27.0 (total-OC)
Total-N (mg/L)	13.8	15.0
Organic-N (estimated) (mg/L)	1.4	6.7
Ammoniacal-N (mg/L)	12.3	5.3
Nitrate-N (mg/L)	0.1	3.0
Total-P (mg/L)	4.1	5.8
Dissolved Reactive P (mg/L)	2.3	4.3
Plant-N uptake kg/ha/year	380	186-437
Nitrate-N leaching kg/ha/year	180 (estimated leaching by urine was 100 kg/ha)	8-92

Given the limited study and the vast differences between the trials, it is not easy to make any sensible comparisons between industrial and municipal effluents. The two year border-dyke (irrigation by flooding) study (Quin and Forsythe, 1978) not only had very high instant hydraulic loading, but it was held under grazing (sheep) conditions hence sustained heavy nitrate-N leaching loss of 180 kg/ha of which 100 kg/ha was estimated as from the livestock urine patches alone. Despite using clover-based-pasture there was no assessment of clover-N fixation, which alone could be 100-200kgN/ha/year.

On the other hand, Barton et al. (2005) found with high effluent hydraulic loading of 2100-2300 mm/year heavy leaching of 92 and 86.5 kg effluent-N/ha/year from Gley and Recent soils respectively whilst the Allophanic and Pumice soils only sustained lower effluent-N leaching losses of 8.5 and 15.5 kg/ha/year respectively (Table 5). In the above study, regardless of the soil types, much of the effluent-N leached was in organic-N form (69-88%). The study cautioned the regional councils to monitor total-N (including organic-N) in the leachates rather than just inorganic-N such as nitrate-N because of greater environmental risks associated with underestimating the N leaching losses. It could be argued that high hydraulic loadings could promote organic-N leaching because of the effluent organic-N not being able to be adsorbed onto soil particles under ‘saturated’ conditions. Is there a possibility of native or residual soil organic-N leaching in addition to that of effluent organic-N?

Table 5. Annual estimated N sources and sinks (kg/ha) (Barton et al., 2005)

Soils	Treatment	Effluent & fertiliser-N	Nitrate-N	Leaching Organic-N	Total-N	Plant-N
Allophanic	Irrigation	386	1.9	6.5	8.5	437
	No irrigation	100	0.1	1.0	1.3	163
Gley	Irrigation	373	22.0	63.5	92	185
	No irrigation	100	1.8	6.0	6.5	111
Pumice	Irrigation	407	4.4	10.5	15.5	264
	No irrigation	100	4.3	2.6	7.0	68
Recent	Irrigation	386	9.5	75.5	86.5	390
	No irrigation	100	1.9	17.0	20.0	88

The Waikato study by Barton et al. (2005) demonstrated that the high plant-N removal did not necessarily relate to lower leaching judging by the Recent soil 390 kg/ha plant-N versus 86.5 kg effluent-N/ha leaching. The workers argued that the Gley soil had heavy leaching because of preferential flows and low plant-N uptake owing to anaerobic conditions caused by effluent/water logging. By using total organic-C: total-N ratio of the leachates the workers postulated the high preferential effluent drainage in Gley soil causing heavy effluent organic-N leaching whilst the high organic-N leaching in Recent soils was caused by soil-borne or residual organic-N despite the high plant-N uptake.

As for the organic-N leaching, there has been other New Zealand non-effluent-N leaching studies also detecting high quantities of organic-N leaching. A suction cup field study by one of New Zealand's Crown Research Institutes AgResearch (Smith et al., 2016) in the Matukituki area in the Otago Region showed 23 and 34 kg dissolved organic-N/ha leached from sheep and beef cropping/grazing and grazed pasture sites respectively (along with inorganic-N leaching of 62 and 19 kg/ha respectively). The fate of the leached organic-N in the subsoil, vadose zone and groundwater has been studied and understood poorly. It is likely the leached organic-N can be adsorbed to soil, mineralised into ammoniacal-N, nitrified and leached. Some workers have already demonstrated by laboratory incubation studies of the collected leachates that much of the leached organic-N is readily mineralisable (Ghani et al., 2012), indicating leached organic-N beyond rhizosphere has the potential to mineralise and form nitrate-N which in turn could be leached.

From the above limited scientific information, it can be concluded that

- (a) Lower plant uptake and high N leaching is possible in cut and carry LTS applied with high organic effluent or hydraulic loads
- (b) Greater plant uptake and lower N leaching is possible with low organic and high mineral-N effluent such as pre-treated effluent
- (c) Much of the applied-N in effluent with high organic content can be immobilised in soil owing to high loading of available-C
- (d) It is not known the extent of long-term immobilisation rate and the fate of stored N in the LTS soils. Judging by the long-term soil biochemical studies, high N fluxes from nitrification, denitrification and immobilisation are possibilities complementing plant removal of N
- (e) Owing to high available-N from livestock urine to compensate high available-C in effluent, grazed systems can promote better pasture growth than cut & carry system
- (f) However, intensive grazed systems (e.g. dairy) can be highly nitrate-N leaky because of higher available-N
- (g) Higher hydraulic loading (effluent or water) does not necessarily leach more nitrate-N in volcanic soils
- (h) High hydraulic loadings can leach high amount of organic-N leaching (*soil* organic-N in porous soils and *effluent* organic-N in Gley soils), hence organic-N leaching monitoring should be mandatory in LTSs along with that of nitrate-N, should leaching be monitored
- (i) Obviously more similar scientific studies are warranted

CAN OVERSEER® BE USED FOR CONSENTING AND CONSENT MONITORING OF INDUSTRIAL AND MUNICIPAL LAND TREATMENT?

Overseer® has neither been developed nor calibrated to assess N leaching losses from municipal and industrial effluent. To my knowledge, despite being an empirical model, there are no industrial and municipal land treatment data in the Overseer® 'engine'. Since Overseer® has not been developed to deal with municipal and industrial effluent, it not

designed specifically to accept effluent input data. For the above reason, effluent nutrient data must be inputted through irrigation or fertiliser (in combination with nutrient free monthly irrigation to account for the hydraulic loading) or organic effluent (farm dairy effluent) inputs. Obviously, all the above three distinct data inputs will have differing N leaching outputs since irrigation and fertiliser nutrient inputs assume fully mineralised effluents which does not exist in treated or untreated industrial and municipal effluents. The N leaching output could be further compromised because whilst industrial and municipal effluents are irrigated daily, the effluent inputs to Overseer® must be monthly.

As more data are becoming available on the contribution of soil or effluent organic-N to N leaching, the validity of the Overseer® N leaching estimates which rely solely on inorganic-N leaching data is becoming questionable, even in the context of farm nutrient management for which Overseer has been specifically developed. Smith et al. (2016) specifically cautioned the implications of the organic-N leaching on the Overseer® N leaching estimates. Their sheep and beef land use (which did not involve any effluent application) field study using suction cup lysimeters demonstrated that the Overseer® model leaching estimate for the study was 24 kg/ha whilst the actual field measured loss of N was 53 kg/ha.

Overseer® model user guidelines for the field N leaching data collection recommend organic-N monitoring in the leachate as ‘optional’ because it was not accounted in the Overseer® due to insufficient data (Shephard and Wheeler, 2016). Given the significant leaching loss of organic-N documented in the above mentioned leaching studies, urgent review is required on the environmental impacts of the leached organic-N and for accounting organic-N leaching in nutrient models such as Overseer®. I will also urge all future N leaching studies to monitor for organic-N in addition to the conventional nitrate-N and ammoniacal-N and assess critically the causes for organic-N leaching and the fate of leached organic-N.

It is clear that Barton et al.’s (2005) municipal effluent lysimeter studies and Smith et al.’s (2016) grazed pasture suction cup studies have implications to future municipal effluent-N leaching estimates and the use of Overseer® to assess N leaching from grazed pasture respectively. At high hydraulic loading rates, such nutrient models are likely to underestimate the full N losses because of not accounting for organic-N leaching losses/process. Similar to leaching phosphorus (P) from top-soils accumulating in subsoils at land treatment sites with high historical effluent-P loading, I will not be surprised if high quantities of leached organic-N are also accumulating in subsoils and beyond. Given much of the groundwater studies also tend to focus on nitrate-N, it is difficult to assess the fate of such large amounts of organic-N escaping plant root zones.

In short, municipal and industrial effluents should be assessed separately in the context of the N processes owing to significantly differing N fluxes (see Figure 2 for anticipated N fluxes within land treatment system applied with organic effluent). Even within the industrial effluent, pre-treated effluent should be assessed separately. Effluents with high organic contents tend to immobilise N (residual soil or effluent mineral-N conversion to soil microbial biomass) and provide conducive conditions for denitrification losses. On the other hand, soil types could also affect the extent of leaching particularly when there is high hydraulic loading.

As already identified, Overseer® is unable to account for total-N leaching losses. It is also unable assess one of the key N fluxes such as immobilisation of applied-N for differing soil types and conditions. Given not yet developed to model dynamic N processes in municipal and industrial effluent LTSs, it should not be used to restrict or assess effluent-N loading and

N leaching in consenting or consent monitoring process. Any model used in assessing N leaching or N leaching limits must be fit for purpose. For simplicity and convenience, many nutrient and effluent models use first order reactions to capture complex, biological and dynamic soil and wastewater-N transformation processes, which is not technically sound.

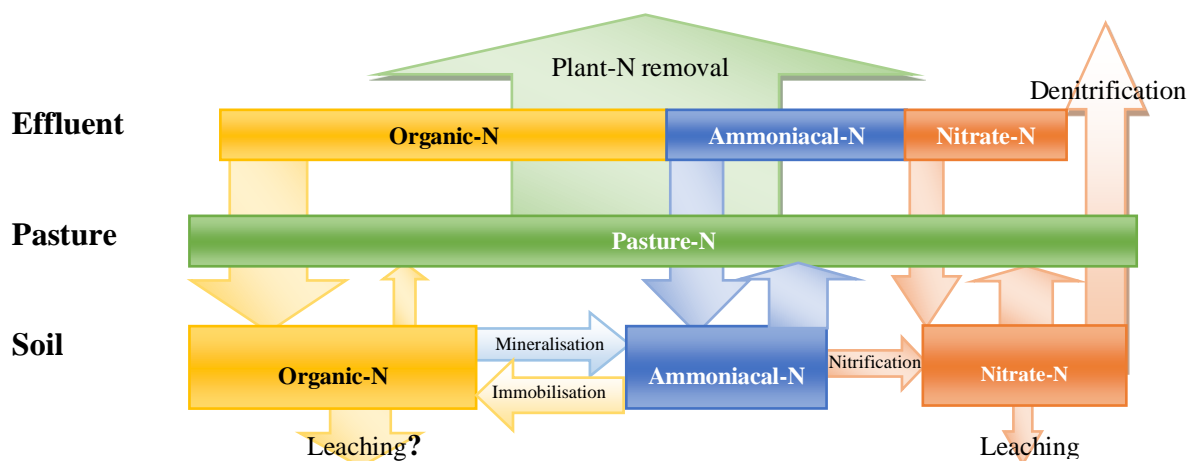


Figure 2. Diagrammatic representation of the industrial effluent-N flow in a cut & carry system (the arrow widths represent the N flux) ©

Using any model which is not fit for purpose (i.e. developed or calibrated for the purpose), particularly for consenting and compliance monitoring may not be defensible legally either. This is crucial when there are unwarranted costly and onerous consenting requirements/limits on consent applicants/consent holders or significantly differing *actual* adverse effects from the activity because of using an unfit model, both of which can be litigious. If councils, consent holders/applicants, consultants and hearing commissioners wish to use Overseer® for consenting or consent monitoring purposes, considerable research, data acquisition and validations are required before the use. If so, what are the alternatives to manage nutrients in the land treatment systems in the meantime?

INTERIM MEASURES TO RESTRICT EFFLUENT-N LOADING AND NITRATE-N LEACHING IN LAND TREATMENT SYSTEMS

Collectively and in collaboration with the consent holders, regional councils must review the current LTS consenting and compliance monitoring practices and adopt consistent and technically and legally defensible methods. An approach may be to adopt acceptable effects-based consenting and compliance monitoring methods based on best management practices. The essence of the best management practices in LTSs is promoting optimum performance of plants/crops by efficient use of effluent components (including moisture), soil and any required supplements (e.g. any deficient nutrients). If grazing systems are allowed, promote sheep grazing over dairying to minimise nitrate leaching.

Apart from monitoring the performance of the LTS by assessing plant-N removal, groundwater nitrate monitoring should also be promoted. Consent reviews can be used to increase or decrease N loading rates depending on 3-5 yearly shallow groundwater N level performance. Regional councils must also provide for the unintended consequences of introducing catchment scale water quality or manage land use rules restrictions on nitrate-N leaching limits affecting the sustainability of the LTSs. If blanket land use rules are applied on LTSs, they are likely to be phased out by the permit holders by reverting to discharges to surface water.

Given the variability in the effluent quality and quantity applied to land and the wide variabilities in soil types, land use, management and climatic conditions, simple and precautionary approach can be taken to determine consents for LTSs until a nationally acceptable technically rigorous method/model is developed. Since plant-N uptake is an excellent index of a *well-managed* LTS's optimal performance and there are sufficient data on plant-N uptakes, I can recommend plant-N uptake as a critical factor in determining effluent-N loading. For example, the upper limit for cut-and-carry ryegrass can be set at 560 kgN/ha/year (at 16,000 kg DM/ha with % herbage-N being 3.5). As you can see, obviously, target and realistic dry matter production (DM kg/ha/year) and high %N in plant are essential for high N-removal. High plant-N uptake limits can be achieved with 'farm style' management of crops with optimum crop performance as one of the key objectives rather than hands-off effluent 'disposal'. Consequently, soil-plant conditions must be managed *proactively* to ensure optimum plant performance or productivity. If grazing is preferred, sheep grazing clover-free-pasture coupled with lower effluent-N loading of <300kgN/ha/year can be used.

In *well-managed* cut-and-carry LTSs, the overall performance can be assessed by subtracting annual plant-N uptake from effluent-N input. If the LTSs are under performing in plant uptake of N or nitrate in groundwater, effluent-N loading or hydraulic loading or conditions causing poor plant uptake must be corrected by monitoring or consent reviews. An example of the above is, if cut & carry LTS effluent-N loading is set at 600 kg N/ha and the average plant-N uptake has been 300 kg N/ha in the 3-5 preceding years, the effluent-N loading must be reduced with corresponding reduction in hydraulic loading. In some cases, poor plant uptake is possible because of lack of/excess soil moisture availability, soil compaction, high/low soil pH, high sodium levels or lack of other essential plant nutrients. In such cases, appropriate corrective actions must be taken. The same applies if the local aquifer or shallow groundwater receiving environment indicating increasing N pollution from proactive or water quality consent condition monitoring by the piezometers or bores.

Because of the lack of N leaching and impact data under varying conditions, N leaching rate in permits need not be set unless, there is prevailing specific operative regional rules. In such cases and in cases where N leaching cannot be set, it is critical to monitor all three N species in leachates or in groundwater from piezometers or shallow bores, without which actual adverse effects of the LTSs cannot be assessed and appropriate interventions cannot be introduced.

CONCLUSIONS

If managed well, effluent treatment by LTS is one of the best options to minimise the impacts of the industrial and municipal effluent on the environment. In the past 30 years there has been no national consistency in granting permits for LTSs in New Zealand. Excessive, unintended and blanket regulatory restrictions coupled with the use of nutrient models such as Overseer® which are not fit for purpose and departure from actual effects/performance based consent monitoring can all lead to limited or no use of LTSs to treat municipal and industrial effluent in New Zealand. Such a trend is concerning with the potential discharges to land reverting to surface water.

By critically assessing sparse but credible science of the LTSs in New Zealand, I am not surprised that N processes in LTSs are complex with N leaching can be as nitrate-N and organic-N, high hydraulic loading could leach *soil* organic-N from porous soils and *effluent* organic-N in Gley soils, grazed systems could promote better plant performance coupled with high N leaching and effluents with high dissolved organic-C can promote N immobilisation

and denitrification in soils thereby resulting in lower nitrate-N leaching. Owing to the complexity of the soil/effluent-N processes, substantial well-designed research, data and effort would be required to develop any future LTS empirical models to simulate such complex processes and provide meaningful outputs.

It is also clear that it is appropriate to restrict hydraulic and N loadings of the effluent in the LTS to promote optimal plant uptake of N and to minimise N leaching. However, restricting/monitoring nitrate-N leaching alone is no longer appropriate, given there is potential for organic-N leaching along with nitrate-N.

In future, models can be used in LTS consenting to assess potential adverse effects on the environment and to set effluent-N loading rate provided they are fit for purpose. In the meantime, consenting and monitoring of the LTSs can be based primarily on the optimal performance of plant/crops (i.e. plant-N removal) given the wealth of information on plant-N uptake. Plant-N removal is an excellent incentive to manage LTS optimally hence setting leaching limit is unnecessary. If livestock grazing is preferred over the cut-and-carry LTSs, sheep grazing is the best practicable option to minimise N leaching and improve plant performance, but at much lower effluent-N loading and without the use of N-fixing crops such as clover. Any long-term adverse effects of the LTS can be assessed by groundwater monitoring.

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