Nitrogen leaching from effluent irrigated pasture

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Abstract

The surface waters of the Taupo region are of high quality and are sensitive to inputs of nitrogen. To reduce the amount of nitrogen discharged to surface water, the Taupo District Council (TDC) has employed a land treatment scheme (LTS), where treated municipal wastewater is irrigated onto ryegrass pasture. To limit the possibility of nitrogen pollution, regulations govern the amount of effluent that TDC may irrigate. This study reports the results from the first year of a five year trial where nitrogen leaching from the Taupo LTS was measured.

To measure nitrogen leaching from the Taupo LTS, 48 intact monolith lysimeters were installed beneath effluent irrigation from two centre pivot irrigators. Four treatments based on nitrogen loading rates were trialled, nominally no-N (0 kg N $ha^{-1}yr^{-1}$), low-N (350 kg N $ha^{-1}yr^{-1}$ or less), mid-N (between 350 and 450 kg N $ha^{-1}yr^{-1}$), and high-N (greater than 450 kg N $ha^{-1}yr^{-1}$). Leachate was collected at least monthly and analysed for total nitrogen (TN), nitrate/nitrite nitrogen (NO_3-N), ammoniacal nitrogen (NH_4-N), dissolved organic nitrogen (DON), and total Kjeldahl nitrogen (TKN). The pasture was removed from the lysimeters to determine dry-matter production and pasture nitrogen concentration to calculate nitrogen uptake.

Effluent irrigation significantly increased pasture growth and nitrogen leaching compared to the un-irrigated treatments ($P<0.001$). The mean rate of pasture growth from the irrigated treatments was 15,800 ± 1,700 kg DM $ha^{-1}yr^{-1}$, but there were no significant difference between the rate of pasture growth between the irrigated treatments. The pasture of the high-N treatments had a significantly higher nitrogen concentration than the low-N treatments ($P<0.001$), consequently the high-N treatment removed 390 kg N ha^{-1}, compared to 310 kg N ha^{-1} removed from the mid-N and low-N treatments. On average, the pasture removed 84 % of the nitrogen that was irrigated.

After 12 months, the no-N treatments leached 5 ± 3 kg TN ha^{-1}, the low-N treatment leached 15 ± 1 kg TN ha^{-1}, the mid-N treatment leached 17 ± 8 kg TN ha^{-1}, and the high-N treatment leached 26 ± 4 kg TN ha^{-1}. The high-N treatments leached significantly more TN than the low-N ($P<0.005$) , but there was no significant difference in TN leached between the high-N and mid-N, or the mid-N and low-N treatments. The TN leached was poorly correlated with the rate of effluent irrigation. TN leached was positively correlated with the volume of water that drained through the soil ($R^2=0.7$). The nitrogen in the leachate of the irrigated treatments comprised on average, 53 % NO_3-N, and 45 % DON, while the leachate of the un-irrigated treatments comprised, on average, 26 % NO_3-N and 72 % DON. NH_4-N accounted for approximately 2% of all nitrogen leached. Most of the NO_3-N leached throughout the year was leached after rain during summer and autumn. The mean concentration of NO_3-N leached from the irrigated treatments was 1.3 g N m^{-3}. The concentration of NO_3-N in the leachate never exceeded Ministry of Health guidelines (11.3 g N m^{-3}). The mean concentration of DON leached from the irrigated treatments was 1.2 g N m^{-3}.

Removing nitrogen in the pasture is the solution to avoid excess nitrogen leaching from the Taupo LTS. There is potential to recover more nitrogen in the pasture by improving the pasture cover and frequency of harvest.

Acknowledgements

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Chapter one - Introduction

1.1 Thesis outline

Since 1995, Taupo District Council (TDC) has irrigated secondary treated municipal wastewater to land in a cut and carry farming operation (Power and Wheeler, 2007). TDC currently operates two irrigation sites within close proximity to the township, one located at Rakaunui Road, the other commissioned in 2008, on View Road. Both irrigation sites of the Taupo wastewater treatment Scheme are cultivated with high yielding perennial ryegrass. The ryegrass uses nitrogen and phosphorous contained in the effluent for plant growth and is harvested a minimum of four times annually. To limit the recycling of nutrients, no stock are grazed on the irrigated areas, and harvested grass is removed from the site and sold as stock feed.

Nitrogen has been identified as a limiting nutrient in surface waters of the Taupo region (White & Payne, 1977) and rules in the regional plan govern the management of nitrogen in the greater Taupo catchment. The resource consent issued for Rakaunui Road allows 640 kg N $ha^{-1} y^{-1}$ to be applied to the farm. However, the resource consent issued for the View Road site has allowed only 550 kg N $ha^{-1} y^{-1}$ to be applied. Subsequently, Environment Waikato (EW) have allowed a trial to run at the View Road site until 2013 where up to 650 kg N $ha^{-1} y^{-1}$ can be applied to 15% of the irrigated land area. At the conclusion of the trial, the application rate and associated consent conditions will be reviewed.

Rates of nitrogen leaching from effluent irrigation schemes are seldom published. If excessive nitrogen leaching is suspected, other authors have tended to retrospectively investigate the cause, often inferred from other data, usually with limited success.

My thesis will provide the basis for ongoing monitoring and research from the very first stages of a land treatment scheme at a scale not previously reported.

1.2 Site description

The following section describes the study setting and details the workings of the Taupo land treatment scheme (LTS).

1.2.1 Geological setting

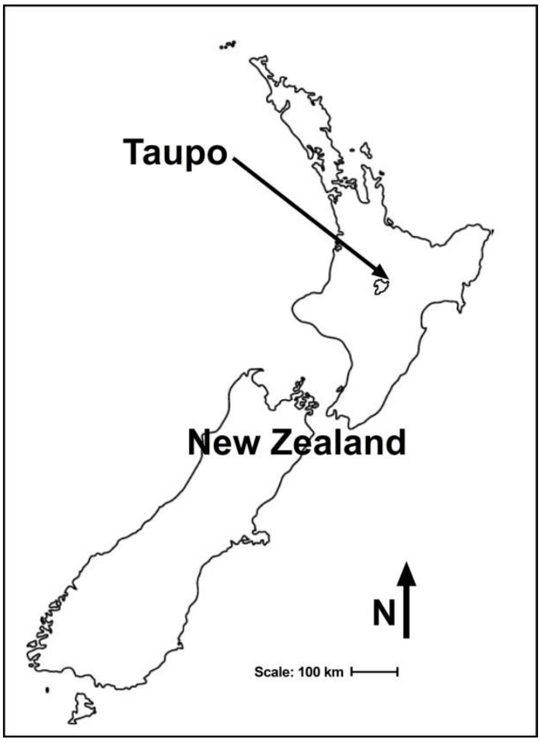

Figure 1.1: Study location.

The central North Island of New Zealand is a region dominated by active volcanism. The town of Taupo (Figure 1.1) lies at the outlet of the Waikato River on the northern shore of Lake Taupo. Lake Taupo is a caldera formed by the c. 26.5 ka rhyolitic eruptive sequence that ejected the equivalent of 530 km^3 of magma (Manville & Wilson, 2004). A subsequent eruption at or around A.D. 186 from the north eastern corner of the present day lake deposited approximately 60 km^3 of debris over the surrounding landscape (Molloy & Christie, 1998).

1.2.2 Lake Taupo and the Waikato River

At approximately 612 km^2, Lake Taupo is New Zealand's largest lake. The lake is oligotrophic, and is an important tourist destination due to excellent water quality and picturesque beauty (John et al., 1978; Barkle et al., 2007). The lake stratifies in summer, but mixes during winter and has a water residence time of approximately 10 years (White et al., 1980; Collier et al., 2010). Lake Taupo is sensitive to nutrient inputs from urban sewage, where enrichment with sewage-contaminated groundwater leads to higher plant biomass and reduced visual water clarity (Hawes & Smith, 1993).

The long water residence time within the lake results in sedimentation and gaseous loss of nitrogen from the lake, so that only 20-30% of the nitrogen entering the lake leaves through the outfall to the Waikato River (Collier et al., 2010). The natural cleaning process of Lake Taupo provides high quality water to the upper reaches of the Waikato River. Irrespective of human inputs to the system, there will be a natural degradation in water quality downstream of the lake outflow, as contributions from the many tributaries naturally carry higher nutrient and sediment loads.

About 10% of the nitrogen in the water leaving Lake Taupo is in the mineral form, the rest of the nitrogen in the water column is organic nitrogen and is typically incorporated in dead phytoplankton. Much of the nitrogen that enters the river downstream of the Taupo control gates is in the form of nitrate. Less than 50 km from the control gates, mineral nitrogen makes up about 50% of the nitrogen pool in the Waikato River (Collier et al., 2010).

Lake Taupo feeds the Waikato River, where eight hydro electric power stations dam the river, impede flow, and modify river water temperature. The hydro dams have increased water residence time within the Waikato River system from about 5-6 days, to around 40 days in times of low flow (Collier et al., 2010).

In the summer of 2002-2003, toxic blue-green algae were detected in the Hamilton drinking water intake on the Waikato River. Blue-green algae pose a potential threat to human life. While no human deaths have been reported in New Zealand as a result of blue-green algal poisoning, some farmers in the Waikato have lost stock that have had access to algal contaminated water (Collier et al., 2010). Algal blooms are not a regular feature of the Waikato River, however certain conditions favouring algal growth can be found in parts of the river, such as the Whirinaki arm of Lake Ohakuri, where a health warning was last issued in 2009 (Collier et al., 2010). Nitrate levels have continued to increase in the lower Waikato River (Environment Waikato, 2008). Harmful algal blooms in the Waikato River are predicted to become more frequent as larger and more intensive dairy farms contribute more nitrogen and phosphorous to the waterways (Collier et al., 2010).

1.2.3 Climate

Taupo boasts the longest rainfall record in the Waikato catchment, with measurements beginning in 1901. The average annual rainfall is 1,120 mm, with a low of 650 mm in 1915 and a high of 1,700 mm in 1960. In general, the Waikato catchment is dominated by a summer minimum and a winter maximum with high monthly variation (Collier et al., 2010), however the Taupo region does not historically show seasonal variation.

1.2.4 The Taupo Land Treatment Scheme

1.2.4.1 Introduction

Prior to 1974, Taupo did not have a reticulated sewage scheme and all wastewater was disposed into septic tanks or soak holes (Gibbs, 1991). Reticulation of the sewage network commenced in stages from 1974 to 1986, with the central business district and streets closest to the lake connected first. Following reticulation of the sewage network, the effluent was secondary treated and discharged into the Waikato River. In 1995, the first stage of land-based treatment scheme (LTS) using a cut and carry farm system was commissioned, avoiding the direct discharge of the treated effluent to the Waikato River.

1.2.4.2 Taupo Land Treatment Scheme design

In 2010, the Taupo wastewater treatment scheme serviced a population of about 20,000, and comprised of a reticulated sewer network, a wastewater treatment station, and two wastewater irrigation fields. At the time of writing, TDC operated two irrigation fields within close proximity to the township, one located at Rakaunui Road, in operation since 1995, the other commissioned in 2008, on View Road (Figure 1.2). Both sites of the Taupo LTS are cultivated with high yielding perennial ryegrass (*Lolium perenne)*.

The treated wastewater (effluent) is dispersed onto the ryegrass pasture by spray irrigation, with limitations placed on hydraulic and nutrient loading. Pop-up sprinklers are employed at Rakaunui Road, while centre pivot travelling irrigators are utilised to spread the effluent at View Road.

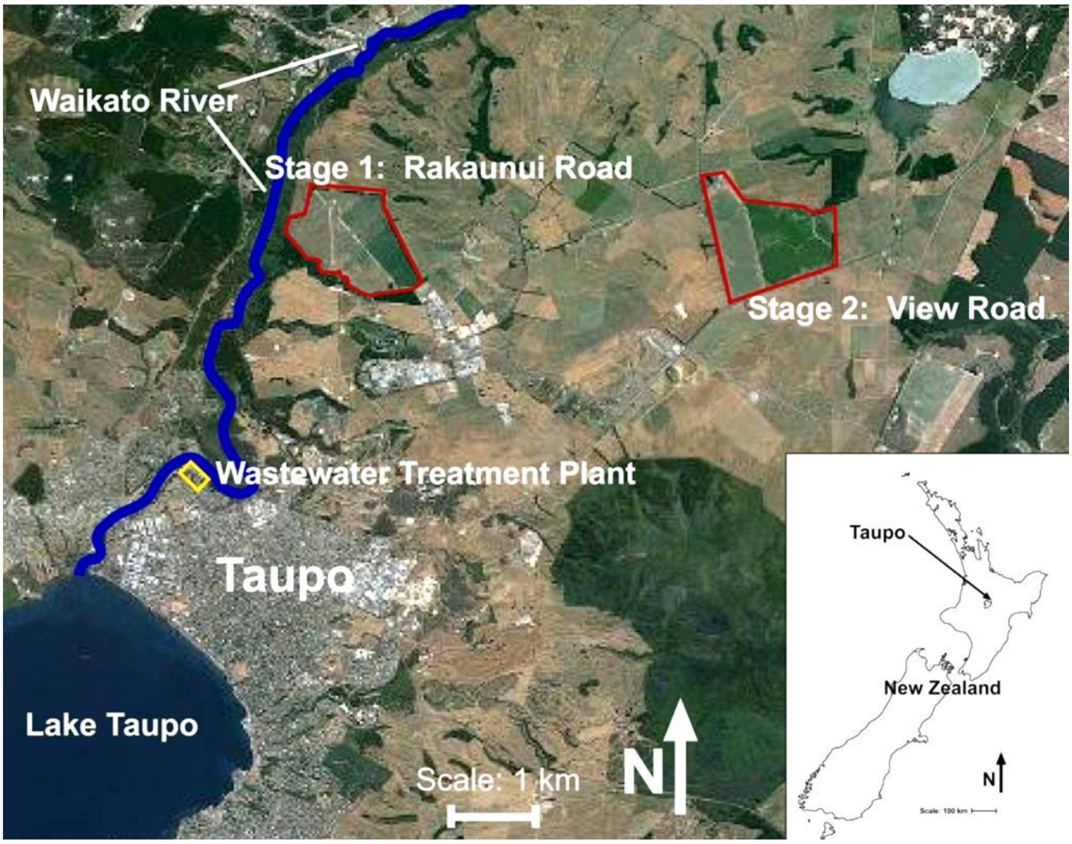

Figure 1.2: Overview of the Taupo sewage treatment scheme. Taupo township lies on the shore of Lake Taupo, with the Waikato River (in blue) flowing north through the town. The wastewater treatment plant (in yellow) supplies secondary treated wastewater to both irrigation sites (in red). Adapted from Google images, 2010.

The View Road irrigation farm is approximately 157 hectares, with about 117 hectares of that area being irrigated. The experimental area of this study is located in the southwest corner of the View Road irrigation field and consists of approximately 29 hectares.

1.2.4.3 Topography

The View Road LTS comprises low rolling hills and near-flat terraces/fans (Orbell, 2007) with a southern aspect. The LTS is roughly divided into two areas, with low rolling hills to the north and near-flat areas to the south. Some minor earthworks in the form of smoothing of steep knolls and filling of small gullies was undertaken prior to site commissioning, however, the experimental area used in this study has not been greatly impacted by earthworks.

1.2.4.4 Soil properties

The A.D. 186 eruption deposited volcanic debris that forms the parent material for much of the Taupo region (Barkle et al., 2007). The low rolling hills of the LTS are formed on airfall tephra, while the near flat areas are formed on rewashed Taupo detritus (Orbell, 2007). The subsoil found at the site is highly variable, both horizontally and vertically. The variability in subsoil texture is more pronounced in the hilly sections where alternating layers of sand, lapilli, and pumice blocks are often found from about 50 cm depth, whereas the near-flat sections are predominantly sandy (Orbell, 2007). The soils are moderately well to well draining (Orbell, 2007).

1.3 Thesis objectives

The purpose of this study was to quantify the nitrogen leached from the soil beneath the Taupo LTS under four effluent loading rates; the consented rate (nominally 550 kg N ha^{-1} yr^{-1}), a higher rate (nominally 650 kg N ha^{-1} yr^{-1}), a lower rate (nominally 450 kg N ha^{-1} yr^{-1}), and un-irrigated soil (0 kg N ha yr-1). The specific objectives were to measure:

- the amount of nitrogen applied to the land surface;
- the volume of water draining through the soil profile;
- the nitrogen concentration of drainage water; and
- the nitrogen uptake by the ryegrass pasture.

The amount of nitrogen applied to the land was calculated by measuring the volume and nitrogen concentration of the effluent that was irrigated. Intact monolithic lysimeters were installed in the field to measure the volume of water draining through the soil and provide a means of collecting the soil water. The pasture was removed from the lysimeters, dried, and analysed for total nitrogen.

The lysimeters installed at the Taupo LTS will enable monitoring of nitrogen leaching to continue beyond the timeframe of this thesis, and provide the infrastructure for possible nitrogen leaching mitigation strategies if deemed appropriate. Furthermore, the large area covered by the varied irrigation rates will enable additional research to be conducted at a later date.

Chapter two - Literature review

2.1 Introduction

Using effluent for irrigation of crops is gaining popularity worldwide as water scarcity and environmental awareness increases (Williamson et al., 1998; Wallach & Graber, 2007). Typically, effluent from industrial or municipal sources provides a constant, reliable water source, reducing the demand on natural resources (Toze, 2006). In New Zealand, land application of wastewater is considered an alternative to tertiary treatment and is the preferred method of treatment of human waste by the indigenous Maori people (Whangapiritia et al., 2003; Barton et al., 2005). Preventing nitrogen pollution of ground and surface water systems is typically a key intention of land treatment systems (Barton et al., 1999b). However, collecting all the water that drains from the Taupo pumice soil at the paddock scale is practically impossible, meaning it is difficult to accurately quantify nitrogen leaching (Cameron et al., 2007).

The following chapter is a review of past literature and will begin with a description of the process of land treatment of wastewater. A summary of the nitrogen cycle in a pastoral system precedes an overview of methods previously employed to measure soil solute leaching. Previous nitrogen leaching studies will be examined and followed with a final section describing the environmental impact of the Taupo land treatment scheme.

2.2 Land treatment of wastewater

2.2.1 Introduction

The occurrence of land based treatment of wastewater is increasing in preference to direct discharge to waterways (Toze, 2006; Vogeler, 2009). The primary objective of most land treatment systems is to remove pathogens, heavy metals, and/or nutrients (primarily nitrogen and phosphorous) from wastewater using plant growth, gaseous loss and soil storage. Previously, applying wastewater to the land surface was seen as a method of disposal, whereas today, the wastewater industry views it as a highly effective means of treatment and a viable alternative to expensive engineering works.

Phosphorous, heavy metals, and pathogens, typically have a localised effect on their surrounding environment, whereas nitrogen is naturally abundant in effluent and mobile in the environment, therefore nitrogen has the potential to negatively affect a much wider area (Tomer et al., 2000). Any nitrogen that is not taken up by plants will follow one of several courses; it may be stored in the soil, lost to the atmosphere, lost to surface waters by overland flow, or leached below the rooting zone to groundwater (Ledgard, 1988; Meisinger & Delgado, 2002; Power & Wheeler, 2007).

2.2.2 Methods of land treatment of wastewater

For over 2000 years humans have been disposing of liquid waste on the land surface (Bastian, 2005), however methods today are much more diverse and technologically advanced than in times past. There are many methods of discharging wastewater to land. Almost without exception, there is some form of pre-treatment of the wastewater prior to land application (Toze, 2006). In many instances, pre-treatment is nothing more than simple screening of large objects to protect the pumping equipment and prevent blockages.

Spray irrigation is the most visible application method and most obvious to the public eye, and often draws the most attention. Methods with no obvious spray effects such as dripper lines (Hamilton et al., 2007), or flood irrigation (Beca, 2008) can also be employed. Rapid infiltration, where large volumes of wastewater are applied to a small area of land and allowed to soak into the soil, is also a method used (Bouwer & Rice, 1984). In a typical rapid infiltration system, all of the wastewater reaches the groundwater system. Highly permeable soils (such as sand) are required for rapid infiltration to work effectively (Bouwer & Rice, 1984).

When permeable soils are not available for land treatment, overland flow can be used to effectively filter the wastewater, where it is applied to the upper section of a gentle slope (Kruzic & Schroeder, 1990). During overland flow, the wastewater interacts physically, chemically and biologically with the soil and vegetation (usually grass) as it passes down the slope, into a receiving drain at the bottom of the slope, and onto a receiving water body. High levels of biological oxygen demand (BOD), suspended solid and organic carbon removal have been reported using the overland flow technique (Tedaldi & Loehr, 1991).

2.2.3 Effluent quality and treatment method

In any scheme, the quality of the wastewater being discharged will ultimately define the method of application. All methods of land treatment rely on some form of bioremediation by the soil or filtration by geological layers to improve the quality of the wastewater before it is utilised by humans again.

There are specific properties pertaining to the different sources of wastewater and methods of disposal that must be assessed in each case (Toze et al., 2006). For example, meat processing effluent often contains high suspended solids, has a high oxygen demand and a high nutrient content when compared to municipal effluent. Surface ponding and infiltration limitations can result from inadequate management of meat processing effluent. The high levels of suspended solids can initially block soil pores, allowing bacteria grow in the stagnant wastewater leading to an impermeable bacterial film, further impeding infiltration (Balks et al., 1997). Conversely, textile wastewater often contains dyes with high heavy metal concentrations. The heavy metals may prove toxic to bacteria and limit their growth, interfering with the treatment process (Sapari, 1996). To accurately assess the potential effects of wastewater discharge, the physical, chemical and biological characteristics of the wastewater must be measured and appropriate treatment methods sought.

In the Taupo region, groundwater that contains nitrogen at higher levels than occur naturally is seen as a threat to the water quality of Lake Taupo and the upper Waikato River (Hadfield, 2007). Consequently, the management of nitrogen in the Taupo LTS has received considerable attention.

2.3 The nitrogen cycle

2.3.1 Introduction

Nitrogen is an essential nutrient required for the growth of plants and animals. Nitrogen is contained in all proteins and nucleic acids of all living things and is a key element utilised in the transfer of energy within organisms (Haynes, 1986; Whitehead, 1995).

2.3.2 Nitrogen stores

About 98% of the nitrogen on Earth is chemically bonded to metals in rocks and minerals or bound into the lattice of primary silicates of the Earth’s crust. Of the remaining 2% of global N, 1.9% is in the gaseous form, primarily as atmospheric N_2 where the gas remains relatively inert due to the strong triple bond between the two nitrogen atoms. The oceans contain most of the 0.01% of global nitrogen that is held within the biosphere. About 90-95% of the very small remaining portion of Earths nitrogen that is contained within the soil is in the organic form and is not readily available to plants. Given sufficient water, nitrogen is the most common factor limiting crop production (Haynes, 1986; Whitehead, 1995; Myrold, 1998).

2.3.3 Additions of nitrogen to the soil

Nitrogen can be added to the soil by natural or human processes (Figure 2.1). A small portion of the naturally deposited nitrogen is fixed from the atmosphere by lightening, while the majority of soil N has been derived from the symbiotic relationship between select microorganisms and leguminous plants (Freiberg et al., 1997). The symbiotic process of biological nitrogen fixation occurs where microorganisms exchange nitrogen fixed from the atmosphere for carbohydrate from leguminous plant roots. The eventual death of the nitrogen fixing plants, together with excrement from animals that have eaten the nitrogen fixing plants, leads to the natural accumulation of nitrogen in the soil system (Haynes, 1986; Whitehead, 1995).

The creation of synthetic nitrogen fertilisers by the Haber-Bosch process has allowed humans to add far more nitrogen to the biosphere than can accumulate under natural processes, enabling substantially greater food production from the soil. Indeed, much of the world’s population would not be alive today if it not for the artificial nitrogen fertilisers that are added to the worlds soils (Lemaire et al., 2004). Other unintentional (and typically unwanted) nitrogen deposition has occurred across much of the planet from the burning of fossil fuels (Haynes, 1986).

2.3.4 Nitrogen cycling within the soil system

With the exception of plants that can fix atmospheric nitrogen, terrestrial plants can typically only utilise nitrate (NO_3) and ammonium (NH_4) for growth (Figure 2.1). Nitrogen must be converted from the organic form contained in dead plant and animal matter to the mineral form by the processes of ammonification (producing NH_4) and nitrification (producing NO_3), before it can be assimilated into the growing plant structure. Together, the processes involved in converting organic nitrogen to mineral nitrogen are termed mineralisation (Haynes, 1986; Whitehead, 1995).

In contrast to agricultural systems, little nitrogen enters or leaves a natural ecosystem when compared to the quantity that is recycled. In a natural ecosystem, mineralised organic nitrogen is utilised by microorganisms or incorporated into living plants. In both natural and cultivated ecosystems, as microorganisms and living plants die, or are eaten by animals and deposited as dung, nitrogen is returned to the organic nitrogen pool within the soil (Haynes, 1986).

Decomposition of detritus by soil microbes is important within the soil as it both mineralises nutrients and forms soil organic matter. Organic matter can be separated into cellular and humic components, and upon decomposition tends to be immobilised into inherently stable and complex structures. As such, the complete decomposition of detritus is a slow process that may take hundreds or thousands of years (Haynes, 1986: Whitehead, 1995).

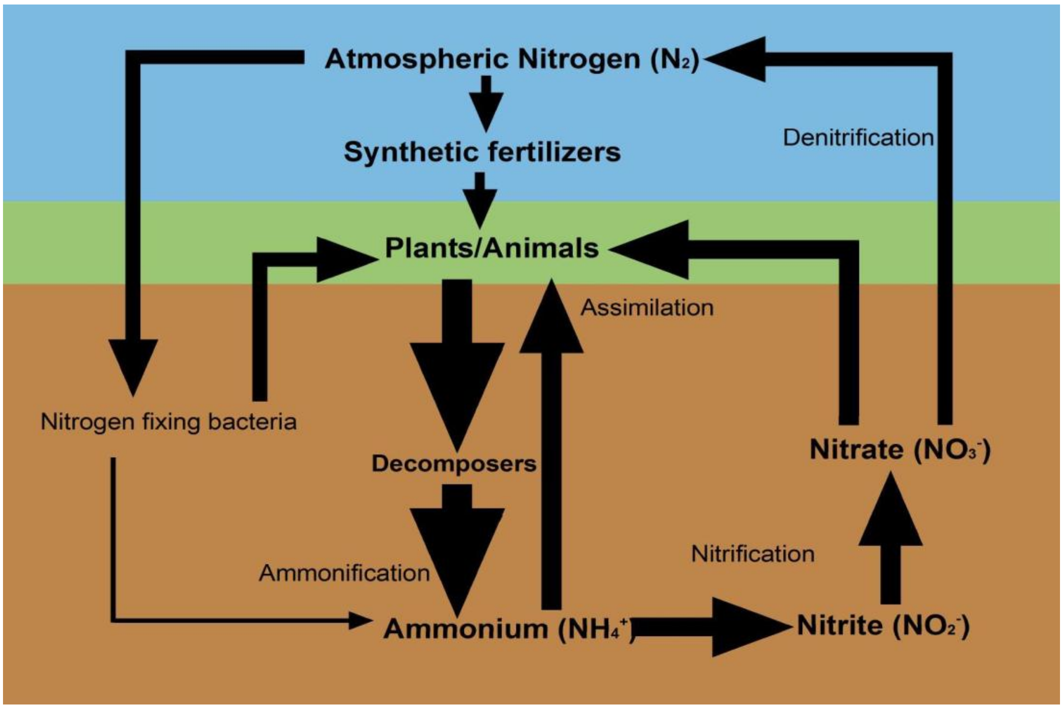

Figure 2.1: Generalised nitrogen cycle. Arrows represent the flow of nitrogen. Adapted from Myrold, 1998.

Organic nitrogen normally represents between 1 and 5% of the dry weight of plants as it is a key element of amino acids, proteins, nucleic acids and chlorophyll. Plants are able to take up both ammonium and nitrate in soil solution and the presence of both is thought to produce the greatest plant growth (Haynes, 1986: Whitehead, 1995).

Typical pastoral plants reach a peak nitrogen concentration in the early stages of growth, after which time nitrogen tends to be recycled within the plant and even though dry matter increases, nitrogen concentration within the plant decreases, with a consequently decreased rate of nitrogen uptake by the plant (Haynes, 1986; Whitehead 1995; Gislum et. al., 2004; Marino et. al., 2004). In pastoral soils, organic nitrogen is typically found in higher concentrations than in forestry/native soils as the organic matter in pastoral systems have higher concentrations of nitrogen than forested organic matter (Ghani et al., 2007).

2.3.5 Losses of nitrogen from the soil

Nitrogen is easily lost from the soil through several processes including plant uptake, leaching, gaseous loss, or erosion and surface runoff (Figure 2.1). The single biggest loss of nitrogen from the soil in an agricultural system is through the removal of plant matter, either directly as crop, or indirectly through consumption by grazing animals. Gaseous losses also play a part in removing nitrogen from the soil, where the processes of nitrification and denitrification release nitrogen gases, mainly di-nitrogen gas (N_2) and nitrous oxide (N_2O), back to the atmosphere (Figure 2.1) (Haynes, 1986; Myrold, 1998).

2.3.5.1 Nitrification

Nitrification involves two small groups of chemoautotrophic bacteria. The first group oxidises ammonium to nitrite (NO_2), while the second group completes the process by converting nitrite to nitrate, but the process is not 100% efficient, and some nitrogen is lost as nitrous oxide. In the absence of fertiliser or animal urine, the decomposition of dead plants, animals and microorganisms provides the source of free ammonium ions for nitrification (Haynes, 1986; Edmeades, 2004).

2.3.5.2 Denitrification

Denitrification occurs when electrons (typically from carbon) and cellular material contained within organic compounds in the soil are used by heterotrophic denitrifying bacteria for respiration. The bacteria primarily convert nitrate to the inert di-nitrogen gas in the presence of carbon, however the process also emits nitrous oxide (Haynes, 1986). Denitrification can be a beneficial process, such as limiting nitrogen pollution from excessive leaching, or an undesirable process, such as the loss of valuable soil nitrogen from forest and pasture systems (Barton et al., 1999a). The requirement of carbon for the denitrification process typically limits denitrification to the surface soils where the majority of organic matter is present (Haynes, 1986; Barkle et al., 2007). Key requirements for denitrification are: denitrifying microbes, an absence of oxygen, adequate nitrate or other nitrogen oxide and organic carbon (Barton et al., 1999a).

Rates of denitrification vary. Barton (1999a) summarises denitrification rates in forest soils in the range of <0.1 to 40 kg N ha^{-1} yr^{-1}, with most reports below 10 kg N ha^{-1} yr^{-1}. However, in a cropped sandy loam soil firrigated with dairy effluent, denitrification rates up to 239 kg N ha^{-1} yr^{-1} have been measured (Lowrance et al., 1998).

2.3.5.3 Volatilisation

Ammonia volatilisation also contributes to the loss of soil nitrogen. Free ammonia (NH_3) is required at or near the soil surface before it is able to be volatilised. The source of the free ammonia is typically the ammonium ion derived from the ammonification of organic matter, or from animal urine or ammonium based fertilisers. Ammonia can also be intercepted by plants upon deposition, where it may be directly absorbed by the foliage or volatilised from the plant surface before reaching the soil surface (Haynes, 1986; Whitehead, 1995; Edmeades, 2004).

2.3.5.4 Erosion and surface runoff

In some situations, soil erosion or surface runoff can lead to significant losses of nitrogen from the soil profile, especially if eroded material reaches water bodies. Alternatively, soil erosion, can simply represent a transfer of nitrogen as eroded material is often deposited elsewhere. Irrigation can exacerbate surface runoff, where the type, frequency, and amount of water irrigated are important (Haynes, 1986; Smith et al., 1999).

2.3.5.5 Nitrogen leaching

The loss of nitrogen from the soil, through leaching, can have adverse environmental effects when nitrogen reaches ground, and surface waters, particularly lakes and estuaries. Excess nutrient in lakes and rivers is typically termed eutrophication and can bring many undesirable changes to water bodies such as decreased water clarity, severe weed and algal growth, health concerns, and reduced aesthetic value (Haynes, 1986).

2.3.5.5.1 Mechanisms of nitrogen leaching

The primary mineral forms of soil nitrogen, ammonium and nitrate, have different mobility within the soil profile. Ammonium is less likely to be leached as the positively charged ammonium ion is held to negatively charged soil particles by electrostatic forces and fixed by clay lattices and soil organic matter. Nitrate on the other hand, holds a negative charge and is generally repelled by soil particles, therefore is more mobile than ammonium. Ammonium is also quickly nitrified to nitrate and thus the residence time of ammonium within the soil, is often in the order of days (Haynes, 1986; Whitehead, 1995; Addiscott, 2005).

In cultivated soils, nitrate leaching is often the most important loss of nitrogen both environmentally and economically. The addition of nitrogen fertiliser to improve crop yields frequently increases nitrate leaching (Haynes, 1986; Whitehead, 1995; Addiscott, 2005). However, losses of dissolved organic nitrogen (DON) through leaching can be substantial, and should not be overlooked when completing nitrogen budgets (van Kessel et al, 2009). High nitrogen inputs and high soil sand content coupled with increasing rainfall, or adding irrigation have been shown to increase the leaching of DON (van Kessel et al, 2009).

The quantity of nitrogen leached from the soil is primarily controlled by the volume and concentration of nitrogen in water passing through the soil profile. A course textured soil with high nitrogen input, and high water input, is likely to have large leaching losses. Estimating nitrogen losses is however, a difficult task as the concentration of nitrate within soil and the pore water velocity (rate at which water moves through the soil) are variable and difficult to reliably predict (Haynes, 1986).

While irrigation during soil water deficit can increase plant growth and the uptake of nitrogen from the soil, irrigating beyond the needs of plants is likely to lead to leaching, especially if synthetic nitrogen fertilisers are used (Haynes, 1986; Burgess, 2003; Hillel, 2004).

2.4 Leachate collection for nitrogen leaching studies

2.4.1 Introduction

Quantification of drainage is necessary for leaching studies (Van der Velde et al., 2005) however, known volumes and concentrations of soil solutes are difficult to obtain under field conditions (Brye et al., 1999; Logsdon, 2002). The following section reviews common soil moisture sampling devices and their applicability to leaching studies.

2.4.2 Suction cup soil moisture samplers

Suction cup soil moisture samplers, also referred to as porous tubes, lysimeters, vacuum extractors, porous cups and deep pressure vacuum lysimeters (Levin & Jackson, 1970; Riekerk & Morris, 1983; Wu et al., 1993; Crabtree and Seamen, 2006; Weihermuller et al., 2007) constitute a relatively simple method for collecting in situ soil water (Talsma, et al., 1979). Suction cups are most effective when used for comparing differences in soil water quality between time and/or space (Talsma, et al., 1979), where drainage volumes are not needed.

While soil water is able to be sampled from undisturbed soil medium using suction cups (Figure 2.2), the water flow patterns within the soil water can be greatly disturbed (Wu et al., 1995; Su et al., 2004; Weihermuller et al., 2007) resulting in uncertainties surrounding the temporal and spatial resolution of data collected. Suction cups can disturb natural solute flow paths within the soil water and often do not compare to other methods of collection such as barrel lysimeters (Brandi-Dohrn et al., 1996; Burgess, 2003; Barzegar et al., 2004).

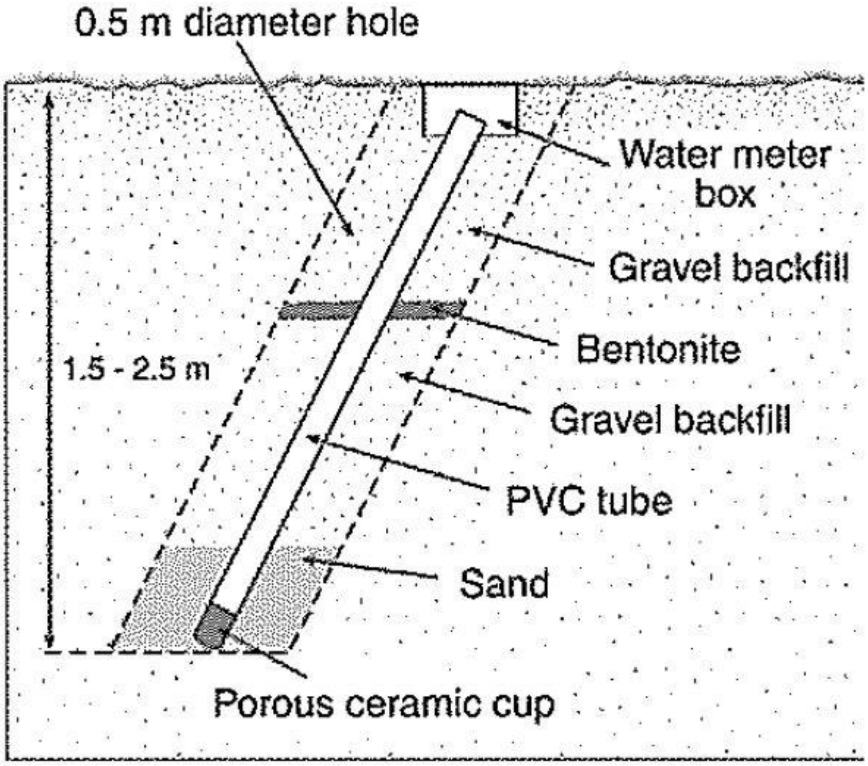

Figure 2.2: Schematic representation of one method of installing a suction cup soil moisture sampler (Close et al., 2004).

2.4.3 Pan lysimeters

Gravity pan or zero-tension lysimeters comprise a pan beneath the soil surface (Figure 2.3) whereby soil water drains into them via gravity (Boll et al., 1991; Zhu et al., 2002; Zhu et al., 2003; Masarik et al., 2004: Weihermuller et al., 2007). Gravity pans have a definitive surface area and therefore provide an advantage over suction cups as the area from which water is sampled can easily be calculated, enabling them to be used for leaching studies.

However, a perched saturated zone has been found to develop above the gravity pan, resulting in flow divergence around the pan and consequently less than optimal percolation collection (Brandi-Dohrn et al., 1996; Zhu et al., 2002; Mertens et al., 2007). Gravity pans are 100% effective only when the soil is fully saturated, where the pan will collect a representative proportion of the water moving down the profile. However, when the soil profile is not saturated, the collection efficiencies of gravity pan lysimeters have been shown to be as low as 7% (Boll et al., 1991) or as high as 40% (Zhu et al., 2003).

To improve collection efficiency, an inert wick has been trialled beneath the pan to provide a hanging water column (Holder et al., 1991; Boll et al., 1992; Brandhi-Dohrn et al., 1996; Zhu et al., 2002; Zhu et al., 2003; van der Velde et al., 2005; Mertens et al., 2007). Typical collection efficiencies from wick-pan lysimeters are close to 100% of predicted drainage (Boll et al., 1991, Zhu et al. 2002). Other more complex systems incorporate mechanical suction to match the matric potential of the surrounding soil and are considered superior (Brye et al., 1999; Barzegar et al., 2004; Masarik et al., 2004; Weihermuller et al., 2007).

Figure 2.3: A zero-tension gravity pan lysimeter during installation. Note undisturbed soil above the pan (from Peters & Durner, 2009).

2.4.4 Barrel lysimeters

A lysimeter with sidewalls extending up to the soil surface will fully eliminate possible convergent or divergent flow of soil water. A barrel lysimeter may contain disturbed or undisturbed (monolithic) soil (Weihermuller et al., 2007) and effectively forms a tank, or container in which the soil and/or vegetation is housed (Howell et al., 1991). Retaining undisturbed soil provides an advantage in that field conditions can more closely be replicated as the original soil structure, vegetation and vertical flow dynamics are maintained (Bergstrom, 1990; Grebet & Cuenca, 1991; Cameron et al., 1992; Weihermuller et al., 2007).

However, installation of the bottom plate in lysimeters creates a surface tension boundary that water moving through the soil must overcome, and was a problem identified as early as 1940 (Grebet & Cuenca, 1991). The boundary represents a barrier to water flow in the same way a gravity pan lysimeters restricts water flow. Problems arise as the soil moisture status inside the lysimeters has been shown to be higher than the surrounding soil due to the impeded drainage caused by the zero-tension boundary (Campbell, 1989; Howell et al. 1991). Higher soil temperatures within the lysimeter compared with the surrounding soil have been recorded and attributed to heat transfer down the steel or concrete walls of the lysimeter (Campbell, 1989; Howell et al., 1991). Wall construction with a poor heat conductor, such as commonly used PVC pipe (Reeder, 1986; Cameron et al. 1990; Derby et al. 2002; Burgess, 2003) will limit heat transfer. Nevertheless, an encased lysimeter does not allow lateral bypass flow as in gravity pans as the side walls prevent lateral water movement.

The saturated layer developed in the bottom of free draining lysimeters is often ignored but can be problematic if precipitation is slight, as plants within the lysimeters are supplied more water than those outside the lysimeter due to the impeded drainage (Grebet & Cuenca, 1991). Ensuring the depth of the lysimeter exceeds that of the plant roots will help alleviate the problem of impeded drainage (Grebet & Cuenca, 1991), especially in freer draining coarser textured soils.

Preferential flow of water between the soil column and lysimeter walls was identified early in lysimeter operation (Cameron et al., 1990). Soil type will affect lysimeter construction as many clays can shrink and crack upon drying. If collected when dry and allowed to wet up to field capacity, clay soil can swell and seal itself to the lysimeter wall, eliminating edge effects (Bergstrom and Johansson 1991). A user friendly method of sealing the soil to the lysimeter, applicable for all soil types, utilises molten petroleum jelly to seal the soil against the side wall of the lysimeter (Figure 2.4, Cameron et al., 1990; Cameron et al., 1992).

Barrel lysimeters can be combined with a mass balance to measure mass change of the soil. When combined with rainfall data, weighing lysimeters offer greater temporal resolution over non-weighing lysimeters and can evaluate changes in the water balance with great precision (Kirkham et al., 1984; Campbell, 1989; Schneider & Howell, 1991; Bardsley & Campbell, 1994; Bardsley and Campbell, 2007).

2.4.5 Leachate collection conclusion

Barrel lysimeters offer perhaps the best combination of all sampling devices. Convergence and divergence of flow is eliminated with high sidewalls, so only the water that is applied to the top of the lysimeter can reach the bottom. A lack of moving parts combined with construction using common materials lowers the cost and maintenance requirements of barrel lysimeters, making them attractive for leaching studies. The bottom plate of the lysimeter may provide an impediment to water movement, as water can only pass through the lysimeter when the soil is saturated. Perhaps the optimal method of soil water sampling would comprise of a barrel lysimeter with some form of assisted drainage at the base of the soil column. The assisted drainage could be a complex system that varied the rate of suction to match the matrix potential of the surrounding soil, or could be a simple fibreglass wick, which would be low cost and more reliable, but would not be able to be adjusted relative to the neighbouring soil moisture status.

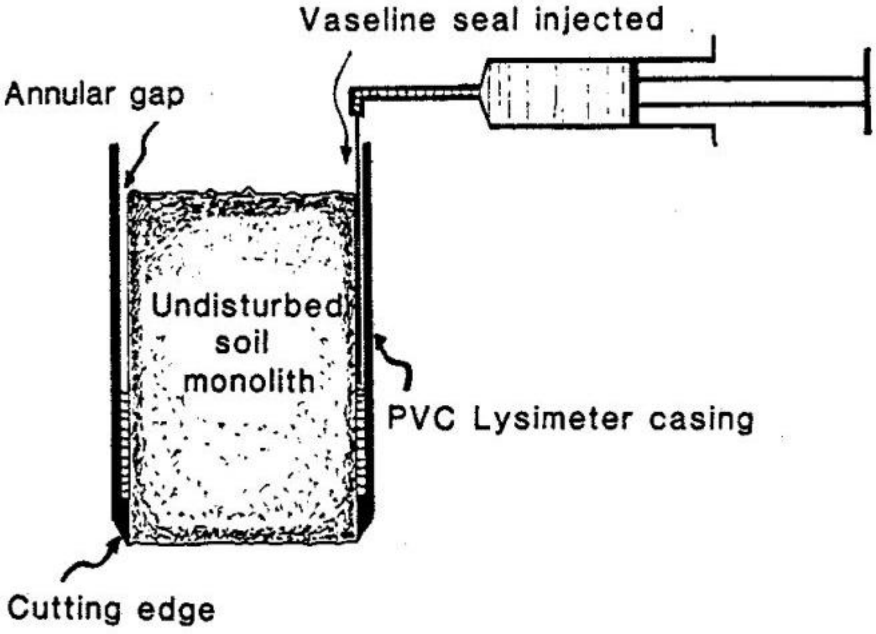

Figure 2.4: Cross-section through a barrel lysimeter. Petroleum jelly is used to seal the soil against the lysimeter wall and prevent edge flow. (from Cameron et al., 1990).

2.5 Previous nitrogen leaching studies

2.5.1 Introduction

The following section examines previously published literature focussed on nitrogen leaching, with particular attention on pastoral or effluent irrigation systems. The effluent irrigation scheme of Rotorua City is examined as a case study.

2.5.2 Source of leaching

Urine patches from grazing animals are regarded as the major contributor to nitrogen leaching under current landuse in New Zealand (Cameron et al., 2007; Environment Waikato, 2008)). Bovine urine can apply the equivalent of approximately 1000 kg N ha^{-1} (Di & Cameron, 2004), to the soil in small patches, leading to elevated nitrogen leaching as the soil system is unable to process such large volumes of the nutrient. Point source applications of nitrogen from grazing animals differ to land disposal of effluent that is spread evenly across the land surface throughout the year, consequently, comparison of results obtained in animal urine studies with land treatment of effluent is difficult (Table 2.1, 2.2).

2.5.3 Reporting of nitrogen leaching

Many studies do not report total nitrogen leached and only focus on mineral nitrogen (NH_4-N, NO_2-N and NO_3-N). While there have been many authors reporting the occurrence of organic nitrogen from forested and aquatic ecosystems, agricultural science often ignores leaching losses of dissolved organic nitrogen (DON) (Ghani et al., 2007; van Kessel et al, 2009). DON can constitute a large proportion of the nitrogen lost from an agricultural system (van Kessel et al., 2009) and can play an important role in the eutrophication of aquatic ecosystems (Berman & Bronk, 2003). Leaching of DON is not always ignored however, as Barton et al. (2005) and Sparling et al. (2006) note high organic nitrogen concentrations (>50%)

in leachate from effluent irrigation. Organic nitrogen may be made available to aquatic plants by mineralisation, or taken up directly by plants in waterways, therefore it is important to include organic nitrogen when calculating total nitrogen leaching (Berman & Bronk, 2003; Ghani et al., 2007; van Kessel et al, 2009).

2.5.4 Accumulation of nitrogen in the soil

It is difficult to measure the accumulation of nitrogen within the soil as the nitrogen pool is spatially variable and is typically an order of magnitude greater than annual additions (Tomer et al., 2000). Many authors have not been able detect significant soil storage of nitrogen under effluent irrigation (e.g. Magesan et al., 1998; Sparling et al., 2001; Tozer et al., 2005; Sparling et al., 2006). Additionally, there has been no measured increase in soil nitrogen at the Rakaunui Road LTS at Taupo since measurements began in 1998 (Power & Wheeler, 2007).

2.5.5 Leaching studies in the Taupo Region

In another LTS in the Taupo region, treated sewage from a population of approximately 1000 at the settlement of Acacia Bay was injected directly into pumiceous subsoil (Hawes & Smith, 1993). The groundwater beneath the LTS was enriched with nitrate and reaches Lake Taupo, where an increase in periphyton abundance and composition has been documented (Hawes & Smith, 1993).

However, the intensification of pastoral farming has been identified as the primary contributor to the increase in nitrogen concentration of Lake Taupo and the Waikato River (Hadfield, 2007; Environment Waikato, 2008). For example, Cameron et al. (2007) showed >95 % of nitrate leaching losses from a Taupo Pumice Soil in a pastoral farm originated from the urine patches of animals. Consequently, much of the literature concerning nitrogen leaching in the Taupo region concentrates on the nitrogen applied by the dung and urine of grazing animals.

Pumice Soils of the Taupo region are considered to have reasonably poor water holding capacity (Rout, 2003) and irrigating grazed pasture on Pumice soil with water alone can lead to increased nitrogen leaching (Burgess, 2003). However, adding nutrients through dairy farm effluent together with irrigation to meet plant water requirements can increase the nitrogen use efficiency of the pasture during summer and reduce levels of nitrogen leaching below that of pasture irrigated solely with water (Burgess, 2003).

A four year study by Sparling et al. (2006) at Temple View, near Hamilton, compared the ability of four differing soil types to accept treated municipal wastewater. The Atiamuri silt loam, from the same soil series as the Atiamuri gritty sandy loam found at both the View Road and Rakaunui Road LTS, was deemed to be suitable for land treatment of effluent, as less than 5% of the applied nitrogen was leached from the Pumice soil (Table 2.1).

Table 2.1. Nitrogen leaching from other New Zealand nitrogen leaching studies.

Region	Farm system/ Soil Type	N Applied (kg ha^{-1} yr^{-1})	N leached (kg ha^{-1} yr^{-1})	Author
Taupo, NZ	Drystock/Pumice	700	133-306*	Cameron et al., 2007
Waikato, NZ	Eff-Irr/Pumice	363	17	Sparling et al., 2006
	Non-Irr/Pumice	100	5	
	Eff-Irr/Allophanic	394	11	
	Non-Irr/Allophanic	100	1	
	Eff-Irr/Recent	347	77	
	Non-Irr/Recent	100	19	
	Eff-Irr/Gley	323	73	
	Non-Irr/Gley	100	7	
Taupo, NZ	DFE+Water/Pumice	377$^{\#\#}$	54$^{\#\#}$	Burgess, 2003
	DFE only/Pumice	358	116	
Rotorua, NZ	LTS/Allophanic	406	157	Gielen et al., 2000
		640	387	
Canterbury, NZ	Irr-Dairy/Pallic	1200	85	Di & Cameron, 2004
Canterbury, NZ	Irr-Dairy/Pallic	1200	134	Di & Cameron, 2005
Canterbury, NZ	Irr-Dairy/Pallic	0	23	Di & Cameron, 2007
		300	60	
		700	188	
		1000	255	
94 farms, NZ	Dairy/varied	n/a	69 (max) 40 (mean)	Judge & Ledgard, 2004
99 farms, NZ	Drystock/varied	n/a	10	Judge & Ledgard, 2004

Table 2.2. Nitrogen uptake by pasture from other nitrogen leaching studies in New Zealand.

Region	Farm system/ Soil Type	N Applied (kg ha^{-1} yr^{-1})	N uptake (kg ha^{-1} yr^{-1})	Dry matter (t ha^{-1} yr^{-1})	Author
Waikato, NZ	Eff-Irr/Pumice	363	229	10.9	Sparling et al., 2006
	Non-Irr/Pumice	100	79	4.6	
	Eff-Irr/Allophanic	394	345	15.9	
	Non-Irr/Allophanic	100	147	8.8	
	Eff-Irr/Recent	347	303	14.6	
	Non-Irr/Recent	100	71	4.4	
	Eff-Irr/Gley	323	194	12.4	
	Non-Irr/Gley	100	101	7.0	
Taupo, NZ	DFE+Water/Pumice	481$^{\#\#}$	688$^{\#\#}$	18.0$^{\#\#}$	Burgess, 2003
	DFE only/Pumice	442	656	17.5	
Canterbury, NZ	Irrigated Dairy/Pallic	1200	529	15.9	Di & Cameron, 2004
Canterbury, NZ	Irr-Dairy/Pallic	1200	449	15.3	Di & Cameron, 2005
Canterbury, NZ	Irr-Dairy/Pallic	0	133	4.4	Di & Cameron, 2007
		300	361	10.8	
		700	451	13.9	
		1000	632	19.7	

DFE, dairy farm effluent

Eff-Irr, irrigated with municipal effluent

Non-Irr, not irrigated

LTS, municipal land treatment scheme

[#] Two year average

[##] Four year average

* Range of leaching values over 3 years

2.5.6 Case study - Rotorua City wastewater irrigation

Rotorua, a city of 60,000 (Tomer et al., 2000), irrigates tertiary treated wastewater to volcanic sandy loam soils (Gielen et al., 2000). Rotorua is approximately 60 km from Taupo and has similar rainfall of 1491 mm yr^{-1} (Tomer et al., 2000). Despite both soils having volcanic parent material, the Allophanic soil of the Rotorua LTS has different structural and chemical properties to that of the Pumice soil of the Taupo LTS. Allophanic soil has been shown to leach less nitrogen under effluent irrigation than Pumice soil (Sparling et al., 2006).

The Rotorua scheme, at Whakarewarewa Forest, was designed to remove a large portion of nitrogen and phosphorous from the effluent that was previously discharged to the eutrophic Lake Rotorua. Complete nitrogen removal was not specified and the LTS was permitted to return up to 24,500 kg N yr^{-1} (127 kg N ha^{-1} yr^{-1} equivalent) to Lake Rotorua.

In Rotorua, the cover crop of the irrigation site is *Pinus radiata* and the effluent is irrigated between 14 blocks with an average loading of 71 mm wk^{-1}. It was intended that some nitrogen (approx 35 kg ha^{-1} yr^{-1}) would be utilised by the cover crop, while some would be denitrified in the upland forest soil, or denitrified in wetlands before the remainder entered water bodies. Volatilization losses were expected to be low due to low potential for evaporation from the soil, low soil pH, and the nitrified form of the effluent (Tomer et al., 2000). The Rotorua scheme was designed for a loading of 312 kg N ha^{-1} yr^{-1}, but during the six years to 1997, an average of 406 kg N ha^{-1} yr^{-1} was irrigated (Tomer et al., 2000).

During the first 2.5 years of operation, the system appeared to work as designed, with only 2.1% of applied nitrogen being exported to adjacent streams. After 2.5 years, nitrogen concentrations in the adjoining streams increased steadily and began to exceed design limitations (Tomer et al., 2000). The proportion of applied nitrogen that leached increased over the first six years of irrigation (Tomer et al., 2000).

Peak nitrogen leaching rates in winter were attributed to less evapotranspiration, and biological processes to remove N were slower than in warmer months (Tomer et al., 2000). The gradual increase of leached nitrogen over the first six years of irrigation may also be attributed to the length of time taken for groundwater to reach streams, which could be in the order of days to years (Tomer et al., 2000). The soils capacity to store nitrogen was thought to have 'filled up' after 2.5 years of effluent irrigation and is the primary suspect for the intensified nitrogen leaching. Nitrogen loading peaked at nearly 500 kg ha^{-1} yr^{-1} in 1995, well above the design limitation. When a trial portion of the pine forest was irrigated with 112 mm wk^{-1} (640 kg N ha^{-1} yr^{-1}), the nitrate concentration of the drainage water exceeded World Health drinking water quality standard of 10 g N m^{3} (Gielen et al., 2000).

The design of the Rotorua LTS assumed 65 kg N ha^{-1} yr^{-1} would be denitrified in the upland soils; however, denitrification rates were low, at 2.4 kg N ha^{-1} yr^{-1} (Tomer et al., 2000). It was discovered that excessive aeration of the free draining volcanic soil did not favour conditions for denitrification (Barton et al., 1999b). Together, plant uptake and upland denitrification accounted for about 37 kg N ha^{-1} yr^{-1}, less than 10% of applied nitrogen, and well below the design capacity of 100 kg N ha^{-1} yr^{-1} (Tomer et al., 2000).

In addition to poor nitrogen removal up the upland soils, wetland denitrification was not as successful as the design allowed for. Modified hydrological patterns due to the irrigation are thought to have led to short water residence time within the wetlands and reduced the potential for denitrification (Tomer et al., 2000).

Of the nitrogen that was removed from the effluent, the growth of understory plants and the accumulation of forest litter are thought to have removed much of the irrigated nitrogen before it had the potential to leach. Soil storage is considered to account for much of the nitrogen applied to the forest, however it is difficult to quantify soil storage (Tomer et al., 2000), even with a large number of samples. To assess nitrogen accumulation in the soil at Whakarewarewa, 1,152 samples were taken after four years of irrigation, yet no discernable accumulation of nitrogen was measured, due to high variability within and between plots (McLay et al., 2000). The capacity of the soil to accumulate large quantities of nitrogen throughout the lifespan of the LTS is not considered a sustainable pathway to avoid nitrogen leaching (Tomer et al., 2000).

Reducing the total volume or increasing the area and increasing the frequency of effluent irrigation have been suggested as methods of reducing the potential for nitrogen leaching from the Rotorua LTS (Magesan et al., 1998). Other techniques include improving crop uptake of nitrogen, improving denitrification rates in wetlands with engineering solutions, controlling the distribution of irrigation to encourage residence time in wetlands and to decrease the overall amount of nitrogen needing to be irrigated (Tomer et al., 2000).

2.6 Impact on the surrounding environment from the Taupo wastewater treatment scheme

Nitrogen has been identified as a limiting nutrient in the Taupo catchment (White & Payne, 1977; Coffey, 2005). Nitrogen concentrations in groundwater were reported to be highest around well populated areas, such as the Taupo township (John et al., 1978). From 1974, the nitrogen concentration of the groundwater entering Lake Taupo from the town continued to fall, and was attributed to the reticulation of the sewage network (John et al., 1978; Gibbs, 1991). In addition, the establishment of the Taupo LTS was shown to lead to a ten-fold decrease of periphyton biomass in the upper Waikato River between 1989 and 1998 (Coffey, 2005).

Groundwater nitrate concentrations increased in the monitoring wells around the Rakaunui Road irrigation site from 1995 to 2004. In some bores, the nitrate concentration exceeded the Ministry of Health drinking water standards of 11.3 mg L^{-1} (Church, 2005). The Rakaunui road LTS borders the Waikato River (Fig. 2.3) and groundwater from beneath the LTS flows toward the river. Coffey (2005) concluded that due to the low nutrient status of the upper Waikato River, groundwater originating from the Rakaunui Road LTS entering the Waikato River was having a measurable (albeit minimal) effect on late summer periphyton biomass. Any potential impact on the Waikato River from the View Road LTS will be difficult to detect in the near future as the View Road LTS lies further from the Waikato River than the Rakaunui Road LTS (Figure 1.2).

Nitrogen removal by the pasture of the Rakaunui Road LTS has not kept pace with the rate of irrigation and has contributed to the rise in nitrogen concentration of the groundwater. The LTS at Taupo relies on vigorous grass growth to remove nitrogen from the effluent and prevent environmental degradation from nitrogen leaching. Perennial ryegrass was chosen as the cover crop of the Taupo LTS as grass pasture has the capacity to take up large amounts of nitrogen relative to other plant species, while being easily sold as stock feed (Whitehead, 1995, TDC, 2007). In favourable conditions, grass swards may assimilate more than 500 kg N ha^{-1} yr^{-1}, and in some cases up to 700 kg N ha^{-1} yr^{-1} (Whitehead, 1995). A high rate of nitrogen removal by the ryegrass of the Taupo LTS will be possible by ensuring pasture growth is limited by no nutrient other than nitrogen, and by maintaining a dense, leafy pasture cover by regular cropping and occasional seed drilling (Crush & Nichols, 2007). Under appropriate management, the ryegrass grown at the Taupo LTS has the capacity to take up more than 600 kg N ha^{-1} yr^{-1} (Crush & Nichols, 2007), however an average of 381 kg N ha^{-1} yr^{-1} was removed as ensilage from the Rakaunui Road site between 1990 and 2005 (Power et al., 2005).

Based on the historic records of the amount of nitrogen removed in haylage, and known nitrogen application rate, the Overseer® computer model predicted up to 133 kg N ha^{-1} yr^{-1} will be leached from the Taupo LTS under current management strategies if effluent is applied at 650 kg N ha^{-1} yr^{-1} (Power et al., 2005). Efficient management of effluent irrigation is important to maximize crop production and decrease the likelihood of degradation of soil and water (Adeli et al., 2003).

Lake Rotokawa lies approximately one kilometre from the View Road LTS (Figure 1.2). It is possible for groundwater from beneath the View Road LTS to reach Lake Rotokawa (Zemansky et al., 2007), where potentially elevated nitrogen concentrations of the groundwater could modify the lake from its present state. However, at 0.2 m day^{-1}, the groundwater flow velocity beneath the View Road LTS is slow, and most of the groundwater from beneath the View Road LTS leads toward the Waikato River, not to Lake Rotokawa (Zemansky et al., 2007). Consequently, the risk of changing the ecology of Lake Rotokawa resulting from groundwater that was potentially contaminated with nitrogen from the View Road LTS was considered low (Poynter et al., 2007).

2.7 Conclusion - Literature review

The water quality of the upper Waikato River is considered very high, with low nutrient, low phytoplankton and very low bacterial levels. Taupo District Council has continued to reduce the impact it has had on the water quality of Lake Taupo and the Waikato River, however the amount of nitrogen leaching from the LTS is not known, therefore the impact on the environment cannot be assessed.

The Taupo LTS has important differences from other land treatment schemes. Variations in soil, cover crop, effluent quality, and application method prevent a direct assumption to be made on the likely amount of nitrogen that will be leached from the Taupo LTS simply by comparing nitrogen loading rates with similar data elsewhere.

Currently, the best estimate of nitrogen leaching from the Taupo LTS is generated by a computer model (Overseer®) developed primarily for animal based pastoral farming in New Zealand. Land application of treated municipal effluent differs from animal farming as nutrients are spread consistently both spatially and temporally, while plant water needs are met during summer months. The amount of nitrogen leached from discreet animal urine plots is likely to be higher than the amount of nitrogen leached from an intensively managed land treatment scheme with the same overall rate of applied nitrogen.

The only way to get a reliable estimate of the amount of nitrogen being leached is to physically measure the volume of water passing through the soil profile and quantify the amount of nitrogen contained within the leachate. It is impossible to capture all the water draining through the coarse textured Pumice soils of the Taupo LTS. However, a series of barrel lysimeters provide a means to collect leachate and measure soil water drainage from a representational portion of the irrigation field.

Although nitrogen leaching from effluent irrigated volcanic soil has been quantified in the Whakarewarewa Forest, disparities in the design of the system with that at Taupo mean that results are not readily transferrable between systems. The poor performance of the Whakarewarewa system, having well draining volcanic soils on similar parent material to the Taupo system, implies that a cautious approach should be adopted to reduce the potential for excess nitrogen leaching.

Direct measurement of a representative portion of the irrigation field, as undertaken in this thesis, is the best way to provide a meaningful estimate of the quantity of nitrogen being leached from the Taupo LTS to prevent degradation of waterways.

Chapter three - Methods

3.1 Introduction

Chapter three provides a description of the equipment and analytical methods used.

3.2. Experimental design

3.2.1 Site description

The experimental area of this study was located on part of the View Road land treatment scheme (LTS) in Taupo, New Zealand (Figure 1.1). At the View Road LTS, approximately 120 hectares of perennial ryegrass was irrigated using centre pivot irrigators (Figure 3.1). The View Road LTS was the second LTS commissioned by Taupo District Council (Figure 2.3), where irrigation began in December 2008. The experimental area of this study covers approximately 29 hectares and lies in the south-west corner of the View Road LTS (Figure 3.1).

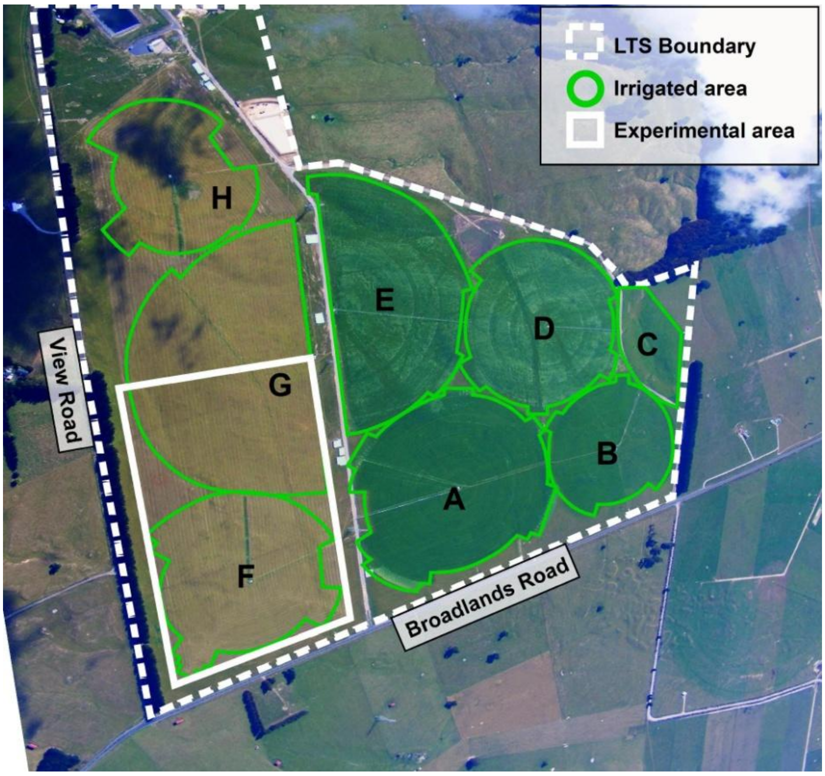

Figure 3.1. Overview of the View Road LTS. The experimental area had recently been harvested when the photograph was taken. Adapted from photograph courtesy of TDC.

3.2.2 Nitrogen application

3.2.2.1 Irrigation rate

To investigate the effect of different rates of effluent application upon nitrogen leaching, four effluent loading rates were trialled at the View Road LTS. To apply three different rates of effluent, the computer software controlling the irrigators was manipulated to vary the speed at which the irrigators travel over the ground. The field area was divided into 12 sectors and randomly assigned one of the three loading rates (Fig. 3.2). The irrigators were programmed to slow down by 18% to apply a higher load rate (more effluent per unit area), and speed up by 18% to apply a lower load rate of effluent (less effluent per unit area). The medium load rate operated at normal speed. The irrigators were linked to a GPS system, ensuring the predetermined treatment sectors did not shift over time. Control sites (no-N) were selected in areas that had not received effluent and were a suitable distance from the irrigators to be unaffected by spray drift.

Based on the total amount of nitrogen irrigated, the effluent loading rates were intended to be 0 (no-N), 450 (low-N), 550 (mid-N) and 650 kg N ha^{-1} yr^{-1} (high-N). In practice, the effluent loading rates were not able to be replicated, consequently there were twelve different rates of effluent irrigation, plus areas that remained un-irrigated (Figure 3.2). As the effluent loading rates were not able to be replicated, the treatment sectors were grouped into treatments that had similar rates of effluent irrigation. The no-N treatments remained, and the balance of the treatment sectors were defined as the low-N treatment (less than 350 kg N $ha^{-1}yr^{-1}$), the mid-N treatment (from 350 to 450 kg N $ha^{-1}yr^{-1}$) and the high N treatment (450 kg N $ha^{-1}yr^{-1}$ or more). In total, 48 lysimeters were installed, with three lysimeters beneath each of the twelve effluent loading rates, plus twelve lysimeters in the un-irrigated portion of the farm (Figure 3.2).

Effluent flow volumes were obtained from flow meters mounted on the intake to each irrigator and calculated against irrigated area to give a measure in mm, of effluent irrigated.

To determine the level of variation between each treatment, and the level of variation within each treatment, a plastic triangular rain gauge with a capacity of 160 mm was placed beside each of the lysimeters that were irrigated (Figure 3.3). As the un-irrigated lysimeters were installed close together, one rain gauge was installed per group of three lysimeters. The rain gauges were installed in March and the level of water within them was recorded at the time of leachate collection.

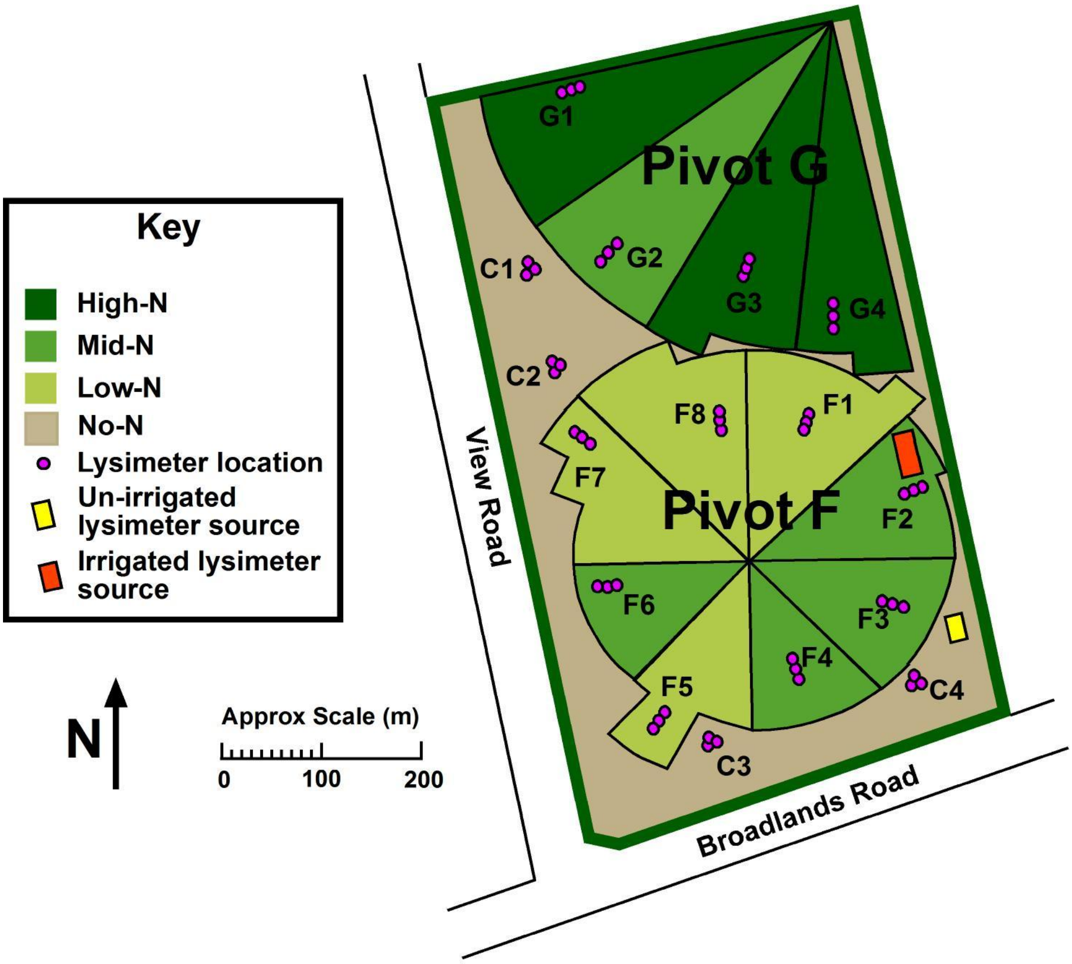

Figure 3.2. Overview of study layout.

Figure 3.3. Installation of a lysimeter in the field. A plastic rain gauge with sampling tube attached is visible in the left foreground, and just visible to its right is a 0.4 x 0.4 m concrete paver. Visible in the middle ground is a bamboo stake identifying the edge of a lysimeter.

3.2.3 Effluent nitrogen

3.2.3.1 Nitrogen concentration of the effluent

The nitrogen concentration of the effluent used for irrigation was obtained using two methods. As part of resource consent compliance, a weekly grab sample was taken by TDC staff from the wastewater treatment plant and analysed by a commercial laboratory for total nitrogen concentration. A composite effluent sampler was installed in the pump house at the View Road site in October 2010. The composite sampler comprised a series of solenoids activated by a data logger. Samples of approximately 50 ml were taken every 30 minutes between the hours of 4 pm and 2 am (the main hours of irrigation) and amalgamated. The sampler collected effluent in weekly allotments that were stored in a refrigerator below 4° C. The composite sampler enabled a more representative sample of the effluent to be obtained than the one-off sample collected by TDC. Any changes in the effluent quality that may have occurred between the wastewater treatment plant and the irrigation field were able to be captured by the composite sampler.

3.2.4 Leachate collection

3.2.4.1 Lysimeter installation

Intact monolithic barrel lysimeters (300 mm dia x 430 mm deep, Cameron et. al., 1992) were used to collect leachate and calculate drainage. Prior to selecting the site for lysimeter extraction, variability of the soil profile across the field area was observed using a hand auger. The upper 500 mm of the soil profile across the entire irrigated portion of the site was considered to be relatively uniform, having a 200 mm ploughed A horizon over a weakly developed sandy B and sandy C horizon (Appendix 1). Upon locating a suitable site for lysimeter extraction, a trench was dug by mechanical excavator to facilitate lysimeter removal. The trench gave an opportunity to visually assess the uniformity of the soil profile before constructing the lysimeters, where the soil was deemed to be suitably uniform. To limit variability between the soil columns, the lysimeters were collected within close proximity to each other (Figure 3.4).

The site had received effluent from December 2008, approximately nine months prior to lysimeter extraction, therefore lysimeters were retrieved from two areas of the farm. Lysimeters that were to receive effluent were collected from an area that had previously received effluent, and control lysimeters that were to remain un-irrigated were collected from an area that had received no effluent (Figure 3.2, 3.4). 36 lysimeters were distributed within the predetermined treatment sectors, with three lysimeters per sector placed ten metres apart. Twelve lysimeters were positioned in four locations beyond the reach of any spray drift originating from the sprinkler heads (Figure 3.2).

Figure 3.4. Collection of lysimeters from previously irrigated plot. Un-irrigated (control) lysimeters were collected in close proximity to the visible soil mounds in left background of figure.

The internal diameter of the lysimeter was 300 mm with a 10 mm side wall giving an external diameter of 320 mm. For calculation purposes, the diameter of the lysimeter was assumed to be 310 mm (i.e. from the mid point of the lysimeter wall).

The lysimeters feature a leachate collection chamber directly below the soil column (Figure 3.5). The lysimeters have a perforated bottom plate to allow drainage to the collection chamber. The collection chamber was secured to the lysimeter using screws, and the two parts were sealed together using adhesive PVC tape (Figure 3.5). To allow leachate to be pumped from the lysimeter, 6 mm PVC piping was perforated and attached to the floor of the collection chamber. The PVC pipe extended above ground and was secured to a wooden stake (Figure 3.3). Prior to crop harvest, the stake was removed and the tubing placed beneath a 400 x 400 mm concrete paver installed to aid location of the lysimeters.

3.2.4.2 Sampling procedure

Leachate was sampled at least monthly, or more frequently in times of heavy rainfall. To retrieve the leachate, a vacuum pump was connected to a sealed 10 litre measuring flask. The PVC pipe extending from the leachate collection chamber of the lysimeter was also connected to the flask during pumping, where the vacuum created in the flask evacuated the collection chamber. The flask featured calibrated marks in 250 ml increments, and the volume of leachate was estimated to the nearest 50 ml.

From April 2010, a set of weighing scales were used to measure the leachate volume from the mass of water collected, where the volume could be determined to within 10 ml. At the time of sampling, each of the 48 lysimeters was pumped individually, and equipment flushed between treatments (group of three lysimeters) with tap water. The leachate was drained from the measuring flask to a plastic jerry can and placed on the scales. In August 2010, the vacuum pump and measuring flask were replaced by a self-priming pump. Initially the equipment was attached to a two wheel farm bike, but from August 2010, a three wheeled ATV was used to transport the sampling equipment.

3.2.5 Nitrogen concentration of the drainage water

Leachate from each set of three lysimeters in each treatment sector was bulked and sub-sampled for analysis by a commercial laboratory. The leachate was analysed for:

- Total ammoniacal nitrogen (NH_4-N) using the method of phenol/hypochlorite colorimetry, with a discrete analyser following the method of APHA 4500-NH_3 F (modified from manual analysis, 21st ed. 2005):
- Total oxidised nitrogen (NO_X-N) (nitrate + nitrite) by automated cadmium reduction using a flow injection analyser following the method of APHA 4500-NO_3^- I (Proposed) 21st ed. 2005:
- Total Kjeldahl nitrogen (TKN) consisting of total Kjeldahl digestion followed by phenol/hypochlorite colorimetry using a discrete analyser following the method of APHA 4500-N_{org} C. (modified) and 4500-NH_3 F (modified) 21st ed. 2005.
- Total nitrogen (TN) was calculated as TKN + NO_X-N.
- Dissolved organic nitrogen (DON) was calculated as TKN - NH_4-N.

3.2.6 Herbage collection

Prior to site harvest, the grass was collected from each lysimeter. Scissors were used to cut the grass to the same height as that of the harvest machinery (approximately 70 mm, Figure 3.6). The pasture was returned to the laboratory and air dried in paper bags (Cookson et al., 2001) at 65°C for a minimum of five days. The samples were too bulky and numerous to be dried in a conventional dessicator, so were allowed to cool in the incubator before being weighed. A representative sub-sample was taken from each lot of dried grass and ground in a domestic coffee grinder. The ground samples were analysed in a LECO furnace (LECO Corporation, Michigan, USA) for total nitrogen.

Figure 3.5. Lysimeter prior to installation. Note PVC tube exiting leachate collection chamber for sampling purposes.

3.2.7 Climatic information

An on-site weather station (Vaisala WXT520 Weather Transmitter) located near the pump house collected rainfall and wind speed data. The weather station was installed when the site was commissioned in 2008.

3.2.8 Statistical analysis

The variance between samples was analysed using the Analysis ToolPak feature of MS Excel, using the regression and t-test features.

Figure 3.6. Typical pasture immediately following harvest. Note patches of exposed soil.

Chapter four - Results

4.1 Nitrogen loading rates

In order to define the high-N, mid-N, and low-N treatments, the amount of nitrogen applied to each treatment sector was calculated using the volume of effluent irrigated and the effluent nitrogen concentration.

4.1.1 Effluent nitrogen concentration

The nitrogen concentration of the raw effluent collected at the field site was amalgamated with the weekly information provided by Taupo District Council (TDC), with preference given to the effluent collected by the composite sampler when available. Using both sets of data, the mean concentration of nitrogen in the irrigated effluent for the 12 month period was 43.2 g N m^{-3}, with a minimum of 30.9 and a maximum of 54.5 g N m^{-3} (Figure 4.1).

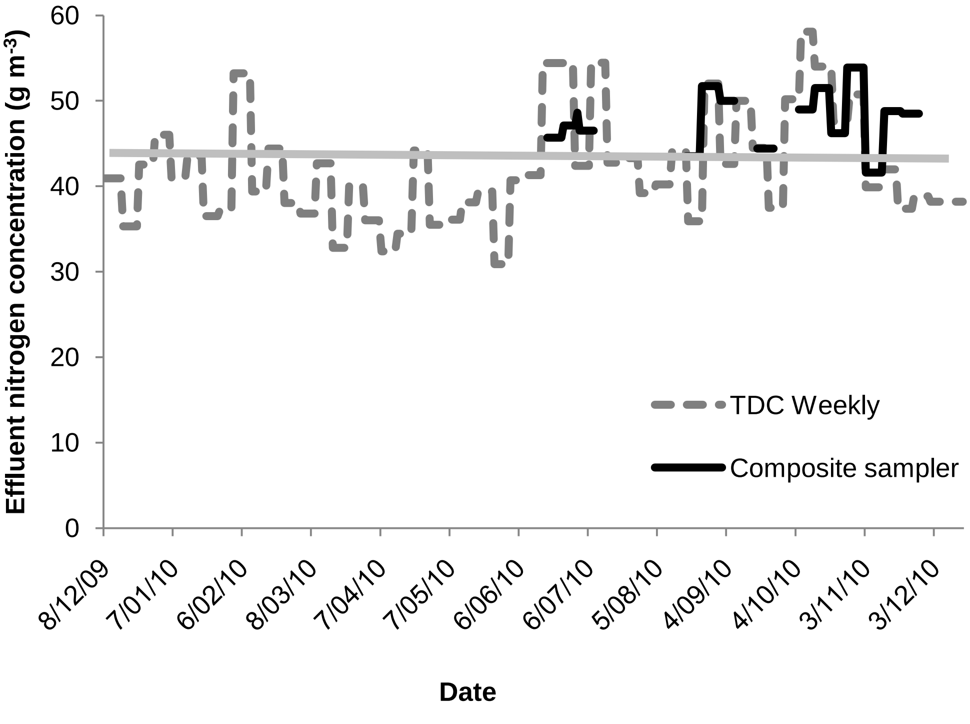

Figure 4.1: Total nitrogen concentration of irrigated effluent from TDC weekly sample and composite sampler installed at the field site for the period 8th December 2009 to 1st December 2010. Horizontal bar represents mean concentration for the monitoring period.

The samples collected by the composite sampler shows the nitrogen in the effluent was on average 93% total ammoniacal nitrogen (NH_4-N), <1% total oxidised nitrogen (NO_X-N) with the remainder being dissolved organic nitrogen (DON) (Appendix 3).

4.1.2 Effluent application

Taupo District Council supplied daily effluent application volumes from each irrigator (Figure 4.2). Plastic rain gauges beside each lysimeter enabled the effluent that was irrigated to be proportioned between the treatments.

By combining the weekly nitrogen concentration (Figure 4.1) with the daily effluent flow volume (Figure 4.2), and the proportion of effluent irrigated to each treatment sector (Appendix 10), the nitrogen loading for each treatment sector was calculated (Table 4.1). The lowest nitrogen load applied to a treatment sector was 280 kg N ha^{-1} and the highest was 520 kg N ha^{-1}.

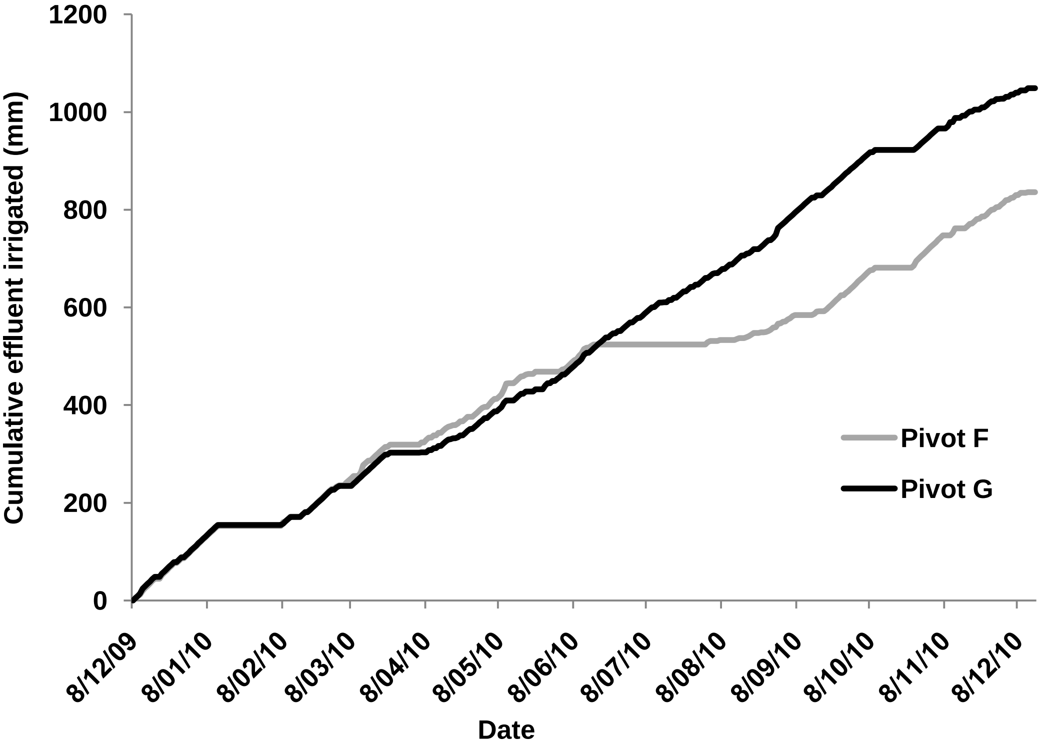

Figure 4.2: Mean cumulative effluent application based on pump flow data from each irrigator for the year from 8th December 2009 to 14th December 2010.

Table 4.1: Total volume of effluent irrigated (mm) and total nitrogen loading (kg N ha^{-1}) to each irrigated treatment sector for the year from 8th December 2009 to 14th December 2010.

Treatment sector	G4	G1	G3	F2	F6	F4	G2	F3	F8	F1	F7	F5
Effluent	1060	1030	910	780	800	800	730	700	650	770	620	510
TN load	520	510	450	420	420	410	370	360	340	340	340	280

4.1.3 Atmospheric input

Inputs from rainfall contribute up to 6 kg N ha^{-1} yr^{-1} in the Taupo region (Dyck et al., 1987 (cited in Davis, 2005)), and a value of 5 kg N ha^{-1} yr^{-1} has previously been used when calculating nitrogen budgets for the Taupo LTS (Power & Wheeler, 2007). It was assumed that an additional 5 kg N ha^{-1} from rainfall was deposited over the duration of this study.

4.1.4 Treatment definition

Based on the nitrogen loading, three treatments were defined (Figure 4.3). The treatments that received 450 kg N ha^{-1} or more (high-N) consisted of sectors G1, G3 and G4, the treatments that received 350-450 kg N ha^{-1} (mid-N) consisted of sectors F2, F6, F4, G2 and F3, and sectors F8, F1, F7 and F5 made up the low-N treatment (less tahn 350 kg N ha^{-1}). The un-irrigated treatments were sectors C1, C2, C3 and C4.

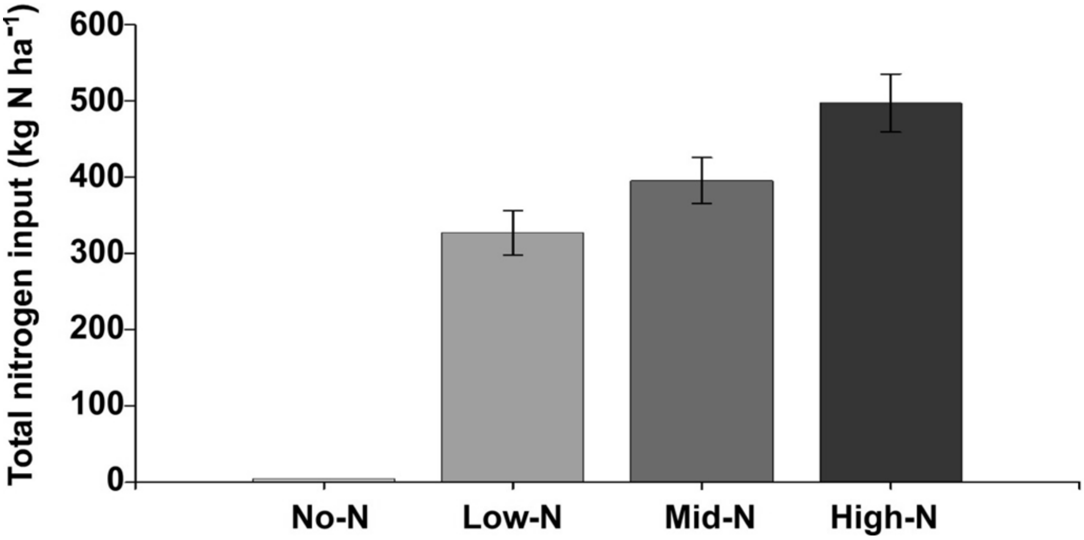

Figure 4.3: Total nitrogen input to each treatment for the year from 8th December 2009 to 14th December 2010. Error bars represent one standard deviation of the mean.

4.2 Hydrology

4.2.1 Rainfall

The weather station on site failed to produce reliable data, however an alternative rain gauge in Taupo township, 8 kilometres from the field site was located. At 891 mm, rainfall in Taupo for the year from 8th December 2009 to 14th December 2010 was below the previous six year average of 1170 mm (Figure 4.4). In the six years prior to 2010, rainfall was, generally consistent throughout the year with no seasonal pattern. During 2010, the pattern of rainfall through the year was dominated by wet periods in June, August and September, and a dry autumn and spring (Figure 4.4).

4.2.2 Drainage through the soil profile

The volume of water draining through the soil was reasonably well correlated with the total water input (R^2=0.84, Figure 4.6). After 12 months, the treatments that had received >900 mm of effluent leached more water than the treatments that received <700 mm of effluent ($P<0.001$), but the correlation between the volume of irrigation and drainage from the irrigated treatments showed scatter (R^2=0.47, Figure 4.6). The high-N treatment leached more water than the low-N and medium treatments-N ($P<0.05$). There was no significant difference between the amount of water that drained from the mid-N, low-N or no-N treatments (Figure 4.5). On average, the irrigated treatments leached more water than the un-irrigated treatments ($P<0.05$). Despite receiving more water through irrigation and rainfall during the 12 month period, some of the irrigated treatments leached less water than the un-irrigated treatments (Figure 4.6, Table 4.2). Until May 2010, on average, the un-irrigated treatments had leached more water than the irrigated treatments (Figure 4.4).

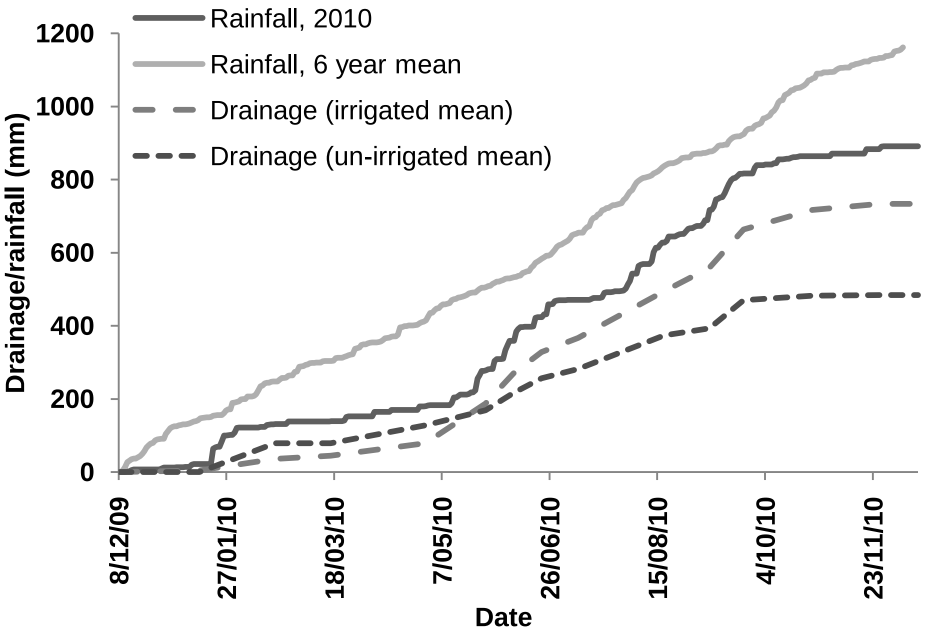

Figure 4.4: Drainage through the soil profile (mean of irrigated and mean of un-irrigated treatments) together with rainfall in Taupo township (8th December 2009 to 14th December 2010, and previous 6 year average (2004-2009)).

Of the irrigated treatments, the lowest total drainage for the 12 month period from an individual lysimeter was 70 mm and the highest was 1300 mm (Appendix 2). Individual lysimeters in the un-irrigated treatments produced between 300 and 690 mm of drainage water during the year.

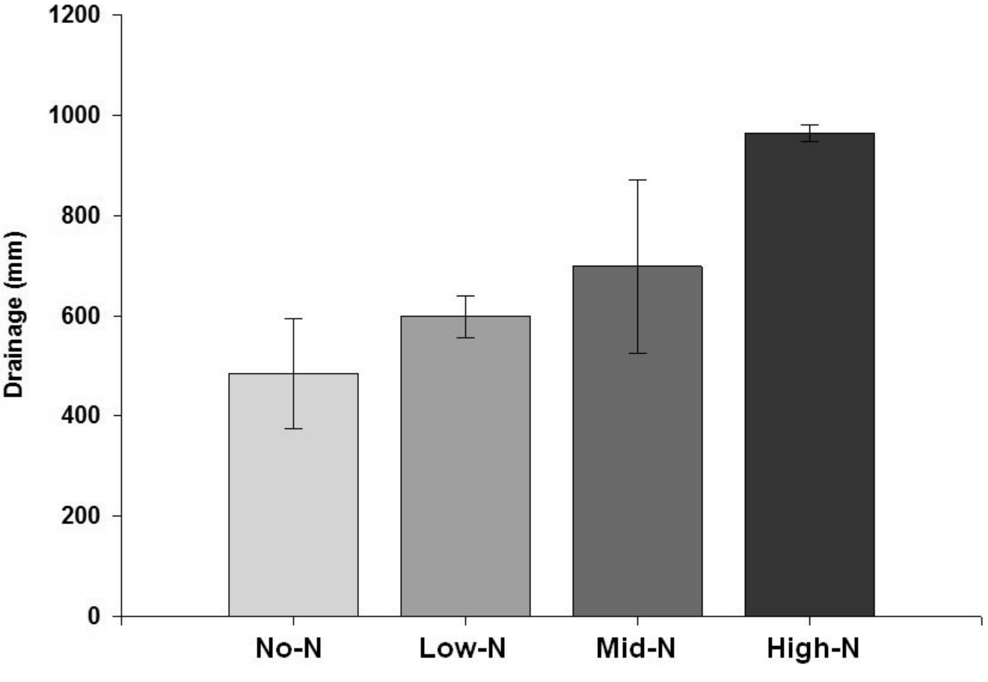

Figure 4.5: Drainage through the soil profile from each treatment for the period December 2009 to December 2010. Error bars represent one standard deviation of the mean.

The un-irrigated treatments had a greater drainage response to heavy rainfall events, such as in January 2010 (Figure 4.8), when 109 mm of rain fell, mostly during two thunderstorms. The treatments that leached the greatest volume of water during the January period were those that were un-irrigated (Figure 4.8).

A higher amount of drainage from the irrigated treatments did not correlate with higher (or lower) grass growth. Total grass growth from each lysimeter over the 12 month period was poorly correlated with the total volume of water collected (R^2=0.19, Figure 4.7). Removing the un-irrigated lysimeters from analysis, gave no correlation between grass growth and total drainage from individual lysimeters (R^2=0.01, Figure 4.7).

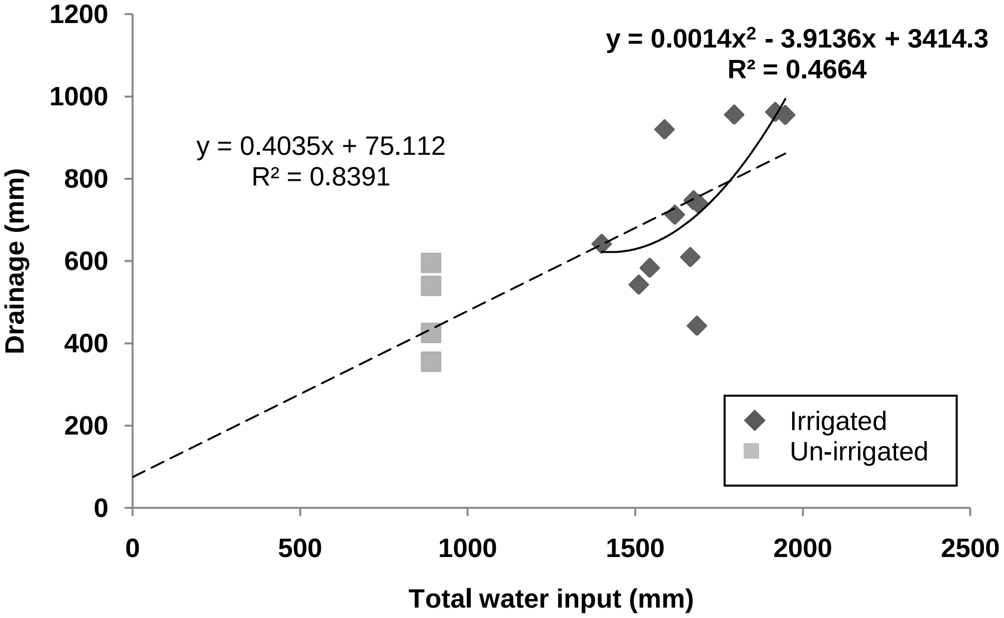

Figure 4.6: Relationship between total water input (rainfall + irrigation) and volume of water that drained through the soil profile for the period December 2009 to December 2010. Equation in bold type relates to the irrigated treatments only, while the equation in normal type encompasses irrigated and un-irrigated treatments.

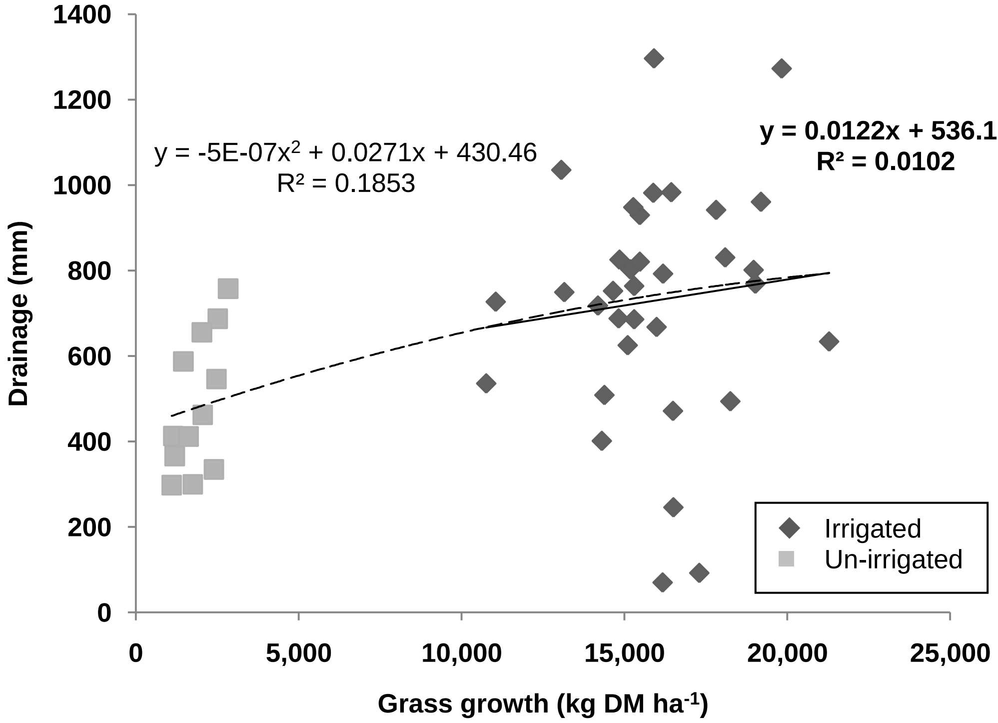

Figure 4.7: Relationship between total grass growth and total volume of water that drained from each lysimeter for the period December 2009 to December 2010. Equation in bold type relates to the irrigated treatments only, while the equation in normal type encompasses irrigated and un-irrigated treatments.

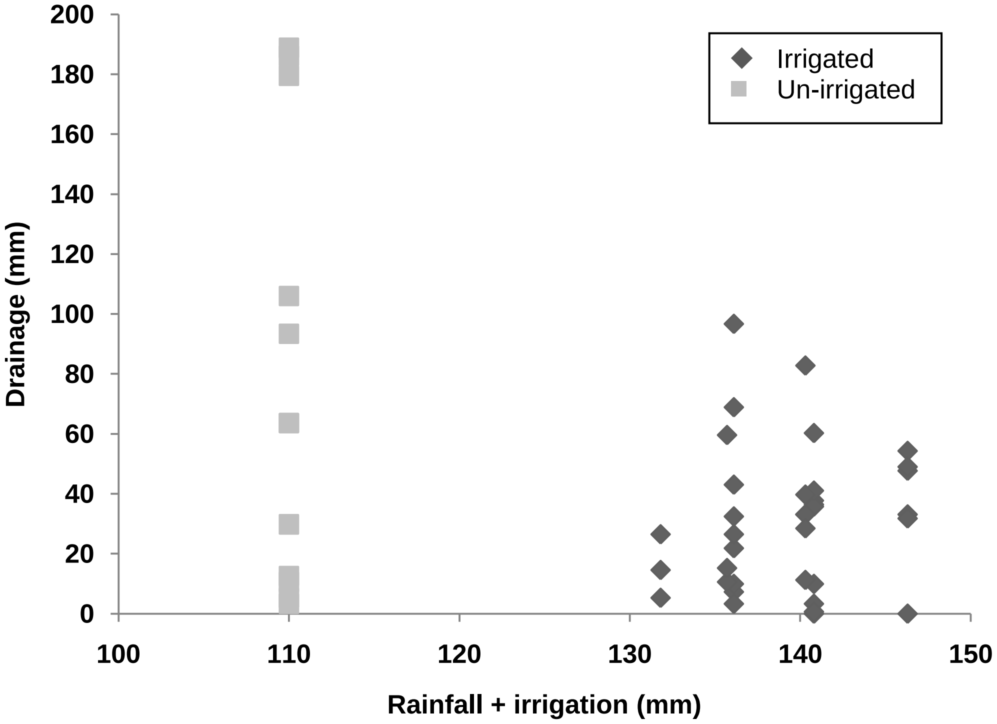

Figure 4.8: Relationship between volume of water applied to the land surface (rainfall + irrigation) and volume of water that drained through the soil profile for the period 14 January to 18 February 2010. Data points represent individual lysimeters.

4.2.3 Evapotranspiration

Evapotranspiration from the pasture and soil was estimated to be the total amount of water that reached the land surface, less the drainage through the soil profile. The mean estimated evapotranspiration (EET) from the irrigated treatments was 940±150 mm and the mean EET from the un-irrigated treatments was significantly lower ($P<0.05$) at 410±110 mm Figure 4.9). There was no significant difference between the EET of the high-N, mid-N or low-N treatments.

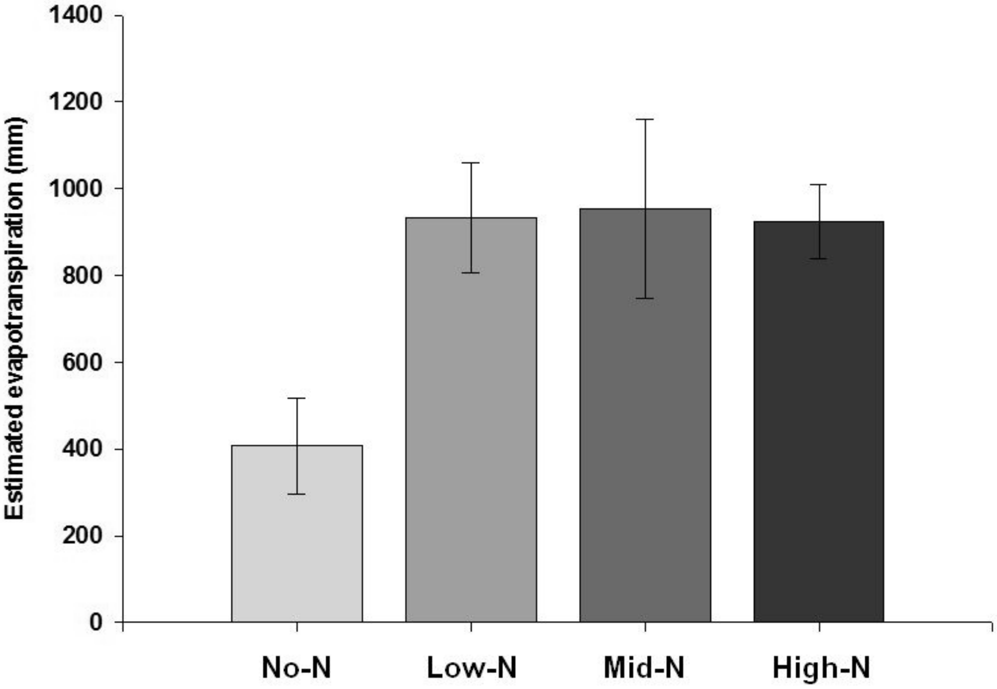

Figure 4.9: Estimated evapotranspiration (effluent + rainfall - drainage) for each treatment for the year December 2009 to December 2010. Error bars represent one standard deviation of the mean.

4.3 Nitrogen leaching

4.3.1 Total nitrogen leached.

Leachate was collected 14 times during the period from 8th December 2009 to 14th December 2010. Leachate was collected each month, with additional sampling in June and September to compensate for heavy rainfall. One lysimeter failed to produce any leachate during the entire 12 month period, where a broken collection chamber base is suspected, causing leachate to drain through. The lysimeter that failed to produce leachate was removed from subsequent calculations, however, the volumes collected from all other lysimeters were included.

Irrigation of the ryegrass pasture with effluent significantly increased the amount of total nitrogen (NO_X-N + NH_4-N) leached compared to un-irrigated pasture ($P<0.01$). Total nitrogen leached from the high-N treatment was higher than the low-N treatment ($P<0.05$) but not significantly different from the mid-N treatment (Figure 4.10). However, between irrigated treatments, there was scatter between the total nitrogen

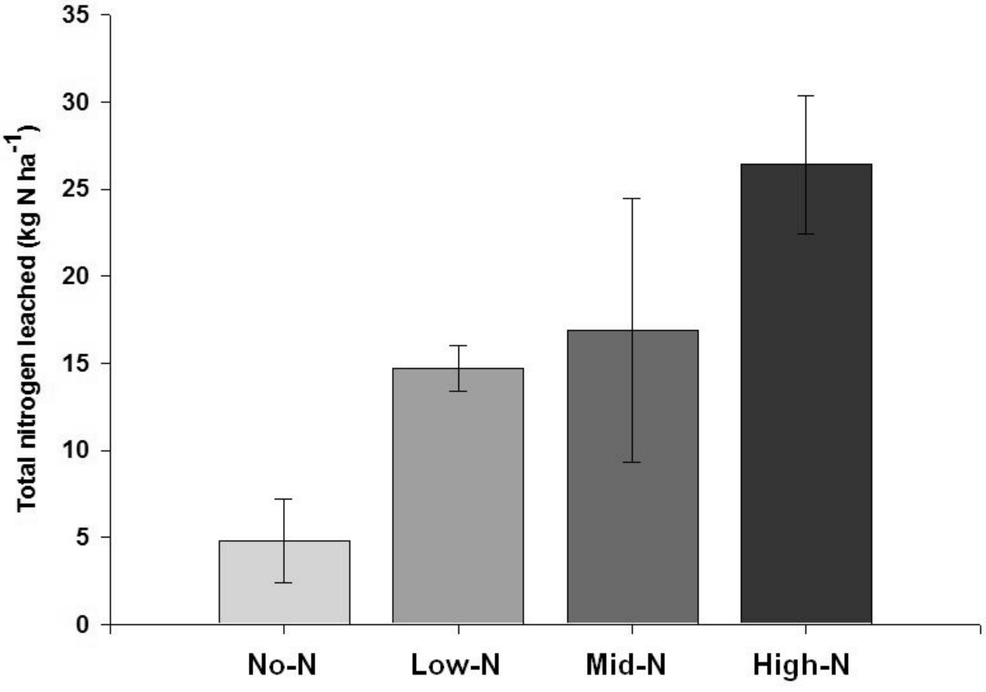

Figure 4.10: Total nitrogen leached from each treatment for the year from December 2009 to December 2010. Error bars represent one standard deviation of the mean.

input and the amount of nitrogen that leached (R^2=0.40, Figure 4.12). Total nitrogen leached from the un-irrigated treatments ranged from 2.1 to 8.1 kg N ha^{-1}, whereas total nitrogen leached from the effluent irrigated treatment sectors ranged from 7.8 to 31.3 kg N ha^{-1} (Figure 4.12, Table 4.2).

Of the treatments that were irrigated, the amount of nitrogen leached was more closely correlated with the volume of water passing through the soil (R^2=0.73, Figure 4.13) than with the amount of nitrogen irrigated (R^2=0.40, Figure 4.12).

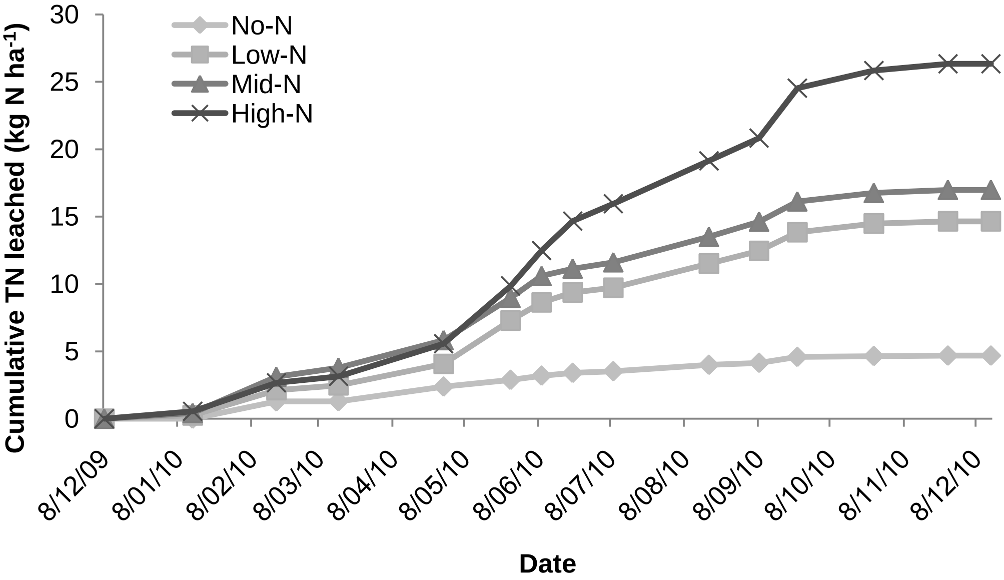

Figure 4.11: Cumulative total nitrogen leached from each treatment for the year from December 2009 to December 2010.

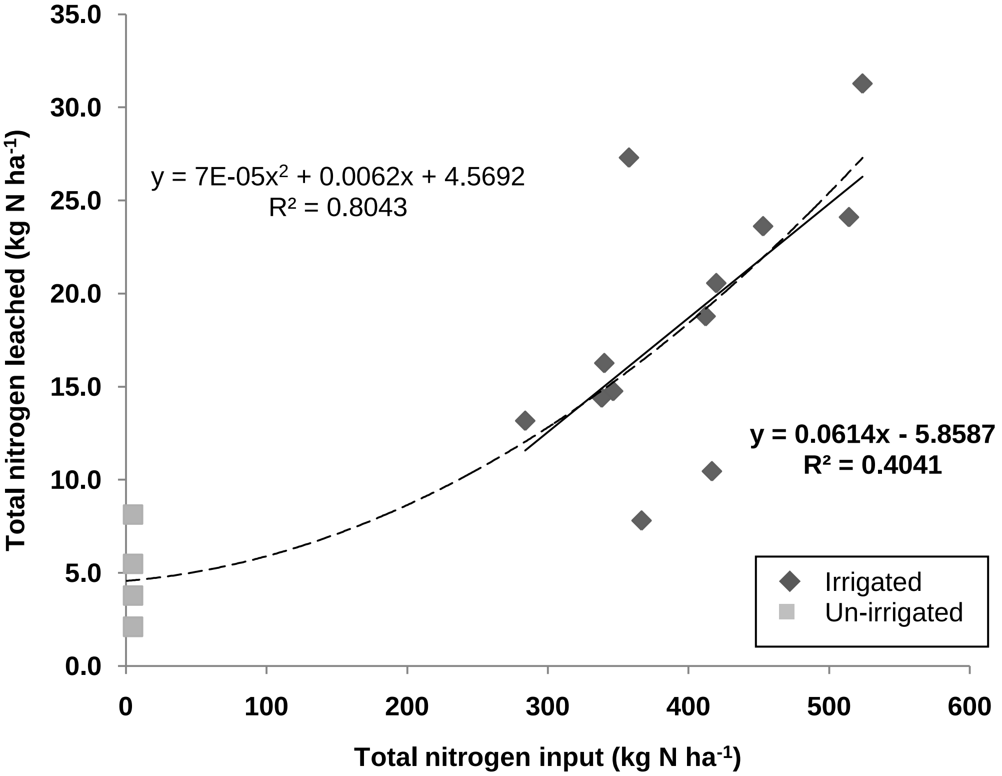

Figure 4.12: Relationship between total nitrogen input and total nitrogen leached for each irrigated treatment during the year from December 2009 to December 2010. Equation in bold type relates to the irrigated treatments only, while the equation in normal type encompasses irrigated and un-irrigated treatments.

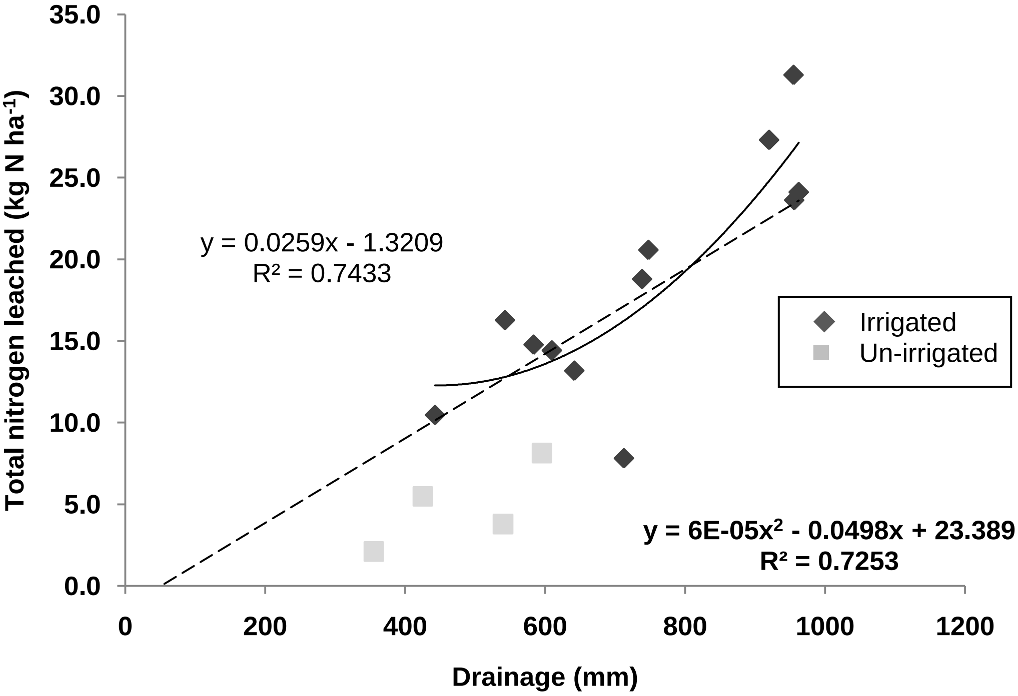

Figure 4.13: Relationship between total drainage through the soil profile and total nitrogen leached during the year from December 2009 to December 2010. Equation in bold type relates to the irrigated treatments only, while the equation in normal type encompasses irrigated and un-irrigated treatments.

4.3.2 Forms of nitrogen leached

The total amount of nitrogen in the leachate was broken down into three components, total oxidised nitrogen (NO_X-N), total ammoniacal nitrogen (NH_4-N) and dissolved organic nitrogen (DON).

4.3.2.1 Nitrate/nitrite leached

The proportion of NO_X-N in the leachate draining from the irrigated treatments was greater than the proportion of NO_X-N draining from the un-irrigated treatments ($P<0.001$). Over the 12 month period, NO_X-N made up on average 53% of all nitrogen leached from the effluent irrigated treatments, and 26% of all nitrogen leached from the un-irrigated treatments. On a kg ha^{-1} day^{-1} basis, NO_X-N leaching was highest during the first half of the year. The amount of NO_X-N that leached decreased following consistent rain that began in May 2010 (Figure 4.4, 4.14 a & b). The proportion of NO_X-N in the leachate draining from the high-N treatments was not significantly different from the mid-N and low-N treatments.

The total amount of NO_X-N that leached was correlated with total drainage ($R^2=0.75$, Figure 4.16 a) and similarly correlated with total nitrogen input ($R^2=0.74$, Figure 4.17 a). When the un-irrigated treatments were removed from analysis, the amount of NO_X-N leached was better correlated to drainage through the soil profile ($R^2=0.64$, Figure 4.16 a) than with total nitrogen input ($R^2=0.35$, Figure 4.17 a). The high-N treatments leached more NO_X-N than the low-N treatments ($P<0.01$) but not more than the mid-N treatment. There was no significant difference in the amount of NO_X-N leached from the mid-N and low-N treatments.

4.3.2.2 Organic nitrogen leached

The proportion of DON in the leachate draining from the irrigated treatments was less than the proportion of DON draining from the un-irrigated treatments ($P<0.001$). DON constituted 45% of all nitrogen leached from the irrigated treatments, and 72% of all nitrogen leached from the un-irrigated treatments. The proportion of DON in the leachate from the high-N treatments was not significantly different from the mid-N or low-N treatments.

The total amount of DON that leached showed a better correlation with total drainage (R^2=0.88, Figure 4.16 b) than with total nitrogen input (R^2=0.74, Figure 4.17 b). When the un-irrigated treatments were removed from analysis, the amount of DON leached was better correlated with drainage through the soil profile (R^2=0.73, Figure 4.16 b) than with total nitrogen input (R^2=0.58, Figure 4.17 b). On a kg N ha^{-1} basis, the high-N treatments leached more DON than the mid-N and low-N treatments ($P<0.05$). The amount of DON leached from the mid-N treatments was not significantly different from the low-N treatments.

4.3.2.3 Ammoniacal nitrogen leached

The proportion of NH_4-N that leached, and absolute amount of NH_4-N leached from the irrigated treatments was not significantly different than the proportion or total NH_4-N leached from the un-irrigated treatments. NH_4-N represented 2% of all nitrogen leached from both irrigated and un-irrigated treatments, with the irrigated treatments leaching on average 0.3 kg NH_4-N ha^{-1} and the un-irrigated treatments leaching 0.1 kg NH_4-N ha^{-1} during the 12 month period. Not all lysimeters leached NH_4-N (Appendix 3), however the lysimeters beneath Pivot G leached more NH_4-N than the lysimeters under Pivot F ($P<0.05$). Leaching of NH_4-N typically followed heavy rainfall events, such as in January 2010 and again in September 2010 (Figure 4.14).

4.3.2.4 Seasonal patterns of nitrogen form leached

4.3.2.4.1 Irrigated treatments - seasonal pattern

The mean concentration of NO_X-N in the leachate from the irrigated treatments peaked in February 2010 at 5.9 g N m^{-3}, and continued to decline until June, where NO_X-N concentrations remained below 1 g N m^{-3} for the remainder of the year (Figure 4.15). In contrast to NO_X-N, DON concentrations remained relatively constant around a mean of 1.1 g N m^{-3} for the entire monitoring period (Figure 4.15).

On a kg $ha^{-1}day^{-1}$ basis, NO_X-N concentrations spiked in January after heavy rainfall and peaked in May, with another smaller spike in September (figure 4.14). Two thirds of all the NO_X-N leached from the irrigated treatments was leached between 18th January and 27th May.

As the concentration of DON in the leachate remained relatively constant, the pattern of DON that leached on a kg $ha^{-1}day^{-1}$ basis followed the pattern of drainage, with peaks in June and September when rainfall was highest.

4.3.2.4.2 Un-irrigated treatments -seasonal pattern

The concentration of both DON and NO_X-N in the leachate from the un-irrigated treatments peaked in January and steadily declined until June (Figure 4.15). Approximately 70 % of all the nitrogen leached from the un-irrigated treatments leached between 18th January and 9th June (Figure 4.14).

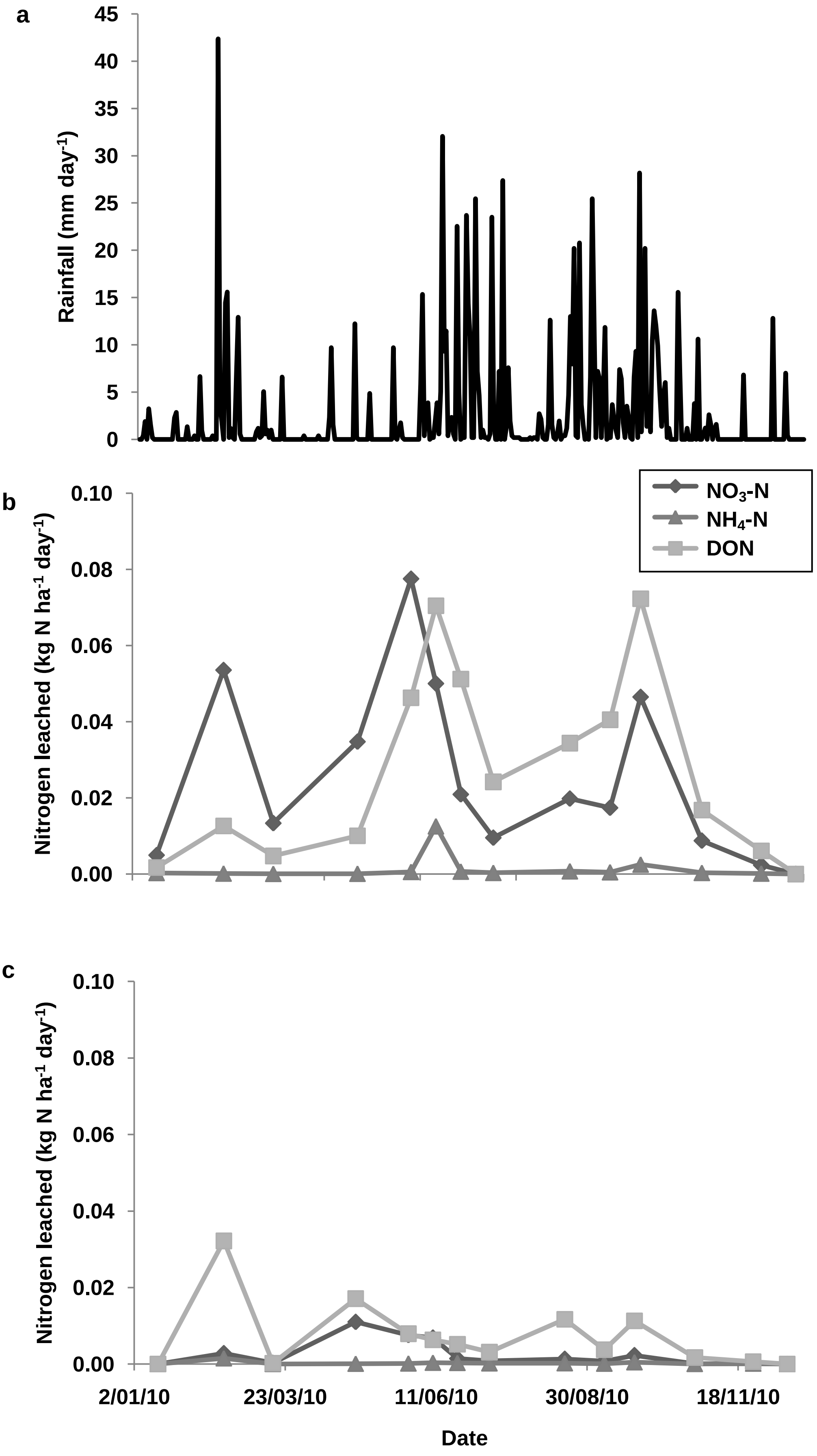

Figure 4.14: (a) Rainfall (mm day^{-1}) and seasonal pattern of rate of nitrogen leached (kg N ha^{-1} day^{-1}) for the year from 8th December 2009 to 14th December 2010 for (b) irrigated treatments and (c) un-irrigated treatments.

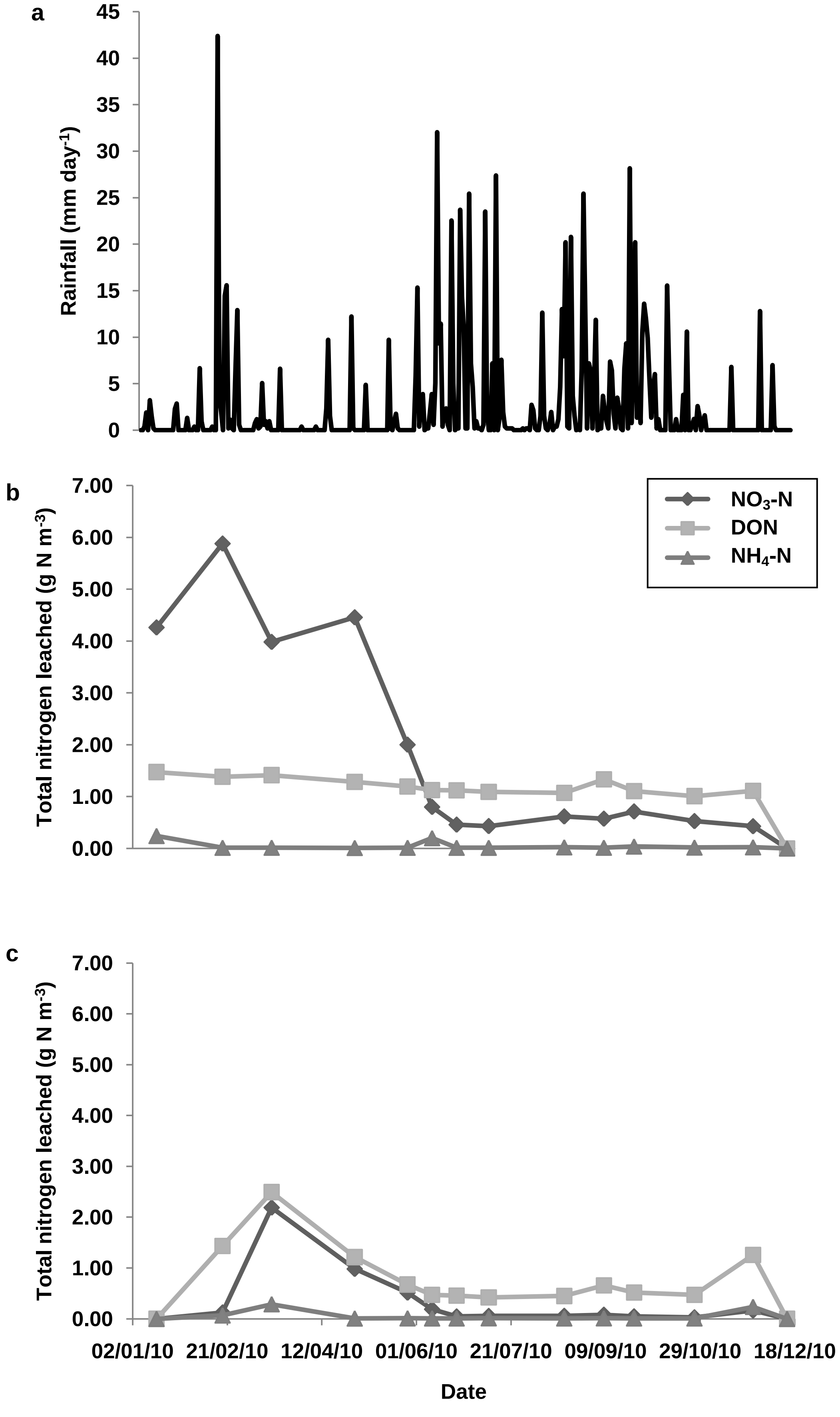

Figure 4.15: (a) Rainfall (mm day^{-1}) and seasonal pattern of the nitrogen concentration (g N m^{-3}) of the leachate for the year from 8th December 2009 to 14th December 2010 for (b) irrigated treatments and (c) un-irrigated treatments.

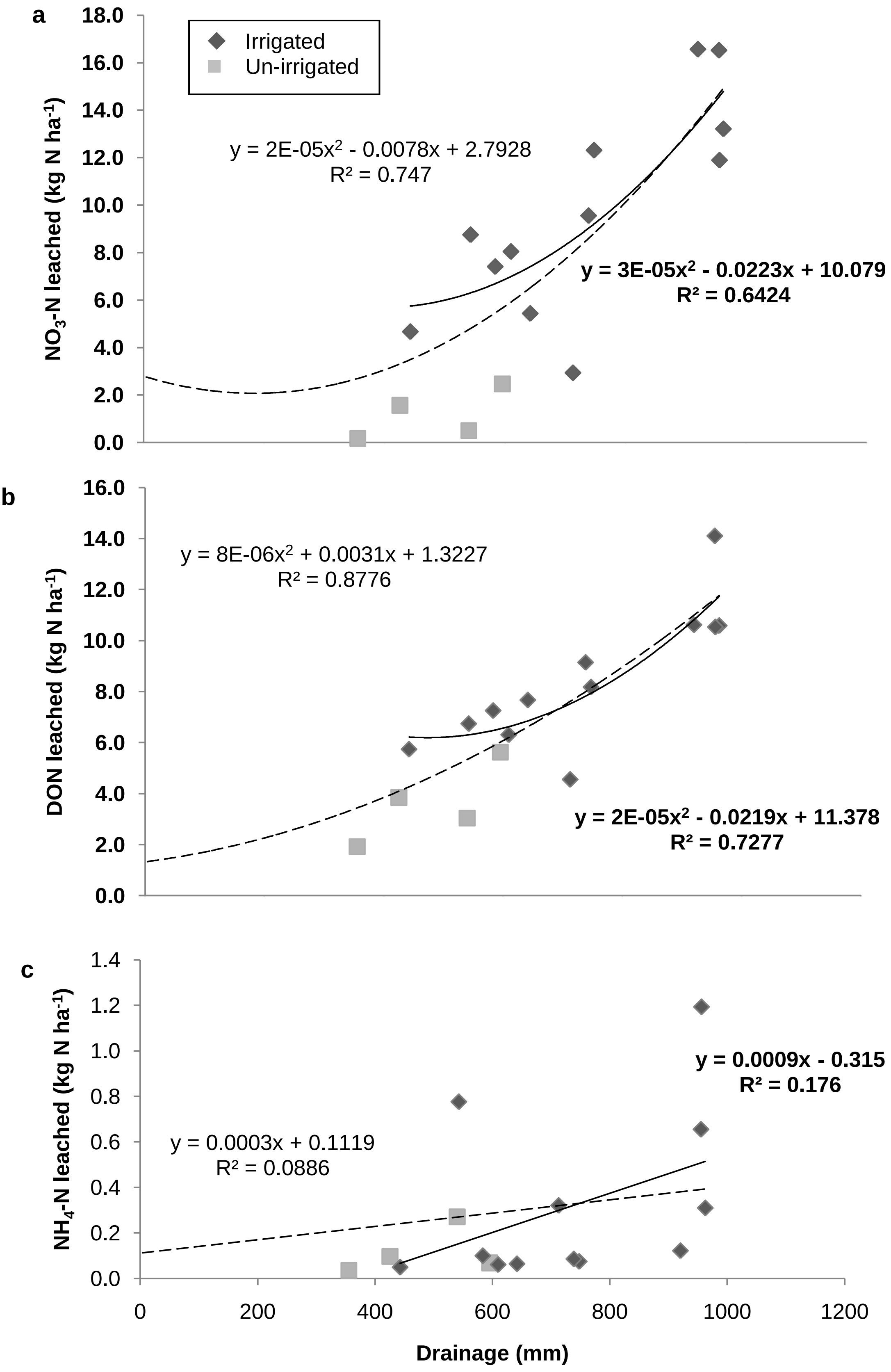

Figure 4.16: Relationship between drainage through the soil profile and total nitrate (a), total organic nitrogen (b), and total ammonium leached during the period 8th December 2009 to 14th December 2010. Equation in bold type relates to the irrigated treatments only, while the equation in normal type encompasses irrigated and un-irrigated treatments.

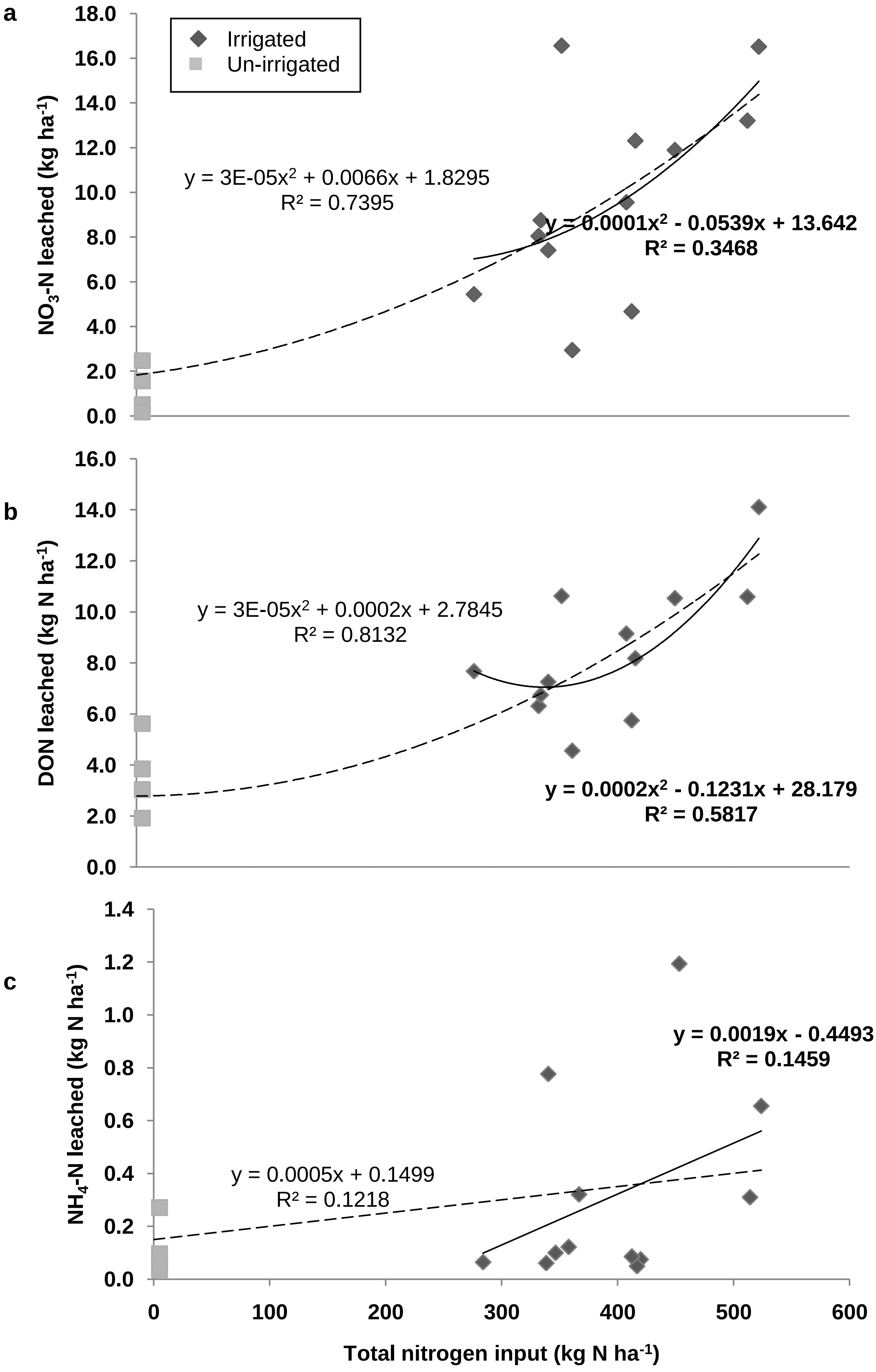

Figure 4.17: Relationship between total nitrogen input and total nitrate (a), total organic nitrogen (b), and total ammonium leached during the period 8th December 2009 to 14th December 2010. Equation in bold type relates to the irrigated treatments only, while the equation in normal type encompasses irrigated and un-irrigated treatments.

4.3.3 Nitrogen concentration of the leachate

The mean total nitrogen concentration in the water leached from the irrigated treatments was 2.5 g m^{-3}, and the mean nitrogen concentration from the un-irrigated treatments was significantly lower ($P<0.001$) at 1.0 g m^{-3}. There was no significant difference in the concentration of total nitrogen in the leachate between the high-N, mid-N, or low-N treatments.

The mean concentration of NO_X-N leached was 1.3 g N m^{-3} (irrigated) and 0.2 g N m^{-3} (un-irrigated). The mean concentration of DON leached was 1.2 g N m^{-3} (irrigated) and 0.7 g N m^{-3} (un-irrigated). The mean concentration of NH_4-N in the leachate collected from both irrigated and un-irrigated was less than 0.1 g N m^{-3}.

The mean total nitrogen concentration of the leachate collected from each treatment sector was correlated with the total volume of leachate collected from the lysimeters over the 12 month monitoring period ($R^2=0.7$, Figure 4.20 a). The mean nitrogen concentration of the leachate from each treatment sector was linearly correlated with both the total nitrogen input ($R^2=0.77$, Figure 4.20 b) and with the amount of nitrogen removed in the pasture ($R^2=0.78$, Figure 4.20 c). However, when the un-irrigated treatments were removed from analysis there was poor correlation between the mean nitrogen concentration of the leachate and total drainage ($R^2=0.07$), total nitrogen irrigated ($R^2=0.12$), and total nitrogen removed as pasture ($R^2=0.05$, Figure 4.20).

In June 2010, samples from each of the 48 lysimeters were analysed for nitrogen concentration. There was no correlation between the volume of water that drained through the soil profile and the concentration of nitrogen within that drainage during June 2010 ($R^2=0.03$, Figure 4.18). There was a reasonable correlation ($R^2=0.65$, Figure 4.19) between the volume of water collected from each lysimeter in June, and the total volume of water collected during the 12 month period, indicating the drainage in June was representative of the total drainage.

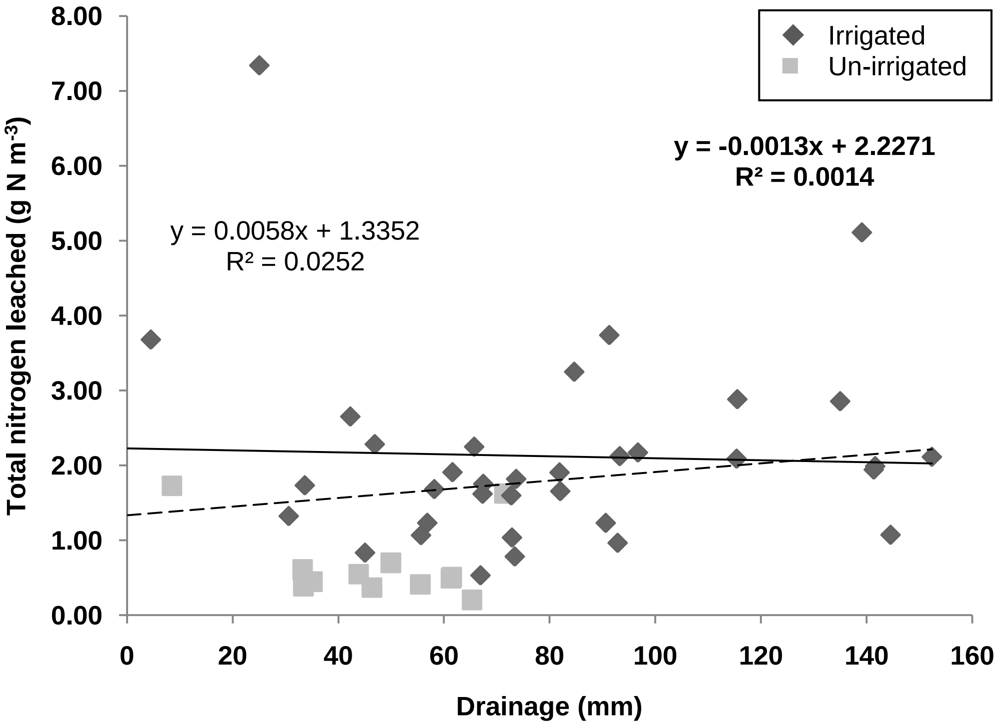

Figure 4.18: Relationship between volume of water that drained from individual lysimeters and concentration of nitrogen in the drainage water for the period 27th May to 9th June 2010. Equation in bold type relates to the irrigated treatments only, while the equation in normal type encompasses irrigated and un-irrigated treatments.

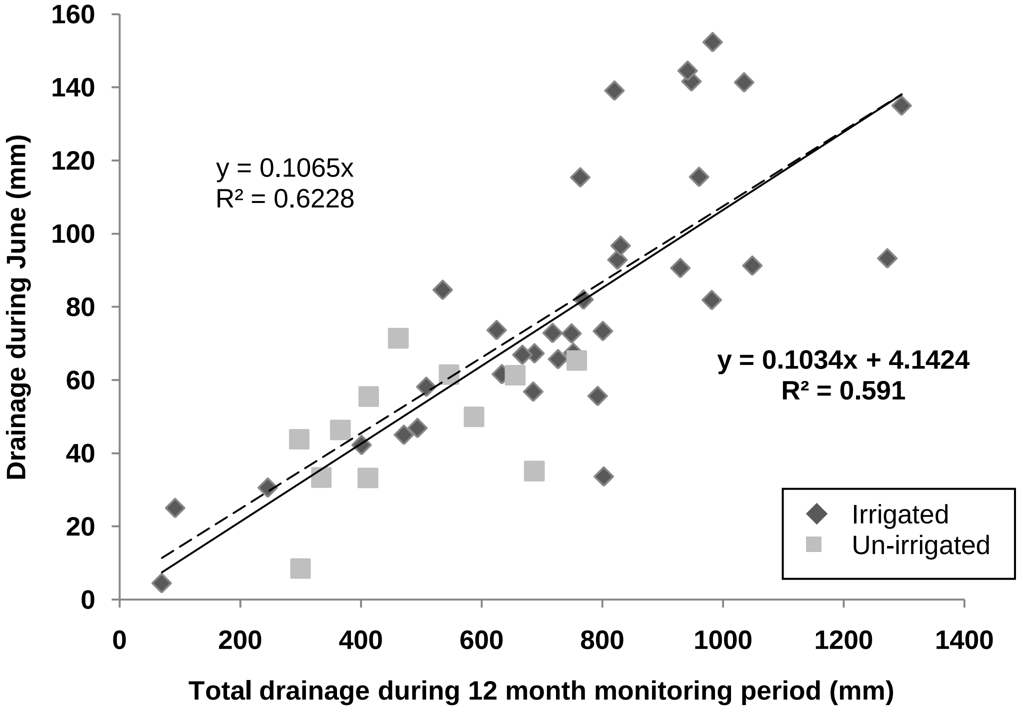

Figure 4.19: Relationship between volume of water that drained from individual lysimeters during the 12 month monitoring period and the volume of water that drained from individual lysimeters during the period 27th May to 9th June 2010. Equation in bold type relates to the irrigated treatments only, while the equation in normal type encompasses irrigated and un-irrigated treatments.

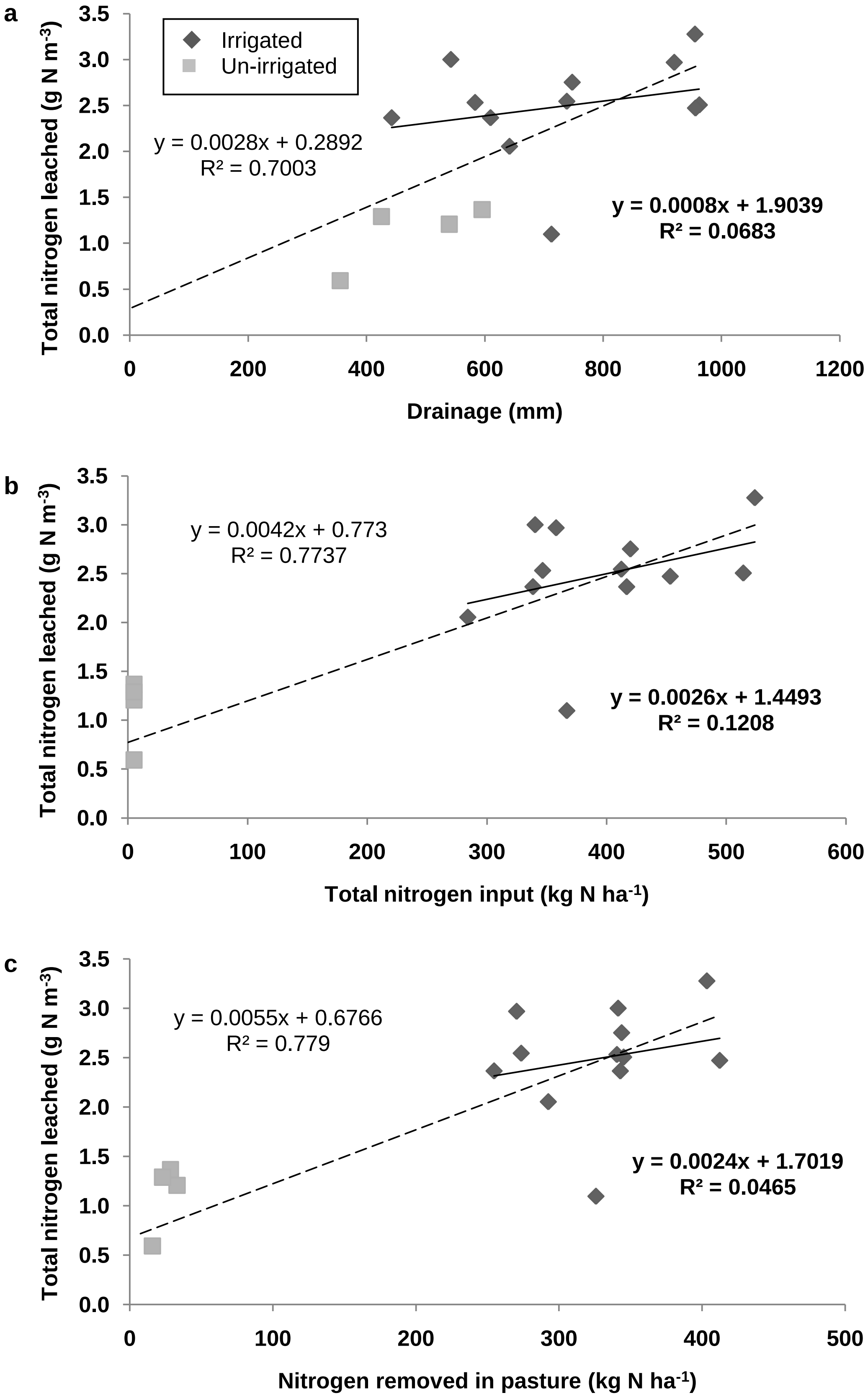

Figure 4.20: Relationship between mean total nitrogen concentration of the leachate and (a) total nitrogen input, (b) total drainage, and (c) total nitrogen removed as pasture for the period 8th December 2009 to 14th December 2010. Equation in bold type relates to the irrigated treatments only, while the equation in normal type encompasses irrigated and un-irrigated treatments.

4.4 Herbage nitrogen

4.4.1 Pasture yield

After being harvested in December 2009, herbage was collected from the lysimeters in January, March, October and December of 2010. Effluent irrigation increased dry-matter production almost 10 fold compared to the un-irrigated treatments (P<0.001)(Figure 4.21), and significantly removed the amount of nitrogen removed by the pasture (P<0.001). The mean pasture growth from the irrigated lysimeters was 15,800 kg DM ha^{-1}, with a mean of 330 kg N ha^{-1} removed, while the un-irrigated lysimeters produced on average less dry matter (1,800 kg DM ha^{-1}) and on average removed less nitrogen (25 kg N ha^{-1}). There was no significant difference in the amount of dry matter produced between the high-N, mid-N or low-N treatments (Figure 4.21). There was a strong correlation between the rate of nitrogen irrigated and the amount of dry matter produced (R^2=0.95, Figure 4.22), but removing the un-irrigated treatments from analysis revealed no correlation (R^2=0.03, Figure 4.22). The mean rate of nitrogen uptake from the irrigated treatments was 84% of irrigated nitrogen, with a maximum of 103%, and a minimum of 67% (Table 4.2).

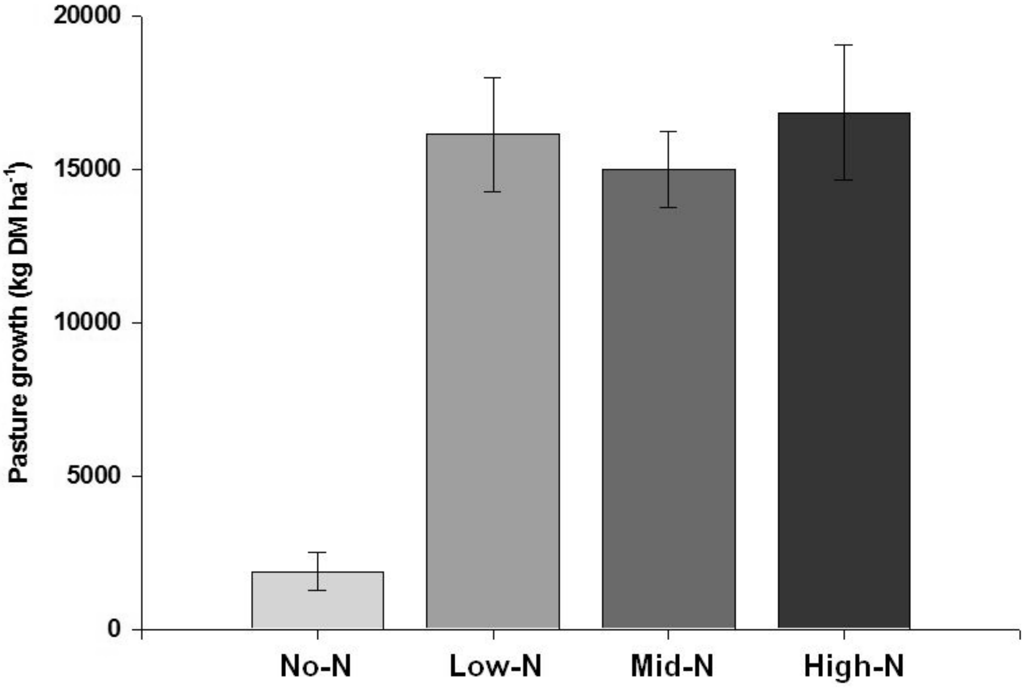

Figure 4.21: Pasture removed from each treatment for the year from December 2009 to December 2010. Error bars represent one standard deviation of the mean.

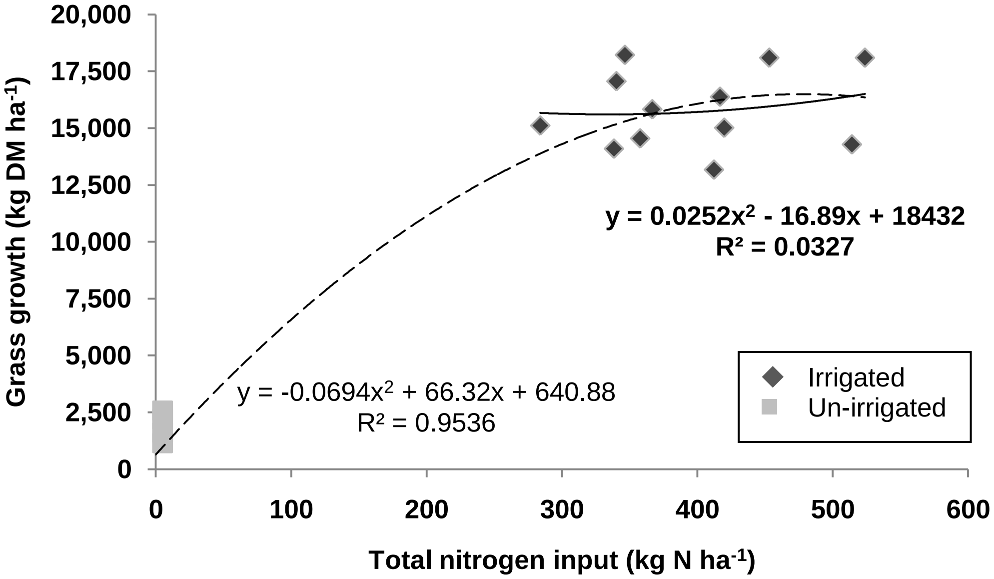

Figure 4.22: Relationship between total nitrogen input and grass growth (measured as dry matter) for the period December 2009 to December 2010. Equation in bold type relates to the irrigated treatments only, while the equation in normal type encompasses irrigated and un-irrigated treatments.

4.4.2 Concentration of nitrogen in the pasture

At the time of harvest, the mean concentration of total nitrogen in the irrigated pasture was higher than the mean concentration of nitrogen in the un-irrigated pasture ($P<0.001$). The mean nitrogen concentration in the irrigated pasture ranged from 1.8 to 2.4%, while in the un-irrigated pasture, the mean nitrogen concentration ranged from 1.4 to 1.5%. When considering both irrigated and un-irrigated treatments, there was a positive correlation ($R^2=0.67$, Figure 4.24) between the nitrogen concentration of the pasture and the total nitrogen input. The nitrogen concentration of the pasture in the high-N treatment was higher than the nitrogen concentration of the pasture in the mid-N and low-N treatments ($P<0.05$), but the concentration of nitrogen in the pasture was not significantly different between the mid-N and low-N treatments.

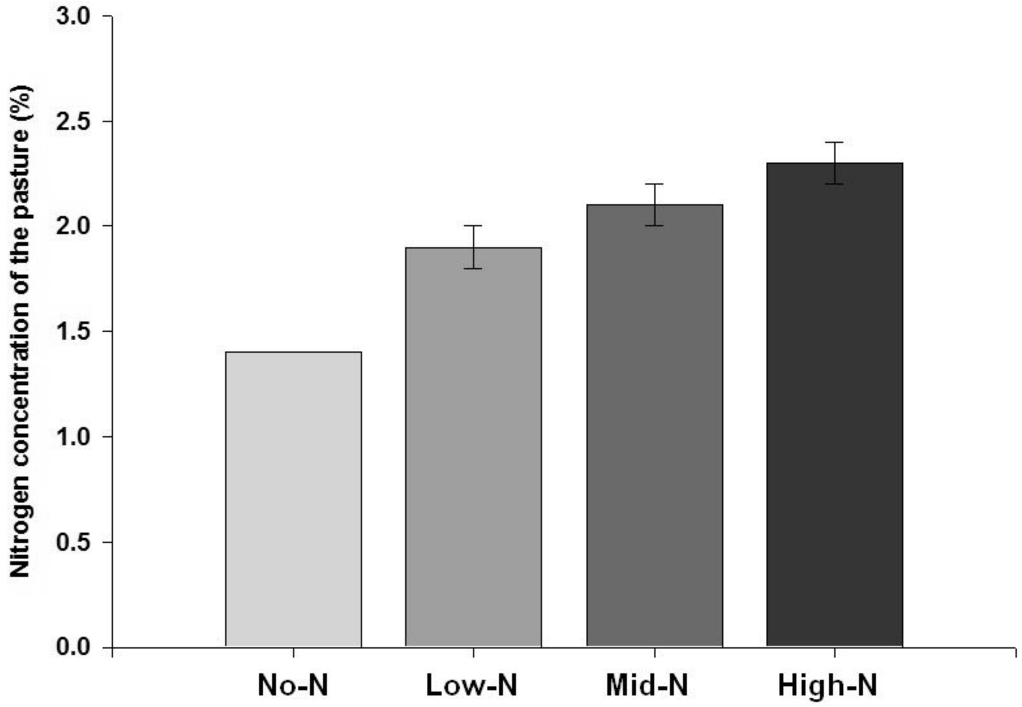

Figure 4.23: Mean nitrogen concentration (%) of the pasture at the time of harvest from each treatment for the year from December 2009 to December 2010. Error bars represent one standard deviation of the mean.

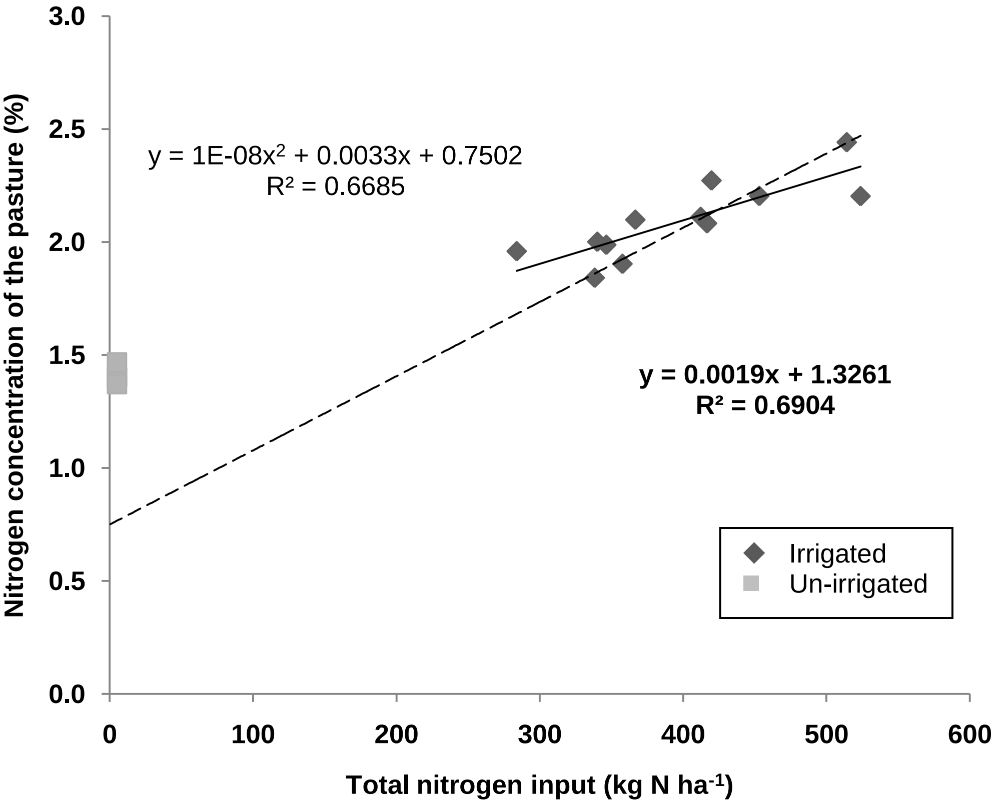

Figure 4.24: Relationship between the total nitrogen input and the mean nitrogen concentration of the harvested pasture for the period December 2009 to December 2010. Equation in bold type relates to the irrigated treatments only, while the equation in normal type encompasses irrigated and un-irrigated treatments.

4.5 Unaccounted nitrogen

Of the irrigated treatments, the amount of unaccounted nitrogen (irrigated N - leached N - pasture N) ranged from -20 to 150 kg N ha^{-1} (Table 4.2). The mean nitrogen unaccounted for was 50 kg N ha^{-1}, or 12% of the total irrigated, however some treatments appear to have a small deficit of nitrogen, where more nitrogen was leached and/or taken off in herbage than was irrigated. There was a poor correlation between the total nitrogen input and the amount of unaccounted nitrogen (R^2=0.34, Figure 4.25).

The mean rate of nitrogen leached from the un-irrigated treatments matched the assumed rate of nitrogen deposition from rainfall (5 kg N ha^{-1}yr^{-1}). In addition to leaching, on average, 25 kg N ha^{-1}yr^{-1} was removed by the pasture of the un-irrigated treatments. The un-irrigated treatments were not fertilised or irrigated, indicating more nitrogen was being removed from the soil than was deposited.

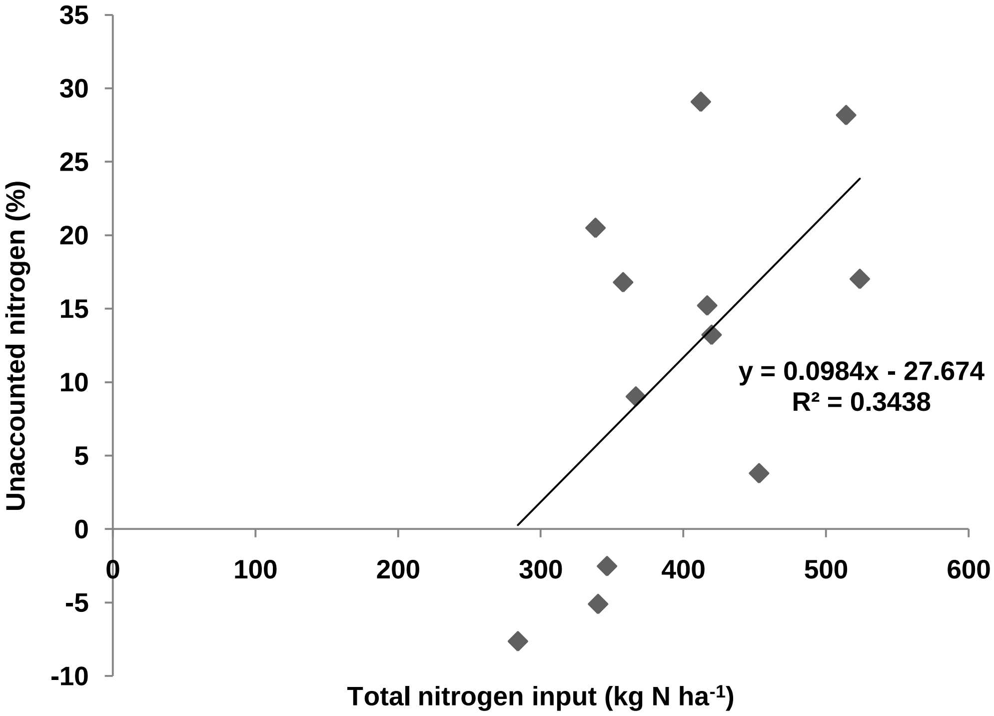

Figure 4.25: Relationship between nitrogen input and unaccounted nitrogen (percentage of nitrogen input) for the period December 2009 to December 2010.

Table 4.2: Total nitrogen irrigated, total nitrogen leached, total nitrogen removed as pasture and unaccounted nitrogen, for the year from December 2009 to December 2010. Values in parenthesis are percentages of irrigated nitrogen.

TN input (kg ha^{-1})	TN leached (kg ha^{-1})	TN removed in pasture (kg ha^{-1})	N unaccounted for (kg ha^{-1})	Irrigation (mm)	Water input (mm)	Drainage (mm)
520	31.1 (6%)	400 (77%)	89 (17%)	1060	1950	950
510	24.4 (5%)	350 (67%)	145 (28%)	1030	1920	980
450	23.8 (5%)	410 (91%)	17 (4%)	910	1800	970
420	19.7 (5%)	340 (82%)	56 (13%)	780	1670	690
420	10.7 (3%)	340 (82%)	63 (15%)	790	1680	430
410	18.8 (5%)	270 (66%)	120 (29%)	800	1690	740
370	8.2 (2%)	330 (89%)	33 (9%)	730	1620	720
360	27.3 (8%)	270 (76%)	60 (17%)	700	1590	920
340	14.8 (4%)	340 (99%)	-12 (-3%)	650	1540	580
340	14.5 (4%)	260 (75%)	69 (20%)	770	1670	610
340	16.4 (5%)	340 (100%)	-17 (-5%)	620	1510	550
280	13.3 (5%)	290 (103%)	-22 (-8%)	510	1400	650
5	3.9	33	-32	0	910	550
5	7.7	28	-31	0	910	600
5	2.1	16	-13	0	910	360
5	5.5	23	-23	0	910	430

Chapter five - Discussion

5.1 Introduction

The following chapter will discuss the results presented in Chapter four, by comparing with the published literature, and identifying possible explanations for the anomalies observed. The limitations of the study will also be considered. The implication of the results for the Taupo wastewater treatment scheme will also be addressed.

5.2 Nitrogen leaching

5.2.1 Total nitrogen leached

The effluent irrigated treatments leached significantly more nitrogen over the year than the un-irrigated treatments ($P<0.01$). Increasing the rate of irrigation above 450 kg N ha^{-1} yr^{-1} appears to have led to more nitrogen being leached as the treatments that received more than 450 kg N ha^{-1} yr^{-1} leached more total nitrogen than the treatments that received less than 350 kg N ha^{-1} yr^{-1} ($P<0.01$). However, the amount of nitrogen leached from the irrigated treatments was better correlated with the volume of water that drained from the soil profile ($R^2=0.73$, Figure 4.13) than the total nitrogen input ($R^2=0.4$, Figure 4.12). Higher rates of effluent irrigation increased the volume of water that drained through the soil, as the high-N treatments leached more water than the low-N treatments ($P<0.001$). There was no significant difference in estimated evapotranspiration (Figure 4.9) between any of the irrigated treatments, so it is likely that the grass was supplied with sufficient water to support growth even at the lowest irrigation rate, and the extra water applied in the high-N treatments was leached through the soil.

Burgess (2003) observed a similar pattern, where total nitrogen leached from dairy effluent irrigated Pumice Soil was better correlated to drainage volume ($R^2=0.57$) than with total nitrogen input ($R^2=0.26$). Cameron et al

(2007) also noted higher nitrate leaching losses from a Taupo Pumice Soil in years when rainfall (and subsequently drainage) was higher.

In a similar land treatment system at Rotorua City, approximately 60 km from Taupo, treated sewage is irrigated onto *Pinus radiata* forest. A lag time of approximately two and a half years was observed between initiation of effluent irrigation and elevated nitrogen leaching from the Rotorua LTS (Tomer et al., 2000). Tomer et al. (2000) suggested that the soil had become saturated with nitrogen after two and a half years of effluent irrigation, with the surplus of nitrogen leaching into waterways. Evidence for soil storage came as the proportion of irrigated nitrogen removed by the upper 0.9 m of the soil profile decreased from 87% in year two, to 59% in year six (Gielen et al., 2000)

Given the larger total nitrogen leaching from the high-N treatments in this study, it is possible that the Taupo LTS has behaved in the same manner as the Rotorua LTS and the amount of nitrogen leached may increase after the completion of this study as the soil becomes saturated with nitrogen. However, the Rotorua LTS and the Taupo LTS had substantial differences in their design (refer chapter 1.2 and 2.5.6). In addition to having different soils, the primary mechanism for nitrogen removal at Taupo was plant uptake and harvest, whereas plant uptake played only a minor role in the Rotorua LTS, as denitrification in surface soils and wetlands was intended to remove most of the nitrogen from the wastewater. Consequently, the rate of nitrogen accumulation in the soil at the Taupo LTS is likely to be somewhat slower than that which accumulated in the start-up period of the Rotorua LTS. It is probable that if an increase in nitrogen leaching does occur from the Taupo LTS, it will take longer than two and a half years to detect.

Over the two years since irrigation started at View Road, up to 1000 kg N ha^{-1} has been irrigated, yet there does not appear to be a large excess of readily leachable nitrogen within the soil, as the mean NO_X-N leached from the irrigated treatments was only 9.5 kg N ha^{-1}, or 2% of the mean amount of total nitrogen that was irrigated.

In the Waikato region, the average amount of nitrogen leached from dairy pasture was reported to be 40 kg N $ha^{-1}yr^{-1}$ (Environment Waikato, 2008), yet the total amount of nitrogen leached from the irrigated portion of Taupo LTS was on average 19 kg N $ha^{-1}yr^{-1}$. In terms of nitrogen leaching, at the time of writing, the Taupo LTS appears to have performed better than the average dairy farm. Notwithstanding, the un-irrigated treatments leached on average 5 kg N $ha^{-1}yr^{-1}$, so the addition of effluent irrigation on average increased total nitrogen leaching by 14 kg N $ha^{-1}yr^{-1}$. Even at the highest rate of effluent application (520 kg N $ha^{-1}yr^{-1}$), the maximum rate of total nitrogen that leached (31.3 kg N $ha^{-1}yr^{-1}$) was below that of the average dairy farm in the Waikato. This study has not identified any long-term trends in the amount of nitrogen that was leached at the high rate of effluent irrigation. If nitrogen continues to be irrigated at a higher rate than it is removed by harvesting the pasture, it is quite possible that soil storage of nitrogen will occur, which may lead to an increase in the amount of total nitrogen leached when the soil reaches nitrogen saturation at some time in the future.

5.2.2 Nitrogen concentration of the drainage water

Applying nitrogen gradually throughout the year through effluent irrigation may have helped keep the total nitrogen concentration of the drainage water low, as the mean concentration of nitrogen in the water draining through the soil profile of the irrigated treatments was 2.5 g N m^{-3}. The maximum concentration of total nitrogen recorded was 12.2 g N m^{-3}, during summer (Appendix 3) and the minimum concentration recorded from the irrigated treatments was 0.6 g N m^{-3}. The peak total nitrogen concentration in leachate was less than ten times that recorded under pasture irrigated with dairy farm effluent applied at the rate of 1100 kg N ha^{-1}, which peaked at 190 g TN m^{-3} (Williamson et al., 1998). As expected, the mean concentration of nitrogen in the leachate from the irrigated treatments of this study (2.5 g N $m^{-3)}$ was higher than the mean concentration of nitrogen of the drainage water of the un-irrigated treatments (1.0 g N m^{-3}) ($P<0.001$).

The hypothesis that the lysimeters that leached more water would have a lower concentration of nitrogen within the leachate resulting from dilution was proved wrong. There appeared to be a positive correlation (R^2=0.7, Figure 4.20 a) between the mean volume of water that drained from each treatment and the mean concentration of nitrogen in the leachate. However, removing the un-irrigated treatments from the analysis showed no correlation (R^2=0.07, Figure 4.20 a) between drainage volume and nitrogen concentration of the leachate. There was no significant difference between the mean concentration of nitrogen in the leachate of the high, medium or low treatments. Of the treatments that were irrigated, the rate of effluent irrigation did not influence the concentration of nitrogen in the drainage water. The amount of total nitrogen in the soil water appeared to be in some form of constant exchange with the soil, therefore the amount of nitrogen that leached was most likely a function of the volume of water that drained through the soil, and not the amount of nitrogen that was irrigated.

The hypothesis that bulking of the leachate may be hiding the relationship between leachate volume and nitrogen concentration of the leachate was also disproved. In June 2010, each lysimeter was sampled individually, as opposed to having the leachate bulked with the other lysimeters in the respective treatments as per the normal sampling regime. There was no correlation (R^2=0.03, Figure 4.18) between the volume of water that drained from each lysimeter (including un-irrigated) and the concentration of nitrogen within the leachate. The volumes recorded in June were reasonably representative of the total volumes collected for each lysimeter over the entire 12 month period (R^2=0.63, Figure 4.19).

Due to prohibitive cost, it was not possible to have the leachate from each lysimeter analysed separately on more than one occasion. In future, finding a more cost effective method of analysis could enable testing on the leachate from each lysimeter, and would improve the resolution of the data.

5.2.3 Forms of nitrogen leached

On average, the organic nitrogen (DON) fraction comprised 45% of all nitrogen leached from the irrigated lysimeters of the Taupo LTS, while total oxidised nitrogen (NO_X-N) made up 53% of nitrogen leached, and total ammoniacal nitrogen (NH_4-N) represented the remaining 2%.

5.2.3.1 Total oxidised nitrogen leaching

Most of the NO_X-N that leached was a result of the initial flush from rainfall in late May and early June (Figure 4.15b). NO_X-N leaching from the irrigated treatments spiked after heavy rainfall in January and peaked in May (Figure 4.14b). The peak in absolute NO_X-N leached that occurred in May took place before the peak in rainfall, and NO_X-N leaching declined while rainfall increased. From June, NO_X-N concentrations remained below 1 g N m^{-3}.

The highest NO_X-N concentration in the drainage water recorded in this study was close to New Zealand drinking water standards at 10.9 g N m^{-3} during January. The mean NO_X-N concentration from the irrigated treatments during the year was fairly low at 1.3 g N m^{-3} (Appendix 3). There was no significant difference between the mean NO_X-N in the leachate of the low-N, mid-N or high-N treatments, but the mean NO_X-N concentration of the leachate from all irrigated treatments was higher than the mean NO_X-N concentration of the leachate from the un-irrigated treatments ($P<0.01$). Nitrate concentrations in leachate from effluent irrigated pasture similar to those found in this study were observed by Sparling et al. (2006), where nitrate concentrations in the drainage water were generally <2 g N m^{-3} and never exceeded 10 g N m^{-3}. In other agricultural leaching studies, NO_X-N concentrations can be much higher than what was observed from the Taupo LTS. For example, under dairy cow urine and urea fertiliser applied at the equivalent of 1200 kg N ha^{-1}, NO_X-N concentrations peaked at 125 g m^{-3} (Di & Cameron, 2005).

Before irrigation commenced, NO_X-N concentrations in the groundwater beneath the View Road LTS were generally between 1 and 4 g N m^{-3} (Zemansky et al., 2007). Therefore the water draining from the irrigated portion of the Taupo LTS in this study had, on average, a lower NO_X-N concentration than some of the existing groundwater (Zemansky et al., 2007).

As the majority of nitrate-N leaching that occurs in a grazed pasture system originates from animal excretion (Ledgard et al., 2009), and no stock were held at the Taupo LTS, the nitrate-N losses from the Taupo LTS were somewhat lower than those from grazed pasture with similar nitrogen inputs as reviewed by Ledgard et al., (2009) (Figure 5.1). It should be noted, however, that the nitrogen leaching values reported in this study are following two years of effluent irrigation on what was previously a low-input grass/clover drystock farm. The long-term nitrogen leaching characteristics have not been measured.

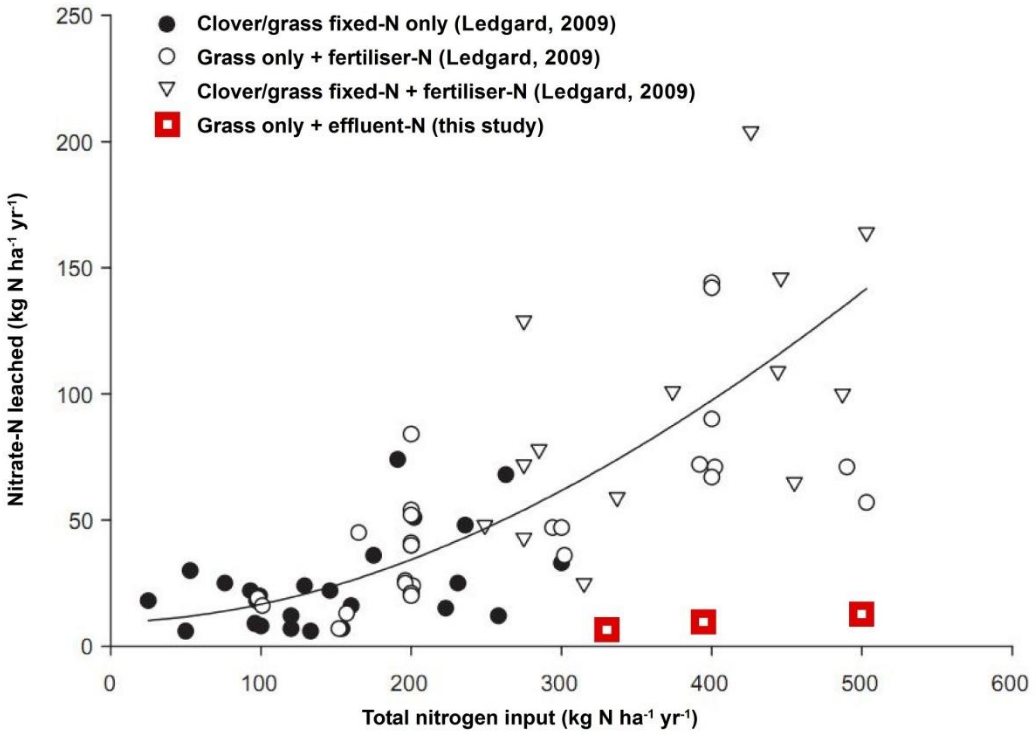

Figure 5.1: Comparison of nitrate-N leached from this study with nitrate-N leached from grazed pasture systems as affected by nitrogen input from fertiliser and/or biological nitrogen fixation by clover. Data are a summary of studies from NZ, France, UK, and Denmark. The line of best fit is an exponential function obtained by fitting the data on the log scale, and does not include data from this study. Adapted from Ledgard et al., (2009).

Using a simple empirical model, Di & Cameron (2000) predicted the maximum amount of nitrogen that could be applied to a cut and carry system before the average NO_X-N concentration in the drainage water reached the New Zealand drinking water standard of 11.3 mg N l^{-1}. The predicted nitrogen application rate was between 390 and 600 kg N $ha^{-1}yr^{-1}$, depending on the form of nitrogen applied. The concentration of nitrogen in the drainage water from the Taupo LTS was, therefore much lower than that predicted by Di & Cameron (2000) for a similar rate of nitrogen application. Possibly, the NO_x-N concentration in the drainage water of the Taupo LTS will increase over time as this study has examined nitrogen leaching from the second year of the effluent irrigation scheme.

There have not been any measurements of nitrogen leaching from the first LTS commissioned by TDC at Rakaunui Road. The only indication that high rates of nitrogen may have been leached was from the NO_X-N concentrations in groundwater monitoring wells surrounding the Rakaunui Road LTS. NO_X-N concentrations in some bores have exceeded the Ministry of Health maximum acceptable value of 11.3 mg l^{-1}. The nitrogen loading rates at the Rakaunui Road LTS were, on average, much higher than the nitrogen loading rates observed at View Road in this study. The mean nitrogen loading at the View Road LTS during this study was 400 kg N $ha^{-1}yr^{-1}$, but between 1999 and 2005, the mean nitrogen loading at the Rakaunui Road LTS was 642 kg N $ha^{-1}yr^{-1}$, with a maximum nitrogen loading of 726 kg N $ha^{-1}yr^{-1}$ in 2004-2005. At the time of writing, there had not been a mkeasurable increase in the NO_x-N concentration of the groundwater monitoring wells beneath the View Road LTS (Figure 5.2, Appendix 11).

When irrigated at a similar rate to Rakauinui Road at 640 kg N $ha^{-1}yr^{-1}$, the groundwater beneath the Rotorua LTS exceeded the World Health drinking water quality standard of 10 g N m^{-3} (Gielen et al., 2000). Comparing nitrogen leaching between the Rotorua LTS and the Taupo LTS becomes problematic as each system relies on a different form of remediation to remove the nitrogen from the effluent. In addition, the effluent irrigated at the Rotorua LTS had a high NO_x-N content compared to the effluent from the Taupo LTS.

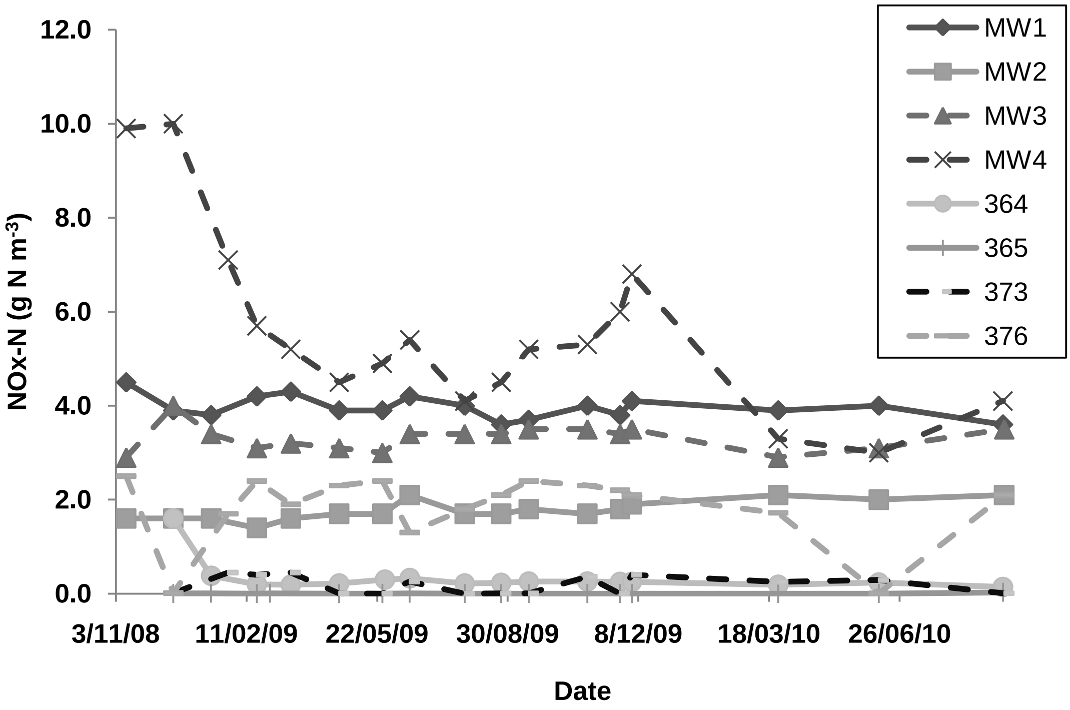

Figure 5.2: NO_x-N concentrations in groundwater monitoring bores beneath the View Road LTS. The location of the bores can be found in Appendix 11. Data supplied by TDC.

5.2.3.2 Organic nitrogen leaching

In contrast to NO_X-N, leaching of DON closely followed rainfall, with peak DON leaching in June and September. The un-irrigated treatments predominantly leached DON, with the peak rate of DON leaching in January when heavy rain fell (Figure 4.13c).

The leaching pattern of DON observed at the Taupo LTS contrasts with the results of Ghani et al. (2007), who report the risk of DON leaching from pastoral soils of New Zealand during winter would be higher than in other seasons as DON concentrations were found to be highest in July. DON concentrations in the drainage water from the irrigated treatments of this study were relatively constant during the year, at around 1.2 g N m^{-3} (Figure 4.15b), and leaching of DON was controlled by the volume of water that drained through the soil, irrespective of the season.

Leaching of DON is more complex than NO_X-N as organic nitrogen is woven into an intricate mixture of organic compounds whose role in agricultural soil is complicated and not widely understood (van Kessel et al., 2007). Some of the organic nitrogen contained within the effluent that was irrigated in this study may have leached directly through the soil as it was unable to be taken up by the pasture. Assuming approximately 7% of the nitrogen contained within the effluent was in the organic form, up to 35 kg DON ha^{-1} may have been irrigated on the high-N treatments. Sparling et al. (2006) also noted that more than half of the nitrogen leached from effluent irrigated cores was in the organic form

5.2.3.3 Ammoniacal nitrogen leaching

Despite the effluent nitrogen predominantly being in the form of NH_4-N, only 2% of the nitrogen that leached was NH_4-N. NH_4-N would typically be nitrified to NO_X-N within a few days of being in the soil, and any NH_4-N that did remain in the soil would likely be adsorbed to soil particles as a result of electrostatic forces (Haynes, 1986; Whitehead, 1995; Addiscott, 2005; van Kessel et al, 2007). Consequently, any NH_4-N that was detected probably leached through preferential flow through macropores, cracks in the soil, or worm holes, which would be why it was only detected in some lysimeters and only after rainfall. Furthermore, as the leachate may have sat in the collection chamber of the lysimeter for up to four weeks, it is quite possible that any NH_4-N that did leach was nitrified through to NO_X-N before being sampled, and therefore was not detected.

5.3 Pasture nitrogen

5.3.1 Pasture growth and nitrogen content

The ryegrass pasture of the Taupo LTS demonstrated high nitrogen use. On average, 84% of all nitrogen irrigated during the monitoring period was removed in the pasture. The pasture was harvested four times during the 2010 year, in January, March, October and December. The nitrogen concentration of the pasture and the amount of dry matter produced controlled the amount of total nitrogen removed by each treatment.

5.3.1.1 Nitrogen concentration of the pasture

The concentration of nitrogen in the pasture harvested from the high-N treatments was 2.3% of dry matter, which was higher than the mid-N at 2.1% ($P<0.05$), and higher than the low-N treatments at 1.9% ($P<0.05$).

As ryegrass grows, the proportion of structural plant material (stems) increases relative to leaf area (Gislum et al., 2005), resulting in a decrease in the total nitrogen concentration of the plant. The later stages of growth also lead to a decreased rate of nitrogen uptake by the ryegrass, even if plentiful nitrogen is supplied to the plant (Lemaire et al., 2004; Marino et al., 2004). Total nitrogen concentrations in the irrigated pasture harvested at the Taupo LTS were typically in the range of 1.5-2.5% (Appendix 6). However, Gislum et al. (2005) report the maximum nitrogen concentration in the early stages of growth of perennial ryegrass to be 4.8%. Marino et al. (2004) found that even though absolute dry matter increased, the nitrogen concentration of annual ryegrass decreased as the plants grew. At the time of harvest, the pasture of the Taupo LTS was up to 75 cm tall (Figure 5.6), and had a high proportion of stem and seed material. It is likely that due to only being harvested four times during 2010, the pasture of the Taupo LTS had grown beyond the optimal stage for maximum nitrogen removal as the stem to leaf ratio was high at the time of harvest.

5.3.1.2 Pasture growth and nitrogen uptake

Effluent irrigation increased dry-matter production more than ten-fold compared to the un-irrigated controls. The mean pasture growth from the irrigated treatments was 15,800 kg DM $ha^{-1}yr^{-1}$, while the un-irrigated treatments produced a mean of 1,400 kg DM $ha^{-1}yr^{-1}$. Pasture growth relative to nitrogen input (Figure 4.22) showed similar variation to nitrogen leaching where correlation between the rate of irrigation and grass growth from the irrigated treatments was poor (R^2=0.03). There were no significant differences between the pasture dry-matter produced by either the high-N, mid-N or low-N treatments.

The pasture of the irrigated treatments removed, on average, 330 kg N ha^{-1}yr^{-1}, and the un-irrigated treatments removed a mean of 25 kg N ha^{-1}yr^{-1}. The maximum rate of nitrogen uptake by an irrigated treatment sector was 104% of the irrigated nitrogen, and the minimum was 66% (Table 4.2). At 390 kg N ha^{-1}yr^{-1}, the high-N treatments removed more nitrogen than both the mid-N (310 kg N ha^{-1}yr^{-1}, $P<0.05$) and low-N treatments (310 kg N ha^{-1}yr^{-1}, $P<0.05$), but there was no significant difference in the amount of nitrogen removed between the mid-N and low-N treatments. The pasture production and nitrogen removal by the pasture during 2010 was similar to historical records from the Rakaunui Road LTS.

Between the years of 1999 and 2005, the mean nitrogen application rate at the Rakaunui Road LTS was 640 kg N ha^{-1}, where, on average, 14,600 kg DM ha^{-1}yr^{-1} was harvested, and on average, 390 kg N ha^{-1}yr^{-1} was removed by the pasture (O'Conner, 2005). In 2010, the View Road LTS produced slightly more pasture (approx 1,000 kg DM ha^{-1}) than the average from the Rakaunui Road LTS, but removed on average, less nitrogen (approx 60 kg N ha^{-1}). The pasture production between the Rakaunui Road and View Road LTS were similar, even though nitrogen application rates at Rakaunui Road were higher than View Road. In addition, there was no significant increase in pasture growth between the high-N and low-N treatments of this study. The supply of nitrogen was not limiting the growth of the pasture.

While the extra nitrogen supplied to the high-N pasture, relative to the mid and low-N pasture, did not increase the amount of dry matter produced, it did correlate with an increase in the nitrogen concentration of the plant material. Consequently, the total amount of nitrogen removed by the high-N treatment was more than the mid ($P<0.05$) and low-N treatments ($P<0.05$). Higher nitrogen loading rates than observed at the View Road LTS lead to higher concentration of nitrogen in the pasture at Rakaunui Road. With an average nitrogen loading rate of 640 kg N ha^{-1}yr^{-1}, the pasture of the Rakaunui Road LTS had an total average nitrogen concentration of 2.7% (O'Conner, 2005).

During the two and a half months that Pivot F was not irrigating, the pasture took on a yellow colour (suggesting nitrogen deficiency) and the rate of growth appeared to be stunted (Figure 5.3). The difference in pasture growth and quality was quite apparent when in the field in July, yet when the pasture was harvested in October, there was no discernable difference between the amount of grass collected from beneath Pivot F or Pivot G (Appendix 5). The pasture growth under Pivot F appears to have 'caught up' with the pasture under Pivot G when irrigation commenced in September, indicating the rate of growth during spring can be high. There was an opportunity for improving grass growth and nitrogen uptake where an additional cut toward the end of winter would maximise the ability of the grass to remove nitrogen during spring. The rapid decline in pasture quality while irrigation under Pivot F was stopped for two and a half months (Figure 5.3), also indicated that the pasture is utilising a large proportion of the nitrogen quickly after it is irrigated.

Figure 5.3: The green pasture in the foreground is that beneath Pivot G, while the yellow pasture in the middle ground is that beneath Pivot F. Photograph taken in July 2010, one month after irrigation beneath Pivot F stopped.

5.3.2 Pasture quality

The pasture typically had a sparse cover on the ground, with large gaps between grass swards (Figure 3.5). The overall pasture cover when the grass was harvested was estimated at 50 % (Figure 5.4), and pasture density did not noticeably improve over the duration of the study. Frequent harvesting of ryegrass encourages the emergence of new tillers (Lestienne et al., 2006). The pasture of the Taupo LTS was left for long periods between harvests, consequently the soil remained shaded and new growth was discouraged. Before the grass was harvested at the Taupo LTS, there appeared to be a large amount of dead leaf material accumulating beneath the green leafy growth, suggesting the grass had begun recycling nutrients.

The harvesting frequency may be having a detrimental effect on the rate of grass growth and consequently the amount of nitrogen removed by the pasture. Complete defoliation of the pasture took place at each harvest (Figure 3.5) and the re-growth of the pasture was observed to be slow and patchy (Figure 5.4). For optimum plant growth and nitrogen uptake, ryegrass responds well to regular and conservative leaf removal. Severe defoliation (>75 % leaf area) restricts root growth and reduces the leaf re-growth and nitrogen uptake when compared to regular and more conservative (<50 % leaf area) harvesting (Lestienne et al., 2006). In addition, regular and conservative defoliation promotes a higher number of tiller per grass sward when compared to infrequently and severely defoliated ryegrass (Lestienne et al., 2006).

Figure 5.4: Typical pasture following harvest. The lysimeter can be seen to the right, with sampling tube extending above ground to the left. The pasture was harvested 2/1/2011, and the photograph taken two weeks later.

During autumn, grass grubs infested the experimental area. The grass grubs fed on the roots of the pasture and a yellowing of the pasture due to lack of nutrient uptake was apparent in some parts of the site. To further compound the damage from the grass grubs, sea gulls were feeding on the grass grubs by tearing the pasture from the ground (Figure 5.5). Without destructively investigating, it was impossible to tell which lysimeters became host to grass grubs and which did not, however none of the lysimeters were affected by seagull grazing. The grass grub infestation may have had an impact on the amount of pasture grown in some lysimeters, and could potentially be the explanation for why there was no significant difference in the amount of grass grown between treatments. For instance, G1, a high-N treatment sector, had severe weed growth, where death of some of the ryegrass was suspected as a result of grass grubs, allowing weeds to emerge. The total dry matter produced by G1 was approximately 14,200 kg DM $ha^{-1}yr^{-1}$, while the total dry matter produced by the other two high-N treatments sectors, G3 and G4 (with a low proportion of weeds), was approximately 18,100 kg DM ha^{-1} yr^{-1}.

Figure 5.5: Typical pasture damage caused by grass grubs and seagulls during autumn 2010.

Following the damage to the pasture from the grass grub infestation, the soil was left exposed and considerable weed growth occurred in some areas. The pasture under Pivot G appeared to suffer greater weed growth that under Pivot F. However, high levels of dandelion grew under parts of Pivot F (Figure 5.6). The areas worse affected by dandelion growth were the areas that were affected by the incorrect sprinkler heads (Chapter 5.5.2). The weeds appear to have taken hold in the gaps between the ryegrass (Figure 3.5).

Spraying for weeds with an appropriate herbicide followed by under-sowing with ryegrass would help restore pasture composition, improve the nitrogen uptake, and in turn improve haylage quality.

Figure 5.6: An area of Pivot F that was not harvested (foreground), with harvested pasture in the background. Dandelion, thistle and other un-identified weed species can be seen in the foreground. Also note the length of the pasture relative to the ATV. Photograph taken 15/1/11.

5.4 Other losses of nitrogen

Nitrogen that was irrigated and not leached or removed by the pasture was considered to be unaccounted for. The missing nitrogen could have been lost to the atmosphere by denitrification or volatilisation, or stored in the soil.

The rate of denitrification in another free draining, coarse textured volcanic soil was demonstrated to be low as a result of excessive aeration (Barton 1999). With a similar texture and drainage regime to the soil at the Taupo LTS, it is therefore unlikely that denitrification contributed to a major loss of nitrogen from the soil at the Taupo LTS. Volatilisation of ammonia has been reported to account for up to 24 % of applied nitrogen in wastewater irrigation (Smith et al., 1996). The effluent irrigated at the Taupo LTS was predominantly in the form of NH_4-N, further enhancing the ability for volatilisation of ammonia (NH_3). It is quite likely that a portion of the nitrogen that was irrigated did not actually reach the soil surface as it was volatilised during irrigation. If high rates of volatilisation were occurring, some of the volatilised nitrogen may have been deposited on the un-irrigated treatments.

The amount of nitrogen not accounted for (Chapter 4.4) was variable. The highest amount of unaccounted nitrogen was 150 kg N ha^{-1} (29 % of that applied), and the lowest showed 20 kg ha^{-1} more nitrogen was removed by the pasture and leached from the soil than was irrigated (-8 %). Rapid immobilisation of nitrogen by soil microbes can account for up to 20 % of applied nitrogen (Ledgard et al., 1988), and van Ginkel et al. (1997) showed mineralisation of soil organic nitrogen could contribute to the overall soil-pasture nitrogen budget. It appears that immobilisation followed by mineralisation occurred at the Taupo LTS. The treatments where more nitrogen appeared to be removed than was applied (Figure 4.25, Table 4.2) were affected by a change in irrigator nozzle in January 2010 and consequently received less effluent than other treatments during most of 2010. It is possible that the grass in the affected lysimeters was utilising mineralised nitrogen that was immobilised in the soil prior to the reduction in effluent irrigation as a result of the sprinkler head change.

The maximum rate of unaccounted nitrogen (29%) falls within published values of other losses of nitrogen from the soil. Assuming up to 24% volatilisation (Smith et al., 1996) and up to 20% microbial soil immobilisation (Ledgard et al., 1988), all of the nitrogen that was irrigated but not removed by the pasture or leached from the soil can be accounted for.

Some nitrogen may be stored in the soil, but measuring soil storage of nitrogen is difficult as a result of high spatial variability. McLay et al. (2000) were unable to detect a significant accumulation of nitrogen in the soil at the Rotorua LTS, while, after 10 years of effluent irrigation, no accumulation of nitrogen has been observed in the soil of the Taupo LTS (Power & Wheeler, 2007).

5.5 Limitations of the study

5.5.1 Effluent nitrogen concentration

Calculating the concentration of nitrogen within the effluent presented some problems. TDC collected a weekly sample from the wastewater treatment plant which was analysed for total nitrogen concentration. To improve the frequency that the raw effluent was collected, and to account for any changes that may occur within the effluent between the wastewater treatment plant and the irrigation field, a composite sampler was installed in the pump house at the View Road site. The composite effluent sampler failed to reliably sample effluent until October 2010, consequently the weekly grab sample data provided by TDC was used to supplement that from the composite sampler. As a result of using the effluent nitrogen concentration data provided by TDC, the total amount of nitrogen that was irrigated may be under or over represented. For example, on the 10th and 17th November, TDC show the total effluent nitrogen concentration to be 37.4 and 38.8 g N m^{-3} respectively, while the composite sampler shows a total nitrogen concentration for the two dates of 48.8 and 48.5 g N m^{-3} (Figure 4.1). At the conclusion of the study period, the composite sampler had not produced a sufficient number of samples to compare the two methods of data analysis (Figure 4.1, Appendix 9).

Nevertheless, historical records (Church, 2005; Taupo District Council 2007) showing a high proportion of NH_4-N (>90 %) and low proportion of NO_X-N (<1 %) in the final effluent, concur with the limited number of samples taken by the composite sampler at the experimental area during 2010.

5.5.2 Effluent application

Using plastic rain gauges provided a simple means for assessing variability in the irrigation pattern. It was assumed that edge effects and evaporation were consistent between each rain gauge, and the rain gauges were used for comparative purposes only, not to provide absolute measurements of the amount of effluent irrigated. The rain gauges receiving no effluent (rainfall only) consistently measured within 3 mm of each other (Appendix 10), so their ability to reliably provide a means of comparison between treatments is realistic.

The original experimental design (Chapter 3.2) featured four replicates within four effluent loading rates. Uneven irrigation both within and between treatments necessitated a shift in experimental design, where the treatments were grouped into four different rates. In addition, the total effluent application during the 12 month period was approximately 80 % of the target, therefore the high loading rate of 650 kg N ha^{-1} was not realised.

The flow meters used to calculate the volume of effluent applied to the field are accurate to within 10% (J. Ewert, pers. comm., 2010), therefore the volume of effluent irrigated could be under or over represented.

5.5.2.1 Variability within treatments

In January 2010, new sprinkler heads with a more uniform spray pattern and less spray drift were installed to all irrigators. Incorrect sprinkler heads with a reduced flow rate were installed on part of both irrigators involved in the trial and affected half of the irrigated treatments from January 2010 onwards. As the lysimeters in each irrigated treatment were installed 10 m apart, some of the lysimeters in each of the affected treatments received less than half the effluent of other lysimeters within the same treatment sector (Appendix 10).

The total nitrogen application for each treatment sector was calculated as the mean of effluent applied to each of the three lysimeters within each treatment. As a result, the reported application rate for each treatment sector was not a true representation of the amount of effluent applied to each lysimeter within the treatments that were affected by the variation.

Correct sprinkler heads were installed on Pivot F during May 2010 to restore correct irrigation rates, but were not installed on Pivot G. The effluent irrigation rate between the three lysimeters in the treatments not affected by the sprinkler head variation were typically within 10 % of each other (Appendix 10).

5.5.2.2 Variability between treatments

In early June 2010, Pivot F (Figure 3.1) suffered from severe wheel rutting and did not apply effluent again until late August (Appendix 9). As a result, there is a large difference in the total amount of effluent that was irrigated by Pivot F compared to Pivot G over the study period (Figure 4.2).

The lysimeters under Pivot G received effluent consistently throughout the year, while the lysimeters under Pivot F did not, and the rate of effluent application during the time Pivot F was irrigated varied due to sprinkler head changes. The lack of effluent under Pivot F between June and August was apparent in the field when the grass growth slowed and the pasture became yellow when compared to the pasture under Pivot G (Figure 5.1). The lack of effluent under Pivot F between June and August may have impacted on the amount of nitrogen leached from each treatment.

5.5.3 Variability of drainage

The maximum total drainage recorded from a single irrigated lysimeter during the 12 month period was 1300 mm, while the minimum was 70 mm. The maximum total drainage recorded from a single un-irrigated lysimeter during the 12 month period was 760 mm, while the minimum was 300 mm (Appendix 2). Consequently, between irrigated treatments, there was a a lot of scatter (R^2=0.47, Figure 4.6) between the volume of water that reached the land surface and the volume of water that drained through the soil.

Prior to effluent irrigation, the un-irrigated soil was found to be strongly water repellent (Vogeler 2007), with evidence of the water repellency showing during summer. In January 2010, drainage collected from the un-irrigated lysimeters ranged from 3 to 189 mm, while drainage from the irrigated lysimeters ranged from 0 to 97 mm. Rainfall in Taupo township for the period was 110 mm, with an additional 20 to 35 mm from irrigation. The rainfall recorded in Taupo township may have been somewhat less than the actual rainfall at the experimental area, leading to the disparity between rainfall and drainage volume of the un-irrigated treatments.

Alternatively, during summer, the un-irrigated soils were likely to be hydrophobic (Vogeler, 2007), which led to overland flow when heavy rain fell. The lysimeters were installed flush with the surrounding ground, enabling any surface water to flow across the paddock and onto the top of the lysimeter. Lysimeters with exposed macropores would have leached preferentially to those without macropores, thus some of the un-irrigated lysimeters may have leached more water than they received. By keeping the soil surface moist through regular irrigation, the water repellency of the irrigated soil would have been reduced (Vogeler, 2007), hence during January the irrigated lysimeters recorded less variability in the drainage than the un-irrigated lysimeters.

High variability in drainage through Pumice soil has been noted previously as Burgess (2003) was unable to find significant differences in drainage volumes between irrigated and un-irrigated treatments in a similar lysimeter study. In contrast, Di & Cameron (2005) was able to show a difference in drainage between treatments when using a non-volcanic fine sandy loam. They found higher yielding pasture to have lower drainage than poorer yielding pasture, citing greater evapotranspiration from lysimeters with superior grass growth. There was no correlation (R^2=0.18, Figure 4.7) between grass growth and drainage volume in this study.

The design of the lysimeters used to collect the leachate may possibly restrict the flow of water through the soil (Chapter 2.6). The bottom plate of the lysimeter may act as an impediment to the vertical flow of water, however such flow boundaries naturally occur as a result of abrupt textural changes in the Pumice soil at the site (Orbell, 2007). Therefore the bottom plate of the lysimeter should not be seen as detrimentally affecting this study. In addition, all lysimeters were constructed in the same manner so any potential impediment to drainage would be equal for all lysimeters and would not be the cause of variation of drainage between lysimeters.

The weather station installed on site suffered from lightening strike and did not provide sufficient data to be of use in this study. Consequently, rainfall data was used from a weather station located on Rifle Range Road, approximately eight kilometres from the experimental area. The rainfall recorded at Rifle Range Road could differ from the actual rainfall at the experimental area, especially in heavy rainfall events where spatial variation could be high. The level of rainfall recorded by the plastic rain gauges at the experimental area was at times higher and at other times lower than the rainfall recorded at Rifle Range Road. A dedicated weather station located at the experimental area would provide a more accurate rainfall record.

5.5.4 Measurement error and variability

There was a positive trend between the amount of nitrogen leached and the total nitrogen input, but there was quite a lot of scatter between results. There was no correlation with the amount of nitrogen leached and the amount of nitrogen removed by the pasture. There was no correlation between the rate of effluent irrigation and the rate of pasture growth. Scaling up the small area of the lysimeter (0.075 m^2) to a hectare (10,000 m^2) will always lead to a margin or error in the final reported values, however there were other inaccuracies that contributed to this study.

Having a field based trial as opposed to a more controlled laboratory study has contributed to the errors associated in measuring the various parameters in this study. Consequently the measurement errors associated with this field trial were high and could explain the large variation of the results. When conventional measurement errors were calculated, the results were:

- The nitrogen application rate had a measurement error of ± 35 %.
    - The nitrogen concentration of the effluent for each week was primarily calculated using the data provided by a single sample. Spatial and temporal variation of the irrigation (Chapter 5.5.2) further compounded the difficulty in measuring nitrogen application rates.
- The amount of nitrogen leached had an associated measurement error of ±40 %.
- The pasture growth data had ± 20 % measurement error.
- The amount of nitrogen removed by the pasture had a measurement error of ± 30 %.

It should be noted that with replicate samples, the individual measurement errors become less significant as, with averaging, the errors tend to cancel each other out (R. Littler, pers. comm., 2011). Hence in spite of the large individual measurement errors, it was possible to detect a significant difference between treatments.

By using intact monolith lysimeters, the natural variation of the pasture cover and soil drainage characteristics have been captured. The results of this study have shown the natural variation of the Pumice soil to be high, therefore using small lysimeters for a comparative study such as this one may not be ideal. Nevertheless, other means of collecting soil water (such as suction cups) that rely on numerical models to predict drainage through the soil profile will not capture the variation recorded in this study and are probably not appropriate for use in a Pumice soil. In addition, suction cups may not be efficient at capturing organic nitrogen, which was a substantial component of the nitrogen leached in this study. On the balance, the lysimeters used in this study provided the best compromise for measuring real world effects in an affordable manner. The biggest potential improvement would be to improve the resolution of the data by increasing the frequency of sample collection and improving the resolution of the data by analysing the leachate from each lysimeter separately. Finding a cost effective way of sampling and analysing the leachate would be the biggest challenge.

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Chapter six - Conclusion

6.1 Summary of research

To measure nitrogen leaching from the Taupo Land Treatment Scheme (LTS), 48 intact monolith lysimeters were installed beneath effluent irrigation from two centre pivot irrigators. Four treatments based on nitrogen loading rates were trialled, nominally no-N (0 kg N ha^{-1}yr^{-1}), low-N (350 kg N ha^{-1}yr^{-1} or less), mid-N (between 350 and 450 kg N ha^{-1}yr^{-1}), and high-N (greater than 450 kg N ha^{-1}yr^{-1}). Leachate was collected at least monthly and analysed for nitrogen content, and the pasture was removed from the lysimeters and analysed for nitrogen uptake.

This study reports the results from the first year of a five year trial. The first year of monitoring has revealed high levels of variation in the amount of nitrogen leached and the amount of pasture grown under effluent irrigation. The level of nitrogen leached was below the regional average from typical grazed dairy pasture, and generally below the consented limit of 30 kg N ha^{-1}y^{-1}.

6.1.1 Specific conclusions

- Effluent irrigation significantly increased pasture growth and nitrogen leaching in comparison to un-irrigated treatments.
- There was no significant difference between the rate of pasture growth between the high-N and low-N treatments.
- Of the nitrogen that was irrigated, on average, 84 % was removed in the pasture, 5 % was leached, and 11% remained un-accounted- presumably stored in the soil or converted to nitrogen gasses.
- The mean rate of grass growth from the irrigated treatments was 15,800 kg DM ha^{-1}yr^{-1}.
- The mean rate of nitrogen that leached from the irrigated treatments was 19 kg N ha^{-1}yr^{-1}, while the minimum was 8.2 and the maximum was 31.1 kg N ha^{-1}yr^{-1}. The amount of nitrogen

leached was however, poorly correlated with the rate of effluent irrigation.

- The amount of nitrogen leached was positively correlated with the volume of water that drained through the soil.
- The nitrogen concentration of the leachate was not correlated with the volume of water that drained; the total amount of nitrogen irrigated; or the total amount of nitrogen removed by the pasture.
- The nitrogen in the leachate of the irrigated treatments comprised 53 % nitrate-N and 45 % organic-N, while the leachate of the un-irrigated treatments comprised, on average 26 % nitrate-N and 72 % organic-N. Ammoniacal-N accounted for approximately 2% of all nitrogen leached.
- Most of the nitrate/nitrite leached throughout the year from both irrigated and un-irrigated treatments was leached after rain during summer and autumn.
- During winter and spring, organic nitrogen was the dominant form of nitrogen leached.
- The mean concentration of nitrate/nitrite-N leached from the irrigated treatments was 1.3 g N m^{-3}.
- The concentration of nitrate/nitrite-N leached never exceeded Ministry of Health guidelines.
- The mean concentration of organic nitrogen leached from the irrigated treatments was 1.2 g N m^{-3}.

There was a significant relationship showing higher rates of nitrogen leaching under higher rates of effluent irrigation. Given that, on average, the pasture removed 84% of the nitrogen that was irrigated, maximising the growth and uptake of nitrogen of the pasture is extremely important in controlling nitrogen leaching.

6.2 Recommendations

6.2.1 Management of the Taupo LTS

- The effects of different rates of effluent irrigation may be analysed at some time in the future. It is strongly recommended that the varied rates of effluent irrigation beneath Pivot F and G be continued. Without the varied irrigation rates, further analysis will not be possible.
- The results presented in this study are from the first year of monitoring during the start up phase of the land treatment scheme. The rate of nitrogen leaching may increase in the years following this study as the soil loses its ability to store excess nitrogen. It is strongly recommended that the monitoring of nitrogen leaching from the lysimeters is continued for the duration of the trial consent.
- The ryegrass pasture appears to have a high rate of grass growth during late winter and early spring. Harvesting the grass in mid to late winter will ensure grass growth and nitrogen uptake during late winter and spring are maximised, and may lead to reduced nitrogen leaching in the future.
- The ryegrass pasture had a sparse cover on the ground, and the proportion of weeds in the pasture increased during 2010. Improving the pasture density and quality, possibly by spraying with herbicide for undesirable species followed by under-sowing with ryegrass where required, will give better quality haylage and improve the nitrogen uptake of the LTS.

6.2.2 Research at the Taupo LTS

- The intention of this study was to assess the ability of the LTS to be able to accept effluent at the rate of up to 650 kg N $ha^{-1}yr^{-1}$, while having little impact on the surrounding environment. The maximum rate of effluent irrigation recorded was approximately 520 kg N $ha^{-1}yr^{-1}$, therefore the rate of irrigation needs to be increased to the equivalent of 650 kg N $ha^{-1}yr^{-1}$ to test the system at high loading rates.

- The level of variation in the volume of effluent irrigated between treatments of this study was high. To improve the data resolution, it is recommended that the amount of effluent being applied to each lysimeter is recorded, and leachate from each lysimeter is analysed separately.
- The harvested pasture had a low average nitrogen concentration, suggesting the grass had passed the optimum stage to maximise plant growth rates and nitrogen removal. The possibility of producing more grass and therefore removing more nitrogen from the site by increasing the pasture quality and density, and harvesting the pasture more frequently could be investigated.
- Not all of the nitrogen that was irrigated was removed by the pasture or leached through the soil. Isotopic analysis of the effluent, pasture, soil, and leachate, could be one method used to complete the nitrogen budget.
- Some of the nitrogen that is being irrigated may not be reaching the soil surface. Investigating the rate of ammonia volatilisation occurring due to spray irrigation will help determine how much nitrogen is lost before it reaches the soil.
- Some nitrogen storage may be occurring in the soil, which could lead to the decline in performance of the LTS when the soil reaches its nitrogen storage capacity. Coupling measurements of the soil storage of nitrogen with leaching data may provide an indicator as to the limit of the soil to store nitrogen before excess nitrogen is leached.
- A more controlled environment (such as a dedicated lysimeter facility) would reduce the variability within treatments and enable better metering of the volume of effluent irrigated.

6.2.3 General research

Below are some suggestions for general scientific research not pertaining to the Taupo LTS.

- There are few data that record changes in the amount of nitrogen leached over the lifetime of a LTS. It is recommended that nitrogen leaching and plant uptake of nitrogen is monitored from new land treatment schemes.
- Organic nitrogen comprised almost half of the nitrogen that was leached from the irrigated treatments in this study. Organic nitrogen may be taken up by aquatic life, therefore it is recommended that in all future studies considering nitrogen leaching, the organic fraction must be considered. A better understanding of the processes that lead to organic nitrogen leaching are required.
- Soil storage is often considered to be a method of nitrogen removal from irrigated effluent. The ability of soil to store nitrogen under high loading rates is finite, and the soil may reach nitrogen saturation, leading to excess nitrogen being leached to groundwater. However, many researchers have failed to detect a significant accumulation of nitrogen in the soil under effluent irrigation. Methods of detecting soil nitrogen need to be improved to better understand rates of nitrogen accumulation in soil.

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Appendices

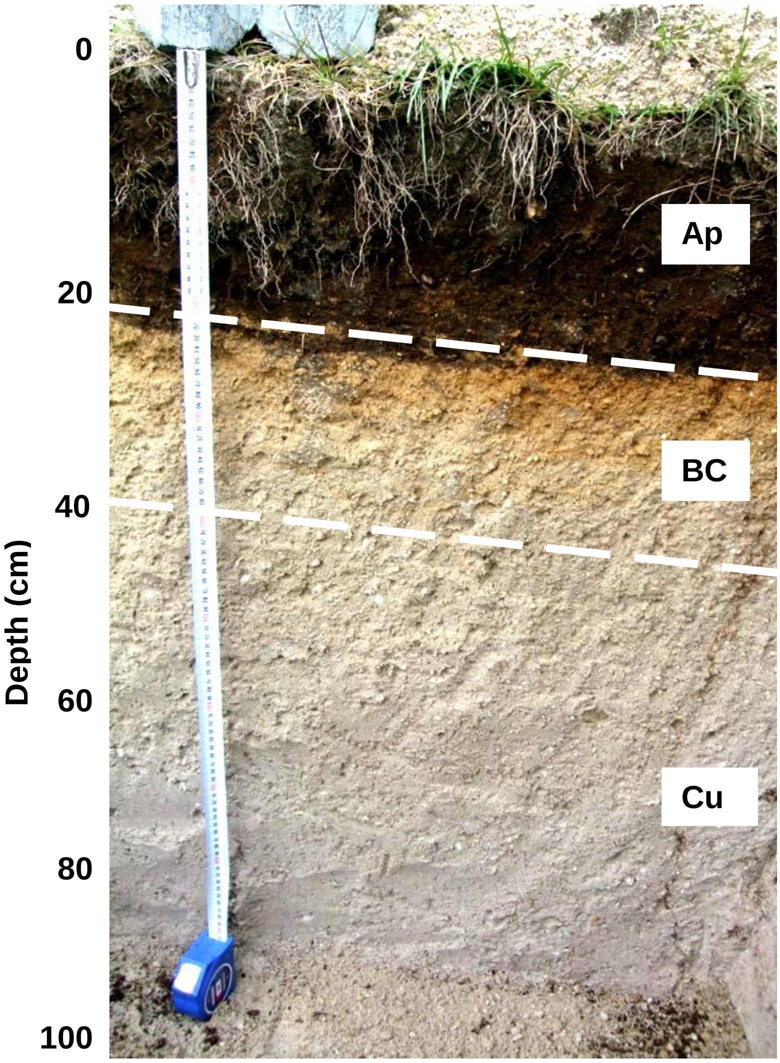
Appendix 1 - Soil profile description

Un-irrigated soil description

Soil name		
	Series:	Whenuaroa
	Type:	Whenuaroa gravelly sandy loam[1]
Soil classification		
	NZ Soil Classification:[2]	Immature Orthic Pumice Soil
	Soil Taxonomy:[3]	Typic Udivitrand
Site Data		
Location		
	Word descriptor:	Pit at View Road site of Taupo Land Treatment Scheme, east of Taupo.
	Map reference:	NZTopo50-BG36/750168
Annual rainfall:		1120 mm
Elevation:		430 m
Geomorphic position:		Near flat terrace/fan.
Erosion/deposition:		Negligible
Vegetation:		Perennial ryegrass (*Lolium perenne*) "Impact"
Parent Material:		Rewashed Taupo detritus from c. AD 186 rhyolitic eruption
Drainage class:		Well drained
Land use:		Municipal wastewater irrigation, ryegrass cropping farm.
Soil Data		
Horizon[4]:	**Depth (cm)**	
Ap	0-20	Dark brown (10YR 3/4) fine sand, non sticky, non plastic,very weak soil strength, very friable, apedal earthy with many fine pumice
BC	20-40	Bright yellowish brown (10YR 7/6), medium sand, non sticky, non plastic, very weak soil strength, very friable, weakly pedal, few fine to medium blocky peds with many fine to medium pumice clasts, diffuse boundary
Cu	40-100	Light gray (5Y 8/2), fine sand, non sticky, non plastic, very weak soil strength, very friable, apedal earthy with common fine to medium pumice clasts.

[1] Orbell (2007)
[2] Hewitt (1998)
[3] Soil Survey Staff (2010). Keys to Soil Taxonomy, 11th ed. USDA-Natural Resources Conservation Service, Washington, DC.
[4] Milne et al., (1991) and Clayden and Hewitt (1994).

Un-irrigated Soil Profile sketch



Disturbed by cultivation. Many fine pumice clasts.

Medium grained sand, very weak soil strength, weakly pedal, many fine to medium pumice clasts.

Fine grained sand, weak soil strength, apedal earthy, common fine to medium pumice clasts.

Irrigated soil description

Soil name		
	Series:	Whenuaroa
	Type:	Whenuaroa gravelly sandy loam[1]
Soil classification		
	NZ Soil Classification:[2]	Immature Orthic Pumice Soil
	Soil Taxonomy:[3]	Typic Udivitrand
Site Data		
Location		
	Word descriptor:	Pit at View Road site of Taupo Land Treatment Scheme, east of Taupo.
	Map reference:	NZTopo50-BG36/750168
Annual rainfall:		1120 mm
Elevation:		430 m
Geomorphic position:		Near flat terrace/fan.
Erosion/deposition:		Negligible
Vegetation:		Perennial ryegrass (*Lolium perenne*) "Impact"
Parent Material:		Rewashed Taupo detritus from c. AD 186 rhyolitic eruption
Drainage class:		Well drained
Land use:		Municipal wastewater irrigation, ryegrass cropping farm.
Soil Data		
Horizon[4]:	**Depth (cm)**	
Ap	0-20	Dark brown (7.5YR 3/4) fine sand, non sticky, non plastic, very weak soil strength, very friable, weakly pedal, few very fine spheroidal peds with common very fine and few fine to medium pumice clasts, many fine roots, smooth sharp boundary.
BC	20-40	Light yellow (2.5Y 7/4), medium sand, non sticky, non plastic, very weak soil strength, very friable, weakly pedal, few very fine spheroidal peds with common very fine pumice clasts, diffuse boundary.
Cu	40-100	Light gray (7.5Y 8/1), medium sand, non sticky, non plastic, weak soil strength, friable, weakly pedal, few fine spheroidal peds and very few medium wedge peds with very few extremely fine pumice clasts.

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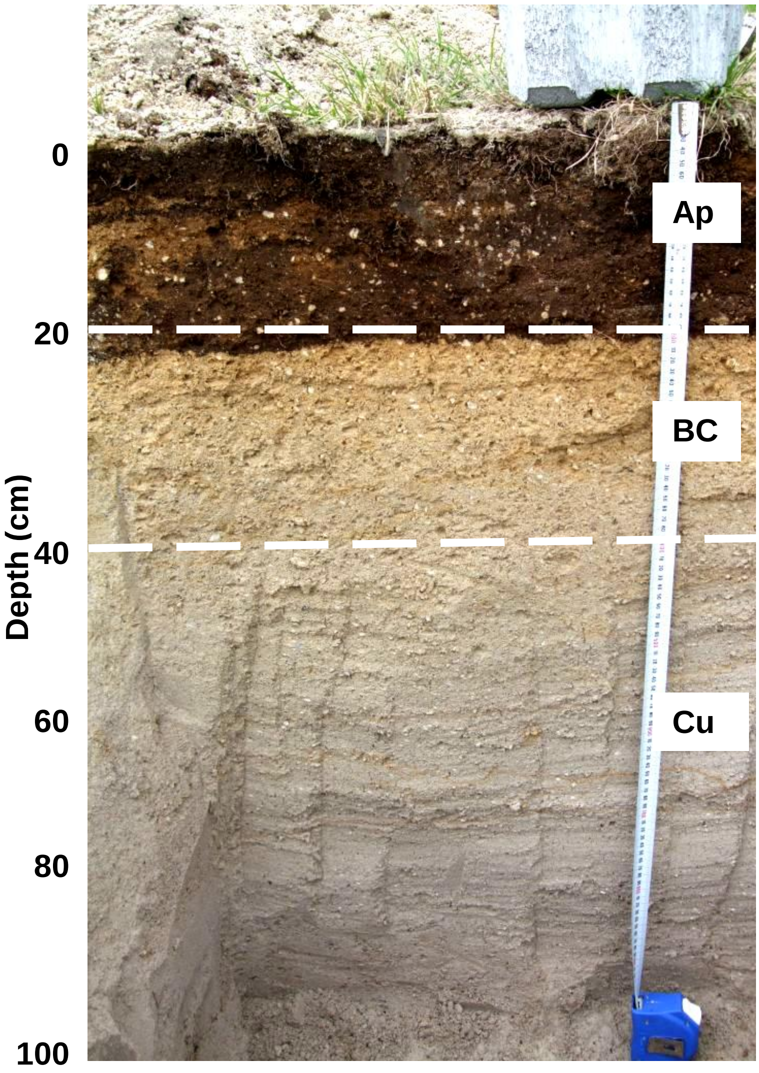
[1] Orbell (2007)
[2] Hewitt (1998)
[3] Soil Survey Staff (2010). Keys to Soil Taxonomy, 11th ed. USDA-Natural Resources Conservation Service, Washington, DC.
[4] Milne et al., (1991) and Clayden and Hewitt (1994).

Irrigated Soil Profile sketch



Disturbed by cultivation. Many fine pumice clasts.

Medium grained sand, very weak soil strength, weakly pedal, many fine to medium pumice clasts.

Fine grained sand, weak soil strength, apedal earthy, common fine to medium pumice clasts.

Appendix 2 - Drainage through the soil

Date	Sector		Drainage (mm)
14/01/2010	F1	A	0.00
14/01/2010	F1	B	0.00
14/01/2010	F1	C	0.00
14/01/2010	F2	A	2.65
14/01/2010	F2	B	18.55
14/01/2010	F2	C	7.95
14/01/2010	F3	A	0.66
14/01/2010	F3	B	0.66
14/01/2010	F3	C	9.94
14/01/2010	F4	A	2.65
14/01/2010	F4	B	0.00
14/01/2010	F4	C	0.00
14/01/2010	F5	A	0.00
14/01/2010	F5	B	0.00
14/01/2010	F5	C	0.00
14/01/2010	F6	A	0.00
14/01/2010	F6	B	0.00
14/01/2010	F6	C	0.00
14/01/2010	F7	A	7.29
14/01/2010	F7	B	19.08
14/01/2010	F7	C	0.00
14/01/2010	F8	A	0.66
14/01/2010	F8	B	1.32
14/01/2010	F8	C	1.59
14/01/2010	G1	A	1.32
14/01/2010	G1	B	2.32
14/01/2010	G1	C	14.24
14/01/2010	G2	A	9.94
14/01/2010	G2	B	5.30
14/01/2010	G2	C	1.32
14/01/2010	G3	A	2.65
14/01/2010	G3	B	1.32
14/01/2010	G3	C	1.99
14/01/2010	G4	A	1.32
14/01/2010	G4	B	21.86
14/01/2010	G4	C	16.56
14/01/2010	C1	A	0.00
14/01/2010	C1	B	0.00
14/01/2010	C1	C	0.00
14/01/2010	C2	A	0.00
14/01/2010	C2	B	0.00
14/01/2010	C2	C	0.00
14/01/2010	C3	A	0.00
14/01/2010	C3	B	0.00
14/01/2010	C3	C	0.00
14/01/2010	C4	A	0.00
14/01/2010	C4	B	0.00
14/01/2010	C4	C	0.00
18/02/2010	F1	A	7.29
18/02/2010	F1	B	21.86
18/02/2010	F1	C	32.46
18/02/2010	F2	A	54.32
18/02/2010	F2	B	33.12
18/02/2010	F2	C	31.80
18/02/2010	F3	A	68.90
18/02/2010	F3	B	43.06
18/02/2010	F3	C	96.72
18/02/2010	F4	A	37.76
18/02/2010	F4	B	0.00
18/02/2010	F4	C	36.44
18/02/2010	F5	A	9.94
18/02/2010	F5	B	3.31
18/02/2010	F5	C	26.50
18/02/2010	F6	A	3.31
18/02/2010	F6	B	0.66
18/02/2010	F6	C	35.77
18/02/2010	F7	A	47.70
18/02/2010	F7	B	49.02
18/02/2010	F7	C	0.00
18/02/2010	F8	A	60.28
18/02/2010	F8	B	41.07
18/02/2010	F8	C	9.94
18/02/2010	G1	A	11.26
18/02/2010	G1	B	82.81
18/02/2010	G1	C	33.12
18/02/2010	G2	A	14.57
18/02/2010	G2	B	5.30
18/02/2010	G2	C	26.50
18/02/2010	G3	A	10.60
18/02/2010	G3	B	59.62
18/02/2010	G3	C	15.24
18/02/2010	G4	A	39.75
18/02/2010	G4	B	33.12
18/02/2010	G4	C	28.49
18/02/2010	C1	A	63.60
18/02/2010	C1	B	186.15
18/02/2010	C1	C	93.41
18/02/2010	C2	A	179.53
18/02/2010	C2	B	3.31
18/02/2010	C2	C	105.99
18/02/2010	C3	A	29.81
18/02/2010	C3	B	5.30
18/02/2010	C3	C	10.60
18/02/2010	C4	A	188.80
18/02/2010	C4	B	12.59
18/02/2010	C4	C	63.60
16/03/2010	F1	A	0.00
16/03/2010	F1	B	11.26
16/03/2010	F1	C	11.26
16/03/2010	F2	A	17.22
16/03/2010	F2	B	17.22
16/03/2010	F2	C	25.17
16/03/2010	F3	A	18.55
16/03/2010	F3	B	6.62
16/03/2010	F3	C	21.20
16/03/2010	F4	A	14.57
16/03/2010	F4	B	0.00
16/03/2010	F4	C	3.31
16/03/2010	F5	A	0.66
16/03/2010	F5	B	0.00
16/03/2010	F5	C	2.65
16/03/2010	F6	A	1.32
16/03/2010	F6	B	0.00
16/03/2010	F6	C	25.17
16/03/2010	F7	A	3.97
16/03/2010	F7	B	15.90
16/03/2010	F7	C	0.00
16/03/2010	F8	A	1.32
16/03/2010	F8	B	9.27
16/03/2010	F8	C	7.95
16/03/2010	G1	A	1.99
16/03/2010	G1	B	18.55
16/03/2010	G1	C	7.95
16/03/2010	G2	A	0.00
16/03/2010	G2	B	0.00
16/03/2010	G2	C	0.00
16/03/2010	G3	A	1.32

16/03/2010	G3	B	27.82
16/03/2010	G3	C	10.60
16/03/2010	G4	A	7.29
16/03/2010	G4	B	3.97
16/03/2010	G4	C	10.60
16/03/2010	C1	A	0.66
16/03/2010	C1	B	0.66
16/03/2010	C1	C	0.66
16/03/2010	C2	A	0.66
16/03/2010	C2	B	0.66
16/03/2010	C2	C	0.66
16/03/2010	C3	A	0.66
16/03/2010	C3	B	0.66
16/03/2010	C3	C	0.66
16/03/2010	C4	A	0.66
16/03/2010	C4	B	0.66
16/03/2010	C4	C	0.66
29/04/2010	F1	A	8.61
29/04/2010	F1	B	41.07
29/04/2010	F1	C	39.08
29/04/2010	F2	A	23.19
29/04/2010	F2	B	48.36
29/04/2010	F2	C	107.98
29/04/2010	F3	A	54.32
29/04/2010	F3	B	48.36
29/04/2010	F3	C	76.18
29/04/2010	F4	A	47.70
29/04/2010	F4	B	0.00
29/04/2010	F4	C	21.20
29/04/2010	F5	A	3.31
29/04/2010	F5	B	49.68
29/04/2010	F5	C	36.44
29/04/2010	F6	A	1.99
29/04/2010	F6	B	1.32
29/04/2010	F6	C	60.95
29/04/2010	F7	A	0.00
29/04/2010	F7	B	54.32
29/04/2010	F7	C	0.00
29/04/2010	F8	A	0.00
29/04/2010	F8	B	33.12
29/04/2010	F8	C	39.75
29/04/2010	G1	A	23.19
29/04/2010	G1	B	73.53
29/04/2010	G1	C	42.40
29/04/2010	G2	A	10.60
29/04/2010	G2	B	9.27
29/04/2010	G2	C	17.22
29/04/2010	G3	A	23.19
29/04/2010	G3	B	60.95
29/04/2010	G3	C	25.17
29/04/2010	G4	A	29.81
29/04/2010	G4	B	37.76
29/04/2010	G4	C	51.67
29/04/2010	C1	A	0.00
29/04/2010	C1	B	22.52
29/04/2010	C1	C	1.32
29/04/2010	C2	A	172.24
29/04/2010	C2	B	27.16
29/04/2010	C2	C	109.31
29/04/2010	C3	A	0.00
29/04/2010	C3	B	0.00
29/04/2010	C3	C	0.00
29/04/2010	C4	A	65.58
29/04/2010	C4	B	80.16
29/04/2010	C4	C	113.28
31/05/2010	F1	A	47.70
31/05/2010	F1	B	98.84
31/05/2010	F1	C	91.95
31/05/2010	F2	A	160.31
31/05/2010	F2	B	88.77
31/05/2010	F2	C	152.36
31/05/2010	F3	A	138.45
31/05/2010	F3	B	94.20
31/05/2010	F3	C	143.75
31/05/2010	F4	A	154.62
31/05/2010	F4	B	0.00
31/05/2010	F4	C	78.43
31/05/2010	F5	A	59.09
31/05/2010	F5	B	64.92
31/05/2010	F5	C	106.66
31/05/2010	F6	A	14.18
31/05/2010	F6	B	10.73
31/05/2010	F6	C	158.72
31/05/2010	F7	A	162.43
31/05/2010	F7	B	151.04
31/05/2010	F7	C	28.75
31/05/2010	F8	A	73.53
31/05/2010	F8	B	99.77
31/05/2010	F8	C	63.86
31/05/2010	G1	A	99.90
31/05/2010	G1	B	159.25
31/05/2010	G1	C	141.63
31/05/2010	G2	A	107.32
31/05/2010	G2	B	83.73
31/05/2010	G2	C	87.44
31/05/2010	G3	A	131.03
31/05/2010	G3	B	179.92
31/05/2010	G3	C	82.67
31/05/2010	G4	A	168.93
31/05/2010	G4	B	123.48
31/05/2010	G4	C	186.02
31/05/2010	C1	A	41.73
31/05/2010	C1	B	72.61
31/05/2010	C1	C	57.90
31/05/2010	C2	A	94.20
31/05/2010	C2	B	14.31
31/05/2010	C2	C	45.97
31/05/2010	C3	A	21.60
31/05/2010	C3	B	53.79
31/05/2010	C3	C	29.02
31/05/2010	C4	A	20.01
31/05/2010	C4	B	15.37
31/05/2010	C4	C	27.29
9/06/2010	F1	A	42.26
9/06/2010	F1	B	72.74
9/06/2010	F1	C	67.31
9/06/2010	F2	A	90.62
9/06/2010	F2	B	58.16
9/06/2010	F2	C	33.65
9/06/2010	F3	A	141.63
9/06/2010	F3	B	115.40
9/06/2010	F3	C	141.37
9/06/2010	F4	A	144.55
9/06/2010	F4	B	0.00
9/06/2010	F4	C	84.66
9/06/2010	F5	A	45.05
9/06/2010	F5	B	72.87
9/06/2010	F5	C	67.44

9/06/2010	F6	A	30.61
9/06/2010	F6	B	4.50
9/06/2010	F6	C	152.36
9/06/2010	F7	A	92.88
9/06/2010	F7	B	82.01
9/06/2010	F7	C	25.04
9/06/2010	F8	A	73.67
9/06/2010	F8	B	61.61
9/06/2010	F8	C	46.90
9/06/2010	G1	A	65.72
9/06/2010	G1	B	135.01
9/06/2010	G1	C	81.88
9/06/2010	G2	A	66.91
9/06/2010	G2	B	55.65
9/06/2010	G2	C	56.84
9/06/2010	G3	A	139.12
9/06/2010	G3	B	93.27
9/06/2010	G3	C	73.40
9/06/2010	G4	A	96.72
9/06/2010	G4	B	115.53
9/06/2010	G4	C	91.29
9/06/2010	C1	A	33.39
9/06/2010	C1	B	65.32
9/06/2010	C1	C	61.48
9/06/2010	C2	A	35.11
9/06/2010	C2	B	71.41
9/06/2010	C2	C	61.34
9/06/2010	C3	A	46.37
9/06/2010	C3	B	55.51
9/06/2010	C3	C	43.85
9/06/2010	C4	A	49.95
9/06/2010	C4	B	33.26
9/06/2010	C4	C	8.48
22/06/2010	F1	A	32.99
22/06/2010	F1	B	62.01
22/06/2010	F1	C	68.76
22/06/2010	F2	A	90.09
22/06/2010	F2	B	37.49
22/06/2010	F2	C	37.49
22/06/2010	F3	A	33.12
22/06/2010	F3	B	29.55
22/06/2010	F3	C	39.35
22/06/2010	F4	A	30.87
22/06/2010	F4	B	0.00
22/06/2010	F4	C	17.75
22/06/2010	F5	A	40.14
22/06/2010	F5	B	63.33
22/06/2010	F5	C	49.82
22/06/2010	F6	A	8.35
22/06/2010	F6	B	1.99
22/06/2010	F6	C	30.87
22/06/2010	F7	A	93.41
22/06/2010	F7	B	73.27
22/06/2010	F7	C	6.36
22/06/2010	F8	A	57.90
22/06/2010	F8	B	48.62
22/06/2010	F8	C	38.82
22/06/2010	G1	A	80.82
22/06/2010	G1	B	158.19
22/06/2010	G1	C	119.90
22/06/2010	G2	A	66.51
22/06/2010	G2	B	60.28
22/06/2010	G2	C	54.59
22/06/2010	G3	A	86.91
22/06/2010	G3	B	107.32
22/06/2010	G3	C	82.81
22/06/2010	G4	A	98.71
22/06/2010	G4	B	101.22
22/06/2010	G4	C	158.59
22/06/2010	C1	A	34.58
22/06/2010	C1	B	58.03
22/06/2010	C1	C	52.47
22/06/2010	C2	A	30.08
22/06/2010	C2	B	60.55
22/06/2010	C2	C	52.33
22/06/2010	C3	A	42.40
22/06/2010	C3	B	46.50
22/06/2010	C3	C	36.83
22/06/2010	C4	A	24.51
22/06/2010	C4	B	33.79
22/06/2010	C4	C	5.70
9/07/2010	F1	A	24.25
9/07/2010	F1	B	32.46
9/07/2010	F1	C	35.51
9/07/2010	F2	A	34.18
9/07/2010	F2	B	20.80
9/07/2010	F2	C	14.71
9/07/2010	F3	A	39.22
9/07/2010	F3	B	28.22
9/07/2010	F3	C	45.31
9/07/2010	F4	A	39.61
9/07/2010	F4	B	0.00
9/07/2010	F4	C	25.17
9/07/2010	F5	A	20.40
9/07/2010	F5	B	32.86
9/07/2010	F5	C	33.92
9/07/2010	F6	A	13.25
9/07/2010	F6	B	2.12
9/07/2010	F6	C	43.06
9/07/2010	F7	A	41.07
9/07/2010	F7	B	25.70
9/07/2010	F7	C	0.66
9/07/2010	F8	A	21.60
9/07/2010	F8	B	22.39
9/07/2010	F8	C	18.15
9/07/2010	G1	A	64.26
9/07/2010	G1	B	95.53
9/07/2010	G1	C	88.37
9/07/2010	G2	A	42.40
9/07/2010	G2	B	55.51
9/07/2010	G2	C	44.78
9/07/2010	G3	A	47.43
9/07/2010	G3	B	75.92
9/07/2010	G3	C	71.94
9/07/2010	G4	A	62.80
9/07/2010	G4	B	39.61
9/07/2010	G4	C	38.95
9/07/2010	C1	A	18.02
9/07/2010	C1	B	39.22
9/07/2010	C1	C	32.73
9/07/2010	C2	A	26.90
9/07/2010	C2	B	39.08
9/07/2010	C2	C	33.12
9/07/2010	C3	A	23.05
9/07/2010	C3	B	25.57
9/07/2010	C3	C	21.46
9/07/2010	C4	A	19.74
9/07/2010	C4	B	27.43

9/07/2010	C4	C	4.50
18/08/2010	F1	A	69.69
18/08/2010	F1	B	130.13
18/08/2010	F1	C	119.47
18/08/2010	F2	A	139.67
18/08/2010	F2	B	76.40
18/08/2010	F2	C	120.59
18/08/2010	F3	A	159.88
18/08/2010	F3	B	128.81
18/08/2010	F3	C	174.60
18/08/2010	F4	A	139.85
18/08/2010	F4	B	0.00
18/08/2010	F4	C	79.61
18/08/2010	F5	A	112.11
18/08/2010	F5	B	170.80
18/08/2010	F5	C	178.89
18/08/2010	F6	A	32.22
18/08/2010	F6	B	9.17
18/08/2010	F6	C	128.84
18/08/2010	F7	A	118.19
18/08/2010	F7	B	110.13
18/08/2010	F7	C	13.22
18/08/2010	F8	A	91.57
18/08/2010	F8	B	92.84
18/08/2010	F8	C	72.35
18/08/2010	G1	A	179.92
18/08/2010	G1	B	163.89
18/08/2010	G1	C	169.32
18/08/2010	G2	A	155.01
18/08/2010	G2	B	173.96
18/08/2010	G2	C	157.53
18/08/2010	G3	A	147.07
18/08/2010	G3	B	214.37
18/08/2010	G3	C	177.94
18/08/2010	G4	A	138.59
18/08/2010	G4	B	165.35
18/08/2010	G4	C	206.16
18/08/2010	C1	A	68.56
18/08/2010	C1	B	154.79
18/08/2010	C1	C	111.95
18/08/2010	C2	A	121.63
18/08/2010	C2	B	81.75
18/08/2010	C2	C	116.02
18/08/2010	C3	A	85.99
18/08/2010	C3	B	97.05
18/08/2010	C3	C	69.97
18/08/2010	C4	A	80.29
18/08/2010	C4	B	87.44
18/08/2010	C4	C	21.07
8/09/2010	F1	A	53.39
8/09/2010	F1	B	87.97
8/09/2010	F1	C	70.09
8/09/2010	F2	A	72.34
8/09/2010	F2	B	21.73
8/09/2010	F2	C	81.61
8/09/2010	F3	A	77.11
8/09/2010	F3	B	79.36
8/09/2010	F3	C	93.41
8/09/2010	F4	A	78.83
8/09/2010	F4	B	0.00
8/09/2010	F4	C	51.67
8/09/2010	F5	A	41.73
8/09/2010	F5	B	62.93
8/09/2010	F5	C	65.58
8/09/2010	F6	A	33.79
8/09/2010	F6	B	5.70
8/09/2010	F6	C	90.62
8/09/2010	F7	A	45.58
8/09/2010	F7	B	21.20
8/09/2010	F7	C	0.93
8/09/2010	F8	A	56.44
8/09/2010	F8	B	50.61
8/09/2010	F8	C	52.33
8/09/2010	G1	A	72.74
8/09/2010	G1	B	156.21
8/09/2010	G1	C	78.57
8/09/2010	G2	A	52.73
8/09/2010	G2	B	108.51
8/09/2010	G2	C	75.25
8/09/2010	G3	A	64.13
8/09/2010	G3	B	151.57
8/09/2010	G3	C	43.46
8/09/2010	G4	A	48.62
8/09/2010	G4	B	70.35
8/09/2010	G4	C	36.44
8/09/2010	C1	A	11.92
8/09/2010	C1	B	40.28
8/09/2010	C1	C	17.89
8/09/2010	C2	A	5.17
8/09/2010	C2	B	38.55
8/09/2010	C2	C	26.50
8/09/2010	C3	A	22.92
8/09/2010	C3	B	18.55
8/09/2010	C3	C	3.18
8/09/2010	C4	A	23.05
8/09/2010	C4	B	26.23
8/09/2010	C4	C	4.90
24/09/2010	F1	A	72.47
24/09/2010	F1	B	113.15
24/09/2010	F1	C	90.89
24/09/2010	F2	A	124.01
24/09/2010	F2	B	59.09
24/09/2010	F2	C	112.22
24/09/2010	F3	A	124.01
24/09/2010	F3	B	117.65
24/09/2010	F3	C	111.69
24/09/2010	F4	A	133.68
24/09/2010	F4	B	0.00
24/09/2010	F4	C	81.61
24/09/2010	F5	A	65.72
24/09/2010	F5	B	115.53
24/09/2010	F5	C	110.50
24/09/2010	F6	A	61.34
24/09/2010	F6	B	23.58
24/09/2010	F6	C	140.84
24/09/2010	F7	A	123.08
24/09/2010	F7	B	101.62
24/09/2010	F7	C	7.68
24/09/2010	F8	A	116.59
24/09/2010	F8	B	98.44
24/09/2010	F8	C	87.84
24/09/2010	G1	A	86.78
24/09/2010	G1	B	158.99
24/09/2010	G1	C	136.20
24/09/2010	G2	A	98.57
24/09/2010	G2	B	144.95
24/09/2010	G2	C	98.18
24/09/2010	G3	A	105.20

24/09/2010	G3	B	182.71
24/09/2010	G3	C	145.21
24/09/2010	G4	A	84.79
24/09/2010	G4	B	119.77
24/09/2010	G4	C	142.30
24/09/2010	C1	A	54.19
24/09/2010	C1	B	97.25
24/09/2010	C1	C	96.06
24/09/2010	C2	A	18.95
24/09/2010	C2	B	104.27
24/09/2010	C2	C	87.18
24/09/2010	C3	A	82.54
24/09/2010	C3	B	93.94
24/09/2010	C3	C	70.75
24/09/2010	C4	A	93.01
24/09/2010	C4	B	77.90
24/09/2010	C4	C	41.47
26/10/2010	F1	A	36.70
26/10/2010	F1	B	66.78
26/10/2010	F1	C	48.62
26/10/2010	F2	A	82.14
26/10/2010	F2	B	22.39
26/10/2010	F2	C	30.21
26/10/2010	F3	A	69.69
26/10/2010	F3	B	65.72
26/10/2010	F3	C	55.25
26/10/2010	F4	A	85.85
26/10/2010	F4	B	0.00
26/10/2010	F4	C	47.30
26/10/2010	F5	A	48.76
26/10/2010	F5	B	61.34
26/10/2010	F5	C	60.81
26/10/2010	F6	A	37.49
26/10/2010	F6	B	5.70
26/10/2010	F6	C	93.01
26/10/2010	F7	A	68.10
26/10/2010	F7	B	50.74
26/10/2010	F7	C	6.23
26/10/2010	F8	A	60.55
26/10/2010	F8	B	58.69
26/10/2010	F8	C	48.09
26/10/2010	G1	A	20.93
26/10/2010	G1	B	61.08
26/10/2010	G1	C	50.88
26/10/2010	G2	A	37.23
26/10/2010	G2	B	79.23
26/10/2010	G2	C	59.36
26/10/2010	G3	A	45.71
26/10/2010	G3	B	105.07
26/10/2010	G3	C	49.15
26/10/2010	G4	A	39.22
26/10/2010	G4	B	92.08
26/10/2010	G4	C	57.77
26/10/2010	C1	A	7.15
26/10/2010	C1	B	20.27
26/10/2010	C1	C	14.97
26/10/2010	C2	A	2.25
26/10/2010	C2	B	19.61
26/10/2010	C2	C	15.24
26/10/2010	C3	A	9.27
26/10/2010	C3	B	14.84
26/10/2010	C3	C	10.20
26/10/2010	C4	A	19.08
26/10/2010	C4	B	16.16
26/10/2010	C4	C	5.56
26/11/2010	F1	A	5.83
26/11/2010	F1	B	10.86
26/11/2010	F1	C	12.32
26/11/2010	F2	A	38.69
26/11/2010	F2	B	6.36
26/11/2010	F2	C	46.77
26/11/2010	F3	A	22.26
26/11/2010	F3	B	5.96
26/11/2010	F3	C	26.23
26/11/2010	F4	A	30.87
26/11/2010	F4	B	0.00
26/11/2010	F4	C	8.48
26/11/2010	F5	A	24.38
26/11/2010	F5	B	20.14
26/11/2010	F5	C	12.85
26/11/2010	F6	A	7.95
26/11/2010	F6	B	4.50
26/11/2010	F6	C	22.66
26/11/2010	F7	A	21.46
26/11/2010	F7	B	14.84
26/11/2010	F7	C	3.44
26/11/2010	F8	A	10.86
26/11/2010	F8	B	15.90
26/11/2010	F8	C	6.23
26/11/2010	G1	A	17.89
26/11/2010	G1	B	30.61
26/11/2010	G1	C	16.96
26/11/2010	G2	A	5.83
26/11/2010	G2	B	10.60
26/11/2010	G2	C	6.62
26/11/2010	G3	A	15.90
26/11/2010	G3	B	12.45
26/11/2010	G3	C	21.46
26/11/2010	G4	A	13.78
26/11/2010	G4	B	36.30
26/11/2010	G4	C	23.85
26/11/2010	C1	A	0.66
26/11/2010	C1	B	0.66
26/11/2010	C1	C	5.30
26/11/2010	C2	A	0.66
26/11/2010	C2	B	1.32
26/11/2010	C2	C	1.99
26/11/2010	C3	A	1.32
26/11/2010	C3	B	1.32
26/11/2010	C3	C	1.32
26/11/2010	C4	A	2.65
26/11/2010	C4	B	0.66
26/11/2010	C4	C	3.31
14/12/2010	F1	A	0.00
14/12/2010	F1	B	0.00
14/12/2010	F1	C	0.00
14/12/2010	F2	A	0.00
14/12/2010	F2	B	0.00
14/12/2010	F2	C	0.00
14/12/2010	F3	A	0.00
14/12/2010	F3	B	0.00
14/12/2010	F3	C	0.00
14/12/2010	F4	A	0.00
14/12/2010	F4	B	0.00
14/12/2010	F4	C	0.00
14/12/2010	F5	A	0.00
14/12/2010	F5	B	0.00
14/12/2010	F5	C	0.00

14/12/2010	F6	A	0.00
14/12/2010	F6	B	0.00
14/12/2010	F6	C	0.00
14/12/2010	F7	A	0.00
14/12/2010	F7	B	0.00
14/12/2010	F7	C	0.00
14/12/2010	F8	A	0.00
14/12/2010	F8	B	0.00
14/12/2010	F8	C	0.00
14/12/2010	G1	A	0.00
14/12/2010	G1	B	0.00
14/12/2010	G1	C	0.00
14/12/2010	G2	A	0.00
14/12/2010	G2	B	0.00
14/12/2010	G2	C	0.00
14/12/2010	G3	A	0.00
14/12/2010	G3	B	0.00
14/12/2010	G3	C	0.00
14/12/2010	G4	A	0.00
14/12/2010	G4	B	0.00
14/12/2010	G4	C	0.00
14/12/2010	C1	A	0.00
14/12/2010	C1	B	0.00
14/12/2010	C1	C	0.00
14/12/2010	C2	A	0.00
14/12/2010	C2	B	0.00
14/12/2010	C2	C	0.00
14/12/2010	C3	A	0.00
14/12/2010	C3	B	0.00
14/12/2010	C3	C	0.00
14/12/2010	C4	A	0.00
14/12/2010	C4	B	0.00
14/12/2010	C4	C	0.00

Appendix 3 - Leachate nitrogen

Date	Sector	NH4-N (g/m3)	+/-	NO3-N (g/m3)	+/-	TKN (g/m3)	+/-	DON (g/m3)	+/-	TN (g/m3)	+/-	NH4-N (kg/ha)	NO3-N (kg/ha)	TKN (kg/ha)	DON (kg/ha)	TN (ka/ha)
14/01/2010	F1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
14/01/2010	F2	0.0100	0.0067	10.4000	1.3000	1.8200	0.2300	1.8100	0.2367	12.2200	1.5300	0.00	1.01	0.18	0.18	1.19
14/01/2010	F3	0.1050	0.0110	5.2000	0.6300	1.5600	0.2000	1.4550	0.2110	6.7600	0.8300	0.00	0.20	0.06	0.05	0.25
14/01/2010	F4	0.3980	0.0330	2.8500	0.3500	2.7500	0.3400	2.3520	0.3730	5.6000	0.6900	0.01	0.04	0.04	0.03	0.07
14/01/2010	F5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
14/01/2010	F6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
14/01/2010	F7	0.3520	0.0290	8.6000	1.1000	2.2600	0.2800	1.9080	0.3090	10.8600	1.3800	0.03	0.76	0.20	0.17	0.95
14/01/2010	F8	1.1780	0.0950	3.3200	0.3900	3.4600	0.4200	2.2820	0.5150	6.7800	0.8100	0.01	0.04	0.04	0.03	0.08
14/01/2010	G1	0.0100	0.0067	2.2500	0.2800	1.5100	0.2000	1.5000	0.2067	3.7600	0.4800	0.00	0.13	0.09	0.09	0.22
14/01/2010	G2	0.4400	0.0370	7.7700	0.9400	3.0900	0.3800	2.6500	0.4170	10.8600	1.3200	0.02	0.43	0.17	0.15	0.60
14/01/2010	G3	0.0397	0.0074	2.8300	0.3400	2.2300	0.2800	2.1903	0.2874	5.0600	0.6200	0.00	0.06	0.04	0.04	0.10
14/01/2010	G4	0.0100	0.0067	8.0000	0.9700	1.8900	0.2400	1.8800	0.2467	9.8900	1.2100	0.00	1.06	0.25	0.25	1.31
14/01/2010	C1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
14/01/2010	C2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
14/01/2010	C3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
14/01/2010	C4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
18/02/2010	F1	0.0100	0.0067	8.3000	1.0000	1.1300	0.1500	1.1200	0.1567	9.4300	1.1500	0.00	1.70	0.23	0.23	1.94
18/02/2010	F2	0.0100	0.0067	8.9000	1.1000	1.1100	0.1500	1.1000	0.1567	10.0100	1.2500	0.00	3.54	0.44	0.44	3.98
18/02/2010	F3	0.0100	0.0067	5.7300	0.6900	1.1800	0.1600	1.1700	0.1667	6.9100	0.8500	0.01	3.99	0.82	0.81	4.81
18/02/2010	F4	0.0100	0.0067	6.3400	0.7700	1.2000	0.1600	1.1900	0.1667	7.5400	0.9300	0.00	2.35	0.45	0.44	2.80
18/02/2010	F5	0.0100	0.0067	6.7300	0.8100	1.7200	0.2200	1.7100	0.2267	8.4500	1.0300	0.00	0.89	0.23	0.23	1.12
18/02/2010	F6	0.0100	0.0067	7.0300	0.8500	1.7900	0.2300	1.7800	0.2367	8.8200	1.0800	0.00	0.93	0.24	0.24	1.17
18/02/2010	F7	0.0589	0.0082	5.8100	0.7000	1.4600	0.1900	1.4011	0.1982	7.2700	0.8900	0.02	1.87	0.47	0.45	2.34
18/02/2010	F8	0.0700	0.0067	4.5800	0.5600	1.0500	0.1500	0.9800	0.1567	5.6300	0.7100	0.03	1.70	0.39	0.36	2.09
18/02/2010	G1	0.0100	0.0067	2.7900	0.3400	1.4500	0.1900	1.4400	0.1967	4.2400	0.5300	0.00	1.18	0.61	0.61	1.80
18/02/2010	G2	0.0100	0.0067	3.5500	0.4300	1.0700	0.1500	1.0600	0.1567	4.6200	0.5800	0.00	0.55	0.17	0.16	0.71
18/02/2010	G3	0.0100	0.0067	3.3200	0.4000	1.9900	0.2500	1.9800	0.2567	5.3100	0.6500	0.00	0.95	0.57	0.56	1.51
18/02/2010	G4	0.0100	0.0067	7.4500	0.9000	1.6500	0.2100	1.6400	0.2167	9.1000	1.1100	0.00	2.52	0.56	0.55	3.07
18/02/2010	C1	0.1940	0.0170	0.0227	0.0031	1.3100	0.1700	1.1160	0.1870	1.3327	0.1731	0.22	0.03	1.50	1.28	1.52
18/02/2010	C2	0.0144	0.0067	0.0020	0.0017	1.6200	0.2100	1.6056	0.2167	1.6220	0.2117	0.01	0.00	1.56	1.55	1.56
18/02/2010	C3	0.0162	0.0068	0.4740	0.0570	1.5900	0.2000	1.5738	0.2068	2.0640	0.2570	0.00	0.07	0.24	0.24	0.31

18/02/2010	C4	0.0478	0.0077	0.0020	0.0014	1.4900	0.1900	1.4422	0.1977	1.4920	0.1914	0.04	0.00	1.32	1.27	1.32
16/03/2010	F1	0.0100	0.0067	5.5000	0.6600	1.3800	0.1800	1.3700	0.1867	6.8800	0.8400	0.00	0.41	0.10	0.10	0.52
16/03/2010	F2	0.0100	0.0067	6.2500	0.7600	1.1000	0.1500	1.0900	0.1567	7.3500	0.9100	0.00	1.24	0.22	0.22	1.46
16/03/2010	F3	0.0100	0.0067	5.3200	0.6400	1.2100	0.1600	1.2000	0.1667	6.5300	0.8000	0.00	0.82	0.19	0.19	1.01
16/03/2010	F4	0.0584	0.0081	3.1300	0.3800	1.2100	0.1600	1.1516	0.1681	4.3400	0.5400	0.01	0.28	0.11	0.10	0.39
16/03/2010	F5	0.0265	0.0070	4.4100	0.5300	2.6800	0.3300	2.6535	0.3370	7.0900	0.8600	0.00	0.05	0.03	0.03	0.08
16/03/2010	F6	0.0100	0.0067	4.0800	0.4900	1.8700	0.2400	1.8600	0.2467	5.9500	0.7300	0.00	0.36	0.17	0.16	0.53
16/03/2010	F7	0.0132	0.0067	5.9600	0.7200	1.6500	0.2100	1.6368	0.2167	7.6100	0.9300	0.00	0.39	0.11	0.11	0.50
16/03/2010	F8	0.0172	0.0068	3.8700	0.4700	1.3400	0.1800	1.3228	0.1868	5.2100	0.6500	0.00	0.24	0.08	0.08	0.32
16/03/2010	G1	0.0100	0.0067	2.4500	0.3000	1.4300	0.1900	1.4200	0.1967	3.8800	0.4900	0.00	0.23	0.14	0.13	0.37
16/03/2010	G2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
16/03/2010	G3	0.0100	0.0067	3.8500	0.4700	1.8800	0.2400	1.8700	0.2467	5.7300	0.7100	0.00	0.51	0.25	0.25	0.76
16/03/2010	G4	0.0100	0.0067	2.9500	0.3600	1.3900	0.1800	1.3800	0.1867	4.3400	0.5400	0.00	0.21	0.10	0.10	0.32
16/03/2010	C1	0.2870	0.0240	2.1900	0.2700	2.7800	0.3400	2.4930	0.3640	4.9700	0.6100	0.00	0.01	0.02	0.02	0.03
16/03/2010	C2	0.2870	0.0240	2.1900	0.2700	2.7800	0.3400	2.4930	0.3640	4.9700	0.6100	0.00	0.01	0.02	0.02	0.03
16/03/2010	C3	0.2870	0.0240	2.1900	0.2700	2.7800	0.3400	2.4930	0.3640	4.9700	0.6100	0.00	0.01	0.02	0.02	0.03
16/03/2010	C4	0.2870	0.0240	2.1900	0.2700	2.7800	0.3400	2.4930	0.3640	4.9700	0.6100	0.00	0.01	0.02	0.02	0.03
29/04/2010	F1	0.0100	0.0067	4.4400	0.5400	1.0500	0.1400	1.0400	0.1467	5.4900	0.6800	0.00	1.31	0.31	0.31	1.62
29/04/2010	F2	0.0100	0.0067	3.3900	0.4100	0.9200	0.1300	0.9100	0.1367	4.3100	0.5400	0.01	2.03	0.55	0.54	2.58
29/04/2010	F3	0.0100	0.0067	6.1000	0.7400	1.1800	0.1600	1.1700	0.1667	7.2800	0.9000	0.01	3.64	0.70	0.70	4.34
29/04/2010	F4	0.0100	0.0067	3.7600	0.4600	1.1000	0.1500	1.0900	0.1567	4.8600	0.6100	0.00	1.30	0.38	0.38	1.67
29/04/2010	F5	0.0100	0.0067	3.8700	0.4700	2.0000	0.2500	1.9900	0.2567	5.8700	0.7200	0.00	1.15	0.60	0.59	1.75
29/04/2010	F6	0.0100	0.0067	4.4200	0.5400	1.5800	0.2000	1.5700	0.2067	6.0000	0.7400	0.00	0.95	0.34	0.34	1.29
29/04/2010	F7	0.0130	0.0067	8.6000	1.1000	1.6800	0.2200	1.6670	0.2267	10.2800	1.3200	0.00	1.56	0.30	0.30	1.86
29/04/2010	F8	0.0100	0.0067	3.4100	0.4100	1.1000	0.1500	1.0900	0.1567	4.5100	0.5600	0.00	0.83	0.27	0.26	1.10
29/04/2010	G1	0.0100	0.0067	4.6200	0.5600	1.3000	0.1700	1.2900	0.1767	5.9200	0.7300	0.00	2.14	0.60	0.60	2.75
29/04/2010	G2	0.0100	0.0067	1.7300	0.2100	0.8200	0.1200	0.8100	0.1267	2.5500	0.3300	0.00	0.21	0.10	0.10	0.32
29/04/2010	G3	0.0100	0.0067	5.7500	0.6900	1.3500	0.1800	1.3400	0.1867	7.1000	0.8700	0.00	2.10	0.49	0.49	2.59
29/04/2010	G4	0.0100	0.0067	3.3300	0.4100	1.4500	0.1900	1.4400	0.1967	4.7800	0.6000	0.00	1.32	0.58	0.57	1.90
29/04/2010	C1	0.0100	0.0067	1.3900	0.1700	1.8700	0.2400	1.8600	0.2467	3.2600	0.4100	0.00	0.11	0.15	0.15	0.26
29/04/2010	C2	0.0100	0.0067	1.4000	0.1700	1.7100	0.2200	1.7000	0.2267	3.1100	0.3900	0.01	1.44	1.76	1.75	3.20

29/04/2010	C3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
29/04/2010	C4	0.0100	0.0067	1.1400	0.1400	1.3100	0.1700	1.3000	0.1767	2.4500	0.3100	0.01	0.98	1.13	1.12	2.12

31/05/2010	F1	0.0100	0.0067	2.7700	0.3400	1.0100	0.1400	1.0000	0.1467	3.7800	0.4800	0.01	2.20	0.80	0.79	3.00
31/05/2010	F2	0.0100	0.0067	1.8700	0.2300	1.0500	0.1400	1.0400	0.1467	2.9200	0.3700	0.01	2.50	1.41	1.39	3.91
31/05/2010	F3	0.0100	0.0067	2.5900	0.3200	1.1500	0.1600	1.1400	0.1667	3.7400	0.4800	0.01	3.25	1.44	1.43	4.69
31/05/2010	F4	0.0100	0.0067	2.3700	0.2900	1.0100	0.1400	1.0000	0.1467	3.3800	0.4300	0.01	2.76	1.18	1.17	3.94
31/05/2010	F5	0.0100	0.0067	2.1900	0.2700	1.2500	0.1700	1.2400	0.1767	3.4400	0.4400	0.01	1.68	0.96	0.95	2.64
31/05/2010	F6	0.0100	0.0067	1.5200	0.1900	1.4000	0.1800	1.3900	0.1867	2.9200	0.3700	0.01	0.93	0.86	0.85	1.79
31/05/2010	F7	0.0130	0.0067	2.1100	0.2600	1.2500	0.1700	1.2370	0.1767	3.3600	0.4300	0.01	2.41	1.43	1.41	3.83
31/05/2010	F8	0.0100	0.0067	3.0900	0.3800	1.2300	0.1600	1.2200	0.1667	4.3200	0.5400	0.01	2.44	0.97	0.96	3.42
31/05/2010	G1	0.0100	0.0067	1.3600	0.1700	1.3900	0.1800	1.3800	0.1867	2.7500	0.3500	0.01	1.82	1.86	1.84	3.67
31/05/2010	G2	0.0100	0.0067	0.6510	0.0790	0.8100	0.1200	0.8000	0.1267	1.4610	0.1990	0.01	0.60	0.75	0.74	1.36
31/05/2010	G3	0.0422	0.0075	2.2500	0.2700	1.3700	0.1800	1.3278	0.1875	3.6200	0.4500	0.06	2.95	1.80	1.74	4.75
31/05/2010	G4	0.0268	0.0070	1.2200	0.1500	1.5700	0.2000	1.5432	0.2070	2.7900	0.3500	0.04	1.95	2.50	2.46	4.45
31/05/2010	C1	0.0100	0.0067	0.1670	0.0210	0.4650	0.0820	0.4550	0.0887	0.6320	0.1030	0.01	0.10	0.27	0.26	0.36
31/05/2010	C2	0.0140	0.0067	0.4320	0.0520	0.6470	0.0990	0.6330	0.1057	1.0790	0.1510	0.01	0.22	0.33	0.33	0.56
31/05/2010	C3	0.0000	0.0067	0.1810	0.0220	0.6600	0.1000	0.6600	0.1067	0.8410	0.1220	0.00	0.06	0.23	0.23	0.29
31/05/2010	C4	0.0100	0.0067	1.2800	0.1600	0.9700	0.1400	0.9600	0.1467	2.2500	0.3000	0.00	0.27	0.20	0.20	0.47

9/06/2010	F1	0.0100	0.0201	1.2303	0.4460	0.7277	0.3330	0.7177	0.3531	1.9580	0.7790	0.01	0.75	0.44	0.44	1.19
9/06/2010	F2	0.0100	0.0201	0.8023	0.2970	0.7483	0.3450	0.7383	0.3651	1.5507	0.6420	0.01	0.49	0.46	0.45	0.94
9/06/2010	F3	0.0100	0.0201	0.8650	0.3140	1.1433	0.4700	1.1333	0.4901	2.0083	0.7840	0.01	1.15	1.52	1.51	2.67
9/06/2010	F4	0.0100	0.0134	1.0170	0.2500	1.1450	0.3100	1.1350	0.3234	2.1620	0.5600	0.01	1.17	1.31	1.30	2.48
9/06/2010	F5	0.0100	0.0201	0.4793	0.1740	0.7300	0.3290	0.7200	0.3491	1.2093	0.5030	0.01	0.30	0.45	0.44	0.75
9/06/2010	F6	0.0183	0.0206	0.8967	0.3260	1.4767	0.5800	1.4583	0.6006	2.3733	0.9060	0.01	0.56	0.92	0.91	1.48
9/06/2010	F7	1.0067	0.0804	1.2913	0.4750	2.0300	0.7900	1.0233	0.8704	3.3213	1.2650	0.67	0.86	1.35	0.68	2.21
9/06/2010	F8	0.0100	0.0201	0.8713	0.3320	1.1333	0.4700	1.1233	0.4901	2.0047	0.8020	0.01	0.53	0.69	0.68	1.22
9/06/2010	G1	0.0600	0.0284	0.6247	0.2320	1.7133	0.6600	1.6533	0.6884	2.3380	0.8920	0.06	0.59	1.61	1.56	2.20
9/06/2010	G2	0.0100	0.0201	0.1939	0.0707	0.7517	0.3360	0.7417	0.3561	0.9456	0.4067	0.01	0.12	0.45	0.44	0.57
9/06/2010	G3	1.0282	0.2643	0.6190	0.2280	2.0540	0.9900	1.0258	1.2543	2.6730	1.2180	1.05	0.63	2.09	1.05	2.72
9/06/2010	G4	0.2120	0.0597	0.6890	0.2540	2.2433	0.8500	2.0313	0.9097	2.9323	1.1040	0.21	0.70	2.27	2.06	2.97
9/06/2010	C1	0.0110	0.0201	0.0789	0.0304	0.2883	0.2110	0.2773	0.2311	0.3673	0.2414	0.01	0.04	0.15	0.15	0.20

9/06/2010	C2	0.0100	0.0201	0.2976	0.0297	0.5573	0.2830	0.5473	0.3031	0.8549	0.3127	0.01	0.17	0.31	0.31	0.48
9/06/2010	C3	0.0100	0.0201	0.0035	0.0043	0.4393	0.2420	0.4293	0.2621	0.4429	0.2463	0.00	0.00	0.21	0.21	0.22
9/06/2010	C4	0.0100	0.0201	0.3753	0.1360	0.6370	0.3070	0.6270	0.3271	1.0123	0.4430	0.00	0.11	0.19	0.19	0.31

22/06/2010	F1	0.0100	0.0067	0.4950	0.0600	0.8700	0.1300	0.8600	0.1367	1.3650	0.1900	0.01	0.26	0.45	0.45	0.71
22/06/2010	F2	0.0100	0.0067	0.3440	0.0420	1.3900	0.1800	1.3800	0.1867	1.7340	0.2220	0.01	0.19	0.76	0.76	0.95
22/06/2010	F3	0.0100	0.0067	0.6660	0.0800	1.2100	0.1600	1.2000	0.1667	1.8760	0.2400	0.00	0.24	0.43	0.43	0.67
22/06/2010	F4	0.0100	0.0067	0.3350	0.0410	0.8600	0.1200	0.8500	0.1267	1.1950	0.1610	0.00	0.08	0.21	0.21	0.29
22/06/2010	F5	0.0100	0.0067	0.3620	0.0440	1.2800	0.1700	1.2700	0.1767	1.6420	0.2140	0.00	0.17	0.60	0.60	0.77
22/06/2010	F6	0.0100	0.0067	0.2960	0.0360	0.9100	0.1300	0.9000	0.1367	1.2060	0.1660	0.00	0.05	0.16	0.16	0.21
22/06/2010	F7	0.0100	0.0067	0.1850	0.0230	1.2200	0.1600	1.2100	0.1667	1.4050	0.1830	0.01	0.10	0.64	0.64	0.74
22/06/2010	F8	0.0100	0.0067	0.5140	0.0620	1.0700	0.1500	1.0600	0.1567	1.5840	0.2120	0.00	0.25	0.52	0.51	0.77
22/06/2010	G1	0.0100	0.0067	0.6320	0.0076	1.0000	0.1400	0.9900	0.1467	1.6320	0.1476	0.01	0.67	1.07	1.06	1.74
22/06/2010	G2	0.0100	0.0067	0.1120	0.0140	0.8800	0.1300	0.8700	0.1367	0.9920	0.1440	0.01	0.07	0.53	0.53	0.60
22/06/2010	G3	0.0196	0.0068	0.5800	0.0700	1.4900	0.1900	1.4704	0.1968	2.0700	0.2600	0.02	0.51	1.30	1.28	1.81
22/06/2010	G4	0.0472	0.0077	0.9700	0.1200	1.4200	0.1900	1.3728	0.1977	2.3900	0.3100	0.06	1.22	1.78	1.72	3.00
22/06/2010	C1	0.0100	0.0067	0.0741	0.0090	0.4010	0.0770	0.3910	0.0837	0.4751	0.0860	0.00	0.03	0.18	0.18	0.21
22/06/2010	C2	0.0100	0.0067	0.0703	0.0086	0.6100	0.0950	0.6000	0.1017	0.6803	0.1036	0.00	0.03	0.26	0.26	0.29
22/06/2010	C3	0.0100	0.0067	0.0002	0.0014	0.4600	0.0820	0.4500	0.0887	0.4602	0.0834	0.00	0.00	0.19	0.18	0.19
22/06/2010	C4	0.0100	0.0067	0.0394	0.0050	0.3960	0.0770	0.3860	0.0837	0.4354	0.0820	0.00	0.01	0.07	0.07	0.07

9/07/2010	F1	0.0100	0.0067	0.3210	0.0390	1.1000	0.1500	1.0900	0.1567	1.4210	0.1890	0.00	0.10	0.33	0.33	0.43
9/07/2010	F2	0.0100	0.0067	0.2730	0.0330	1.2700	0.1700	1.2600	0.1767	1.5430	0.2030	0.00	0.07	0.31	0.30	0.37
9/07/2010	F3	0.0144	0.0067	0.6410	0.0770	0.8600	0.1200	0.8456	0.1267	1.5010	0.1970	0.01	0.26	0.35	0.34	0.61
9/07/2010	F4	0.0100	0.0067	0.2740	0.0330	1.0600	0.1500	1.0500	0.1567	1.3340	0.1830	0.00	0.09	0.34	0.34	0.43
9/07/2010	F5	0.0100	0.0067	0.2670	0.0330	1.2100	0.1600	1.2000	0.1667	1.4770	0.1930	0.00	0.07	0.34	0.33	0.41
9/07/2010	F6	0.0100	0.0067	0.2720	0.0330	1.1500	0.1600	1.1400	0.1667	1.4220	0.1930	0.00	0.07	0.29	0.29	0.36
9/07/2010	F7	0.0343	0.0072	0.1950	0.0240	0.9900	0.1400	0.9557	0.1472	1.1850	0.1640	0.01	0.04	0.21	0.20	0.25
9/07/2010	F8	0.0100	0.0067	0.3790	0.0460	0.8400	0.1200	0.8300	0.1267	1.2190	0.1660	0.00	0.08	0.17	0.17	0.25
9/07/2010	G1	0.0269	0.0070	1.3000	0.1600	0.9500	0.1300	0.9231	0.1370	2.2500	0.2900	0.02	1.02	0.75	0.72	1.77
9/07/2010	G2	0.0100	0.0067	0.1240	0.0150	1.1300	0.1500	1.1200	0.1567	1.2540	0.1650	0.00	0.06	0.51	0.50	0.56
9/07/2010	G3	0.0100	0.0067	0.5030	0.0610	1.1200	0.1500	1.1100	0.1567	1.6230	0.2110	0.01	0.31	0.69	0.68	1.00
9/07/2010	G4	0.0100	0.0067	0.6020	0.0730	1.5700	0.2000	1.5600	0.2067	2.1720	0.2730	0.00	0.30	0.78	0.77	1.08
9/07/2010	C1	0.0208	0.0069	0.0650	0.0080	0.4210	0.0790	0.4002	0.0859	0.4860	0.0870	0.01	0.02	0.11	0.11	0.13

9/07/2010	C2	0.0100	0.0067	0.0870	0.0110	0.6340	0.0970	0.6240	0.1037	0.7210	0.1080	0.00	0.03	0.20	0.19	0.22
9/07/2010	C3	0.0100	0.0067	0.0033	0.0014	0.3430	0.0730	0.3330	0.0797	0.3463	0.0744	0.00	0.00	0.08	0.08	0.08
9/07/2010	C4	0.0100	0.0067	0.0700	0.0085	0.3400	0.0730	0.3300	0.0797	0.4100	0.0815	0.00	0.01	0.05	0.05	0.06
18/08/2010	F1	0.0100	0.0067	0.5090	0.0620	1.3600	0.1800	1.3500	0.1867	1.8690	0.2420	0.01	0.54	1.45	1.44	1.99
18/08/2010	F2	0.0100	0.0067	0.5890	0.0710	1.3500	0.1800	1.3400	0.1867	1.9390	0.2510	0.01	0.66	1.51	1.50	2.18
18/08/2010	F3	0.0100	0.0067	1.0200	0.1300	1.2600	0.1700	1.2500	0.1767	2.2800	0.3000	0.02	1.58	1.95	1.93	3.52
18/08/2010	F4	0.0100	0.0067	0.4580	0.0550	1.3200	0.1700	1.3100	0.1767	1.7780	0.2250	0.01	0.50	1.45	1.44	1.95
18/08/2010	F5	0.0100	0.0067	0.4330	0.0520	1.1600	0.1600	1.1500	0.1667	1.5930	0.2120	0.02	0.67	1.79	1.77	2.45
18/08/2010	F6	0.0100	0.0067	0.5480	0.0660	1.0800	0.1500	1.0700	0.1567	1.6280	0.2160	0.01	0.31	0.61	0.61	0.92
18/08/2010	F7	0.0100	0.0067	0.3030	0.0370	1.1800	0.1600	1.1700	0.1667	1.4830	0.1970	0.01	0.24	0.95	0.94	1.19
18/08/2010	F8	0.0100	0.0067	0.5300	0.0640	1.3100	0.1700	1.3000	0.1767	1.8400	0.2340	0.01	0.45	1.12	1.11	1.57
18/08/2010	G1	0.0321	0.0071	1.4500	0.1800	0.7500	0.1100	0.7179	0.1171	2.2000	0.2900	0.05	2.48	1.28	1.23	3.76
18/08/2010	G2	0.0407	0.0074	0.1870	0.0230	0.3640	0.0750	0.3233	0.0824	0.5510	0.0980	0.07	0.30	0.59	0.52	0.89
18/08/2010	G3	0.0100	0.0067	0.7710	0.0930	0.7900	0.1200	0.7800	0.1267	1.5610	0.2130	0.02	1.39	1.42	1.40	2.81
18/08/2010	G4	0.1070	0.0110	0.5930	0.0720	1.1800	0.1600	1.0730	0.1710	1.7730	0.2320	0.18	1.01	2.01	1.82	3.01
18/08/2010	C1	0.0100	0.0067	0.0558	0.0069	0.3710	0.0750	0.3610	0.0817	0.4268	0.0819	0.01	0.06	0.41	0.40	0.48
18/08/2010	C2	0.0100	0.0067	0.4790	0.0059	0.5210	0.0870	0.5110	0.0937	1.0000	0.0929	0.01	0.51	0.55	0.54	1.06
18/08/2010	C3	0.0100	0.0067	0.0127	0.0021	0.4470	0.0810	0.4370	0.0877	0.4597	0.0831	0.01	0.01	0.38	0.37	0.39
18/08/2010	C4	0.0100	0.0067	0.1170	0.0150	0.4970	0.0850	0.4870	0.0917	0.6140	0.1000	0.01	0.07	0.31	0.31	0.39
8/09/2010	F1	0.0100	0.0067	0.3930	0.0480	1.4500	0.1900	1.4400	0.1967	1.8430	0.2380	0.01	0.28	1.02	1.01	1.30
8/09/2010	F2	0.0100	0.0067	0.3170	0.0390	1.3200	0.1700	1.3100	0.1767	1.6370	0.2090	0.01	0.19	0.77	0.77	0.96
8/09/2010	F3	0.0100	0.0067	0.5300	0.0640	1.3500	0.1800	1.3400	0.1867	1.8800	0.2440	0.01	0.44	1.12	1.12	1.57
8/09/2010	F4	0.0100	0.0067	0.4440	0.0540	1.8300	0.2300	1.8200	0.2367	2.2740	0.2840	0.01	0.29	1.19	1.19	1.48
8/09/2010	F5	0.0100	0.0067	0.3290	0.0400	1.3200	0.1700	1.3100	0.1767	1.6490	0.2100	0.01	0.19	0.75	0.74	0.94
8/09/2010	F6	0.0100	0.0067	0.4680	0.0570	1.4400	0.1900	1.4300	0.1967	1.9080	0.2470	0.00	0.20	0.62	0.62	0.83
8/09/2010	F7	0.0160	0.0068	0.3010	0.0370	1.5000	0.1900	1.4840	0.1968	1.8010	0.2270	0.00	0.07	0.34	0.33	0.41
8/09/2010	F8	0.0100	0.0067	0.5030	0.0610	1.5800	0.2000	1.5700	0.2067	2.0830	0.2610	0.01	0.27	0.84	0.83	1.11
8/09/2010	G1	0.0100	0.0067	0.9200	0.1100	0.8300	0.1200	0.8200	0.1267	1.7500	0.2300	0.01	0.94	0.85	0.84	1.79
8/09/2010	G2	0.0100	0.0067	0.1820	0.0220	0.8300	0.1200	0.8200	0.1267	1.0120	0.1420	0.01	0.14	0.65	0.65	0.80
8/09/2010	G3	0.0100	0.0067	0.5050	0.0610	1.0600	0.1500	1.0500	0.1567	1.5650	0.2110	0.01	0.44	0.92	0.91	1.35
8/09/2010	G4	0.0691	0.0087	1.9700	0.2400	1.6700	0.2100	1.6009	0.2187	3.6400	0.4500	0.04	1.02	0.87	0.83	1.89

8/09/2010	C1	0.0100	0.0067	0.0703	0.0086	0.4540	0.0820	0.4440	0.0887	0.5243	0.0906	0.00	0.02	0.11	0.10	0.12
8/09/2010	C2	0.0100	0.0067	0.0566	0.0070	0.7200	0.1100	0.7100	0.1167	0.7766	0.1170	0.00	0.01	0.17	0.17	0.18
8/09/2010	C3	0.0113	0.0067	0.0090	0.0017	0.5740	0.0092	0.5627	0.0159	0.5830	0.0109	0.00	0.00	0.09	0.08	0.09
8/09/2010	C4	0.0165	0.0068	0.1860	0.0230	0.9300	0.1300	0.9135	0.1368	1.1160	0.1530	0.00	0.03	0.17	0.17	0.20
24/09/2010	F1	0.0100	0.0067	0.3620	0.0440	0.7000	0.1100	0.6900	0.1167	1.0620	0.1540	0.01	0.33	0.65	0.64	0.98
24/09/2010	F2	0.0100	0.0067	0.2840	0.0350	1.0600	0.1500	1.0500	0.1567	1.3440	0.1850	0.01	0.28	1.04	1.03	1.32
24/09/2010	F3	0.0308	0.0071	0.5380	0.0650	1.1600	0.1600	1.1292	0.1671	1.6980	0.2250	0.04	0.63	1.37	1.33	2.00
24/09/2010	F4	0.0100	0.0067	0.4220	0.0510	1.2700	0.1700	1.2600	0.1767	1.6920	0.2210	0.01	0.45	1.37	1.36	1.82
24/09/2010	F5	0.0100	0.0067	0.2230	0.0270	1.1900	0.1600	1.1800	0.1667	1.4130	0.1870	0.01	0.22	1.16	1.15	1.37
24/09/2010	F6	0.0100	0.0067	0.3570	0.0430	1.2600	0.1700	1.2500	0.1767	1.6170	0.2130	0.01	0.27	0.95	0.94	1.22
24/09/2010	F7	0.0100	0.0067	0.4000	0.0480	1.2200	0.1600	1.2100	0.1667	1.6200	0.2080	0.01	0.31	0.95	0.94	1.25
24/09/2010	F8	0.0100	0.0067	0.4180	0.0510	1.4800	0.1900	1.4700	0.1967	1.8980	0.2410	0.01	0.42	1.49	1.48	1.92
24/09/2010	G1	0.0990	0.0110	1.1300	0.1400	1.0800	0.1500	0.9810	0.1610	2.2100	0.2900	0.13	1.44	1.38	1.25	2.81
24/09/2010	G2	0.1610	0.0150	0.2530	0.0310	0.7400	0.1100	0.5790	0.1250	0.9930	0.1410	0.18	0.29	0.84	0.66	1.13
24/09/2010	G3	0.0100	0.0067	0.9400	0.1200	0.9400	0.1300	0.9300	0.1367	1.8800	0.2500	0.01	1.36	1.36	1.34	2.71
24/09/2010	G4	0.0842	0.0095	3.2100	0.3900	1.6200	0.2100	1.5358	0.2195	4.8300	0.6000	0.10	3.71	1.87	1.78	5.58
24/09/2010	C1	0.0100	0.0067	0.0940	0.0120	0.4100	0.0780	0.4000	0.0847	0.5040	0.0900	0.01	0.08	0.34	0.33	0.42
24/09/2010	C2	0.0100	0.0067	0.0225	0.0031	0.6260	0.0970	0.6160	0.1037	0.6485	0.1001	0.01	0.02	0.44	0.43	0.45
24/09/2010	C3	0.0100	0.0067	0.0105	0.0019	0.5360	0.0880	0.5260	0.0947	0.5465	0.0899	0.01	0.01	0.44	0.43	0.45
24/09/2010	C4	0.0100	0.0067	0.0646	0.0079	0.5360	0.0880	0.5260	0.0947	0.6006	0.0959	0.01	0.05	0.38	0.37	0.43
26/10/2010	F1	0.0100	0.0067	0.2740	0.0330	0.8600	0.1200	0.8500	0.1267	1.1340	0.1530	0.01	0.14	0.44	0.43	0.57
26/10/2010	F2	0.0100	0.0067	0.1360	0.0170	0.7800	0.1200	0.7700	0.1267	0.9160	0.1370	0.00	0.06	0.35	0.35	0.41
26/10/2010	F3	0.0100	0.0067	0.4420	0.0540	0.9500	0.1300	0.9400	0.1367	1.3920	0.1840	0.01	0.28	0.60	0.60	0.88
26/10/2010	F4	0.0100	0.0067	0.2990	0.0360	1.4100	0.1800	1.4000	0.1867	1.7090	0.2160	0.01	0.20	0.94	0.93	1.14
26/10/2010	F5	0.0100	0.0070	0.0767	0.0093	1.1300	0.1500	1.1200	0.1570	1.2067	0.1593	0.01	0.04	0.64	0.64	0.69
26/10/2010	F6	0.0100	0.0067	0.0805	0.0098	1.1200	0.1500	1.1100	0.1567	1.2005	0.1598	0.00	0.04	0.51	0.50	0.55
26/10/2010	F7	0.0100	0.0067	0.2750	0.0330	1.0300	0.1400	1.0200	0.1467	1.3050	0.1730	0.00	0.11	0.43	0.43	0.54
26/10/2010	F8	0.0100	0.0067	0.2590	0.0320	1.1800	0.1600	1.1700	0.1667	1.4390	0.1920	0.01	0.14	0.66	0.65	0.80
26/10/2010	G1	0.0100	0.0067	0.8180	0.0990	0.9500	0.1300	0.9400	0.1367	1.7680	0.2290	0.00	0.36	0.42	0.42	0.78
26/10/2010	G2	0.0100	0.0067	0.2700	0.0330	0.0670	0.1100	0.0570	0.1167	0.3370	0.1430	0.01	0.16	0.04	0.03	0.20
26/10/2010	G3	0.0100	0.0067	0.8500	0.1100	0.9100	0.1300	0.9000	0.1367	1.7600	0.2400	0.01	0.57	0.61	0.60	1.17

26/10/2010	G4	0.0107	0.0067	1.8000	0.2200	1.3200	0.1700	1.3093	0.1767	3.1200	0.3900	0.01	1.13	0.83	0.83	1.97
26/10/2010	C1	0.0100	0.0067	0.0277	0.0036	0.4700	0.0830	0.4600	0.0897	0.4977	0.0866	0.00	0.00	0.07	0.07	0.07
26/10/2010	C2	0.0100	0.0067	0.2180	0.0030	0.4630	0.0820	0.4530	0.0887	0.6810	0.0850	0.00	0.03	0.06	0.06	0.08
26/10/2010	C3	0.0100	0.0067	0.0020	0.0014	0.5860	0.0930	0.5760	0.0997	0.5880	0.0944	0.00	0.00	0.07	0.07	0.07
26/10/2010	C4	0.0100	0.0067	0.0635	0.0078	0.4080	0.0780	0.3980	0.0847	0.4715	0.0858	0.00	0.01	0.06	0.05	0.06
26/11/2010	F1	0.0100	0.0067	0.2090	0.0260	1.4800	0.1900	1.4700	0.1967	1.6890	0.2160	0.00	0.02	0.14	0.14	0.16
26/11/2010	F2	0.0100	0.0067	0.2030	0.0250	0.8300	0.1200	0.8200	0.1267	1.0330	0.1450	0.00	0.06	0.25	0.25	0.32
26/11/2010	F3	0.0100	0.0067	0.5360	0.0650	1.0400	0.1400	1.0300	0.1467	1.5760	0.2050	0.00	0.10	0.19	0.19	0.29
26/11/2010	F4	0.0219	0.0069	0.2500	0.0310	1.3800	0.1800	1.3581	0.1869	1.6300	0.2110	0.00	0.05	0.27	0.27	0.32
26/11/2010	F5	0.0100	0.0067	0.0427	0.0053	1.0200	0.1400	1.0100	0.1467	1.0627	0.1453	0.00	0.01	0.20	0.19	0.20
26/11/2010	F6	0.0100	0.0067	0.0298	0.0039	1.0800	0.1500	1.0700	0.1567	1.1098	0.1539	0.00	0.00	0.13	0.13	0.13
26/11/2010	F7	0.0100	0.0067	0.2260	0.0280	1.0700	0.1500	1.0600	0.1567	1.2960	0.1780	0.00	0.03	0.14	0.14	0.17
26/11/2010	F8	0.0532	0.0079	0.2070	0.0250	1.0300	0.1400	0.9768	0.1479	1.2370	0.1650	0.01	0.02	0.11	0.11	0.14
26/11/2010	G1	0.0100	0.0067	0.8900	0.1100	1.1000	0.1500	1.0900	0.1567	1.9900	0.2600	0.00	0.19	0.24	0.24	0.43
26/11/2010	G2	0.0611	0.0083	0.1600	0.0200	0.9300	0.1300	0.8689	0.1383	1.0900	0.1500	0.00	0.01	0.07	0.07	0.08
26/11/2010	G3	0.0620	0.0083	0.8500	0.1100	1.1600	0.1600	1.0980	0.1683	2.0100	0.2700	0.01	0.14	0.19	0.18	0.33
26/11/2010	G4	0.0100	0.0067	1.5100	0.1900	1.4600	0.1900	1.4500	0.1967	2.9700	0.3800	0.00	0.37	0.36	0.36	0.73
26/11/2010	C1	0.0563	0.0080	0.1360	0.0170	0.0870	0.1300	0.0307	0.1380	0.2230	0.1470	0.00	0.00	0.00	0.00	0.00
26/11/2010	C2	0.0433	0.0075	0.1580	0.0190	1.8900	0.2400	1.8467	0.2475	2.0480	0.2590	0.00	0.00	0.03	0.02	0.03
26/11/2010	C3	0.0514	0.0078	0.0235	0.0032	1.0400	0.1400	0.9886	0.1478	1.0635	0.1432	0.00	0.00	0.01	0.01	0.01
26/11/2010	C4	0.7880	0.0640	0.3380	0.0410	2.1700	0.2700	1.3820	0.3340	2.5080	0.3110	0.02	0.01	0.05	0.03	0.06
14/12/2010	F1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
14/12/2010	F2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
14/12/2010	F3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
14/12/2010	F4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
14/12/2010	F5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
14/12/2010	F6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
14/12/2010	F7	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
14/12/2010	F8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
14/12/2010	G1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
14/12/2010	G2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
14/12/2010	G3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00

14/12/2010	G4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
14/12/2010	C1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
14/12/2010	C2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
14/12/2010	C3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00
14/12/2010	C4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00

Appendix 4 - Individual measurements, June 2010

Date	Sector		NH4-N (g m/3)	+/-	NOx-N (g/m3)	+/-	TKN (g/m3)	+/-	DON (g/m3)	+/-	TN	+/-	Drainage (mm)	NH4-N (kg/ha)	NOx-N (kg/ha)	TKN (kg/ha)	DON (kg/ha)	TN (kg/ha)
9/06/2010	F1	A	0.01	0.0067	2.32	0.28	1.333	0.073	1.323	0.0663	3.653	0.353	42	0.00	0.98	0.56	0.56	1.54
9/06/2010	F1	B	0.01	0.0067	0.57	0.0069	1.03	0.14	1.02	0.1333	1.6	0.1469	73	0.01	0.41	0.75	0.74	1.16
9/06/2010	F1	C	0.01	0.0067	0.801	0.097	0.82	0.12	0.81	0.1133	1.621	0.217	67	0.01	0.54	0.55	0.55	1.09
9/06/2010	F2	A	0.01	0.0067	0.253	0.031	0.98	0.14	0.97	0.1333	1.233	0.171	91	0.01	0.23	0.89	0.88	1.12
9/06/2010	F2	B	0.01	0.0067	0.794	0.096	0.89	0.13	0.88	0.1233	1.684	0.226	58	0.01	0.46	0.52	0.51	0.98
9/06/2010	F2	C	0.01	0.0067	1.36	0.17	0.375	0.075	0.365	0.0683	1.735	0.245	34	0.00	0.46	0.13	0.12	0.58
9/06/2010	F3	A	0.01	0.0067	0.92	0.11	1.08	0.15	1.07	0.1433	2	0.26	142	0.01	1.30	1.53	1.52	2.83
9/06/2010	F3	B	0.01	0.0067	0.99	0.12	1.1	0.15	1.09	0.1433	2.09	0.27	115	0.01	1.14	1.27	1.26	2.41
9/06/2010	F3	C	0.01	0.0067	0.695	0.084	1.25	0.17	1.24	0.1633	1.945	0.254	141	0.01	0.98	1.77	1.75	2.75
9/06/2010	F4	A	0.01	0.0067	0.244	0.03	0.83	0.12	0.82	0.1133	1.074	0.15	145	0.01	0.35	1.20	1.19	1.55
9/06/2010	F4	B	0	0	0	0	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
9/06/2010	F4	C	0.01	0.067	1.79	0.22	1.46	0.19	1.45	0.123	3.25	0.41	85	0.01	1.52	1.24	1.23	2.75
9/06/2010	F5	A	0.01	0.0067	0.252	0.031	0.584	0.093	0.574	0.0863	0.836	0.124	45	0.00	0.11	0.26	0.26	0.38
9/06/2010	F5	B	0.01	0.0067	0.422	0.051	0.616	0.096	0.606	0.0893	1.038	0.147	73	0.01	0.31	0.45	0.44	0.76
9/06/2010	F5	C	0.01	0.0067	0.764	0.092	0.99	0.14	0.98	0.1333	1.754	0.232	67	0.01	0.52	0.67	0.66	1.18
9/06/2010	F6	A	0.035	0.0072	0.275	0.034	1.05	0.14	1.015	0.1328	1.325	0.174	31	0.01	0.08	0.32	0.31	0.41
9/06/2010	F6	B	0.01	0.0067	1.99	0.24	1.69	0.22	1.68	0.2133	3.68	0.46	5	0.00	0.09	0.08	0.08	0.17
9/06/2010	F6	C	0.01	0.0067	0.43	0.052	1.69	0.22	1.68	0.2133	2.115	0.272	152	0.02	0.65	2.57	2.56	3.22
9/06/2010	F7	A	0.01	0.0067	0.10	0.012	0.87	0.13	0.86	0.1233	0.967	0.142	93	0.01	0.09	0.81	0.80	0.90
9/06/2010	F7	B	0.01	0.0067	0.61	0.073	1.05	0.15	1.04	0.1433	1.657	0.223	82	0.01	0.50	0.86	0.85	1.36
9/06/2010	F7	C	3.04	0.25	3.17	0.39	4.17	0.51	1.13	0.26	7.34	0.9	25	0.76	0.79	1.04	0.28	1.84
9/06/2010	F8	A	0.01	0.0067	0.85	0.11	0.97	0.14	0.96	0.1333	1.82	0.25	74	0.01	0.63	0.71	0.71	1.34
9/06/2010	F8	B	0.01	0.0067	1.17	0.015	0.74	0.11	0.73	0.1033	1.91	0.125	62	0.01	0.72	0.46	0.45	1.18
9/06/2010	F8	C	0.01	0.0067	0.59	0.072	1.69	0.22	1.68	0.2133	2.284	0.292	47	0.00	0.28	0.79	0.79	1.07
9/06/2010	G1	A	0.01	0.0067	0.87	0.11	1.38	0.18	1.37	0.1733	2.25	0.29	66	0.01	0.57	0.91	0.90	1.48
9/06/2010	G1	B	0.16	0.015	0.64	0.077	2.22	0.28	2.06	0.265	2.857	0.357	135	0.22	0.86	3.00	2.78	3.86
9/06/2010	G1	C	0.01	0.0067	0.37	0.045	1.54	0.2	1.53	0.1933	1.907	0.245	82	0.01	0.30	1.26	1.25	1.56
9/06/2010	G2	A	0.01	0.0067	0.29	0.0037	0.51	0.086	0.495	0.0793	0.793	0.0897	67	0.01	0.19	0.34	0.33	0.53
9/06/2010	G2	B	0.01	0.0067	0.18	0.022	0.89	0.13	0.88	0.1233	1.069	0.152	56	0.01	0.10	0.50	0.49	0.59
9/06/2010	G2	C	0.01	0.0067	0.37	0.045	0.86	0.12	0.85	0.1133	1.234	0.165	57	0.01	0.21	0.49	0.48	0.70
9/06/2010	G3	A	3.03	0.25	0.97	0.12	4.14	0.51	1.11	0.26	5.11	0.63	139	4.22	1.35	5.76	1.54	7.11
9/06/2010	G3	B	0.04	0.0076	0.30	0.037	1.82	0.23	1.7754	0.2224	2.124	0.267	93	0.04	0.28	1.70	1.66	1.98
9/06/2010	G3	C	0.01	0.0067	0.58	0.071	2.02	0.25	2.01	0.2433	2.603	0.321	73	0.01	0.43	1.48	1.48	1.91

9/06/2010	G4	A	0.01	0.0067	0.27	0.033	1.90	0.24	1.89	0.2333	2.173	0.273	97	0.01	0.26	1.84	1.83	2.10
9/06/2010	G4	B	0.23	0.02	0.50	0.061	2.38	0.3	2.151	0.28	2.884	0.361	116	0.26	0.58	2.75	2.49	3.33
9/06/2010	G4	C	0.40	0.033	1.29	1.16	2.45	0.31	2.053	0.277	3.74	1.47	91	0.36	1.18	2.24	1.87	3.41
9/06/2010	C1	A	0.01	0.0067	0.01	0.002	0.38	0.076	0.364	0.0693	0.3888	0.078	33	0.00	0.00	0.13	0.12	0.13
9/06/2010	C1	B	0.01	0.0067	0.00	0.0014	0.20	0.065	0.193	0.0583	0.205	0.0664	65	0.01	0.00	0.13	0.13	0.13
9/06/2010	C1	C	0.01	0.0067	0.22	0.027	0.29	0.07	0.275	0.0633	0.508	0.097	61	0.01	0.14	0.18	0.17	0.31
9/06/2010	C2	A	0.01	0.0067	0.06	0.0069	0.39	0.077	0.382	0.0703	0.4477	0.0839	35	0.00	0.02	0.14	0.13	0.16
9/06/2010	C2	B	0.01	0.0067	0.07	0.0088	0.90	0.13	0.89	0.1233	0.9725	0.1388	71	0.01	0.05	0.64	0.64	0.69
9/06/2010	C2	C	0.01	0.0067	0.11	0.014	0.38	0.076	0.37	0.0693	0.492	0.09	61	0.01	0.07	0.23	0.23	0.30
9/06/2010	C3	A	0.01	0.0067	0.00	0.0014	0.37	0.075	0.357	0.0683	0.3696	0.0764	46	0.00	0.00	0.17	0.17	0.17
9/06/2010	C3	B	0.01	0.0067	0.01	0.0015	0.41	0.078	0.395	0.0713	0.411	0.0795	56	0.01	0.00	0.22	0.22	0.23
9/06/2010	C3	C	0.01	0.0067	0.00	0.0014	0.55	0.089	0.536	0.0823	0.548	0.0904	44	0.00	0.00	0.24	0.24	0.24
9/06/2010	C4	A	0.01	0.0067	0.16	0.02	0.54	0.089	0.528	0.0823	0.7	0.109	50	0.00	0.08	0.27	0.26	0.35
9/06/2010	C4	B	0.01	0.0067	0.21	0.025	0.40	0.078	0.393	0.0713	0.61	0.103	33	0.00	0.07	0.13	0.13	0.20
9/06/2010	C4	C	0.01	0.0067	0.76	0.091	0.97	0.14	0.96	0.1333	1.727	0.231	8	0.00	0.06	0.08	0.08	0.15

Appendix 5 - Pasture dry-matter measurements

Date	Sector		Dry matter (kg/ha)
29/01/2010	F1	A	5472
29/01/2010	F1	B	4001
29/01/2010	F1	C	4558
29/01/2010	F2	A	4173
29/01/2010	F2	B	5684
29/01/2010	F2	C	3922
29/01/2010	F3	A	5671
29/01/2010	F3	B	4134
29/01/2010	F3	C	3683
29/01/2010	F4	A	3763
29/01/2010	F4	B	2756
29/01/2010	F4	C	4505
29/01/2010	F5	A	5194
29/01/2010	F5	B	3842
29/01/2010	F5	C	5644
29/01/2010	F6	A	4081
29/01/2010	F6	B	4505
29/01/2010	F6	C	4717
29/01/2010	F7	A	5684
29/01/2010	F7	B	4054
29/01/2010	F7	C	4293
29/01/2010	F8	A	5485
29/01/2010	F8	B	10560
29/01/2010	F8	C	8373
29/01/2010	G1	A	4505
29/01/2010	G1	B	6691
29/01/2010	G1	C	5657
29/01/2010	G2	A	5021
29/01/2010	G2	B	5074
29/01/2010	G2	C	6850
29/01/2010	G3	A	5869
29/01/2010	G3	B	2835
29/01/2010	G3	C	2994
29/01/2010	G4	A	6744
29/01/2010	G4	B	3776
29/01/2010	G4	C	4359
29/01/2010	C1	A	994
29/01/2010	C1	B	1431
29/01/2010	C1	C	1073
29/01/2010	C2	A	1126
29/01/2010	C2	B	662
29/01/2010	C2	C	636
29/01/2010	C3	A	397
29/01/2010	C3	B	358
29/01/2010	C3	C	305
29/01/2010	C4	A	265
29/01/2010	C4	B	424
29/01/2010	C4	C	556
30/03/2010	F1	A	1524
30/03/2010	F1	B	1166
30/03/2010	F1	C	1418
30/03/2010	F2	A	1974
30/03/2010	F2	B	2040
30/03/2010	F2	C	2464
30/03/2010	F3	A	1669
30/03/2010	F3	B	1590
30/03/2010	F3	C	2001
30/03/2010	F4	A	2425
30/03/2010	F4	B	1418
30/03/2010	F4	C	1881
30/03/2010	F5	A	1007
30/03/2010	F5	B	835
30/03/2010	F5	C	2372
30/03/2010	F6	A	2650
30/03/2010	F6	B	3206
30/03/2010	F6	C	3723
30/03/2010	F7	A	609
30/03/2010	F7	B	4637
30/03/2010	F7	C	2054
30/03/2010	F8	A	1073
30/03/2010	F8	B	1868
30/03/2010	F8	C	2014
30/03/2010	G1	A	1444
30/03/2010	G1	B	2782
30/03/2010	G1	C	2822
30/03/2010	G2	A	1590
30/03/2010	G2	B	1126
30/03/2010	G2	C	1457
30/03/2010	G3	A	2146
30/03/2010	G3	B	2279
30/03/2010	G3	C	4346
30/03/2010	G4	A	2411
30/03/2010	G4	B	3458
30/03/2010	G4	C	3405
30/03/2010	C1	A	371
30/03/2010	C1	B	371
30/03/2010	C1	C	371
30/03/2010	C2	A	291
30/03/2010	C2	B	291
30/03/2010	C2	C	291
30/03/2010	C3	A	199
30/03/2010	C3	B	199
30/03/2010	C3	C	199
30/03/2010	C4	A	185
30/03/2010	C4	B	185
30/03/2010	C4	C	185
18/10/2010	F1	A	4014
18/10/2010	F1	B	3869
18/10/2010	F1	C	3776
18/10/2010	F2	A	4041
18/10/2010	F2	B	4054
18/10/2010	F2	C	5591
18/10/2010	F3	A	3591
18/10/2010	F3	B	4584
18/10/2010	F3	C	3458
18/10/2010	F4	A	4690
18/10/2010	F4	B	3564
18/10/2010	F4	C	2623
18/10/2010	F5	A	3670
18/10/2010	F5	B	4385
18/10/2010	F5	C	4120
18/10/2010	F6	A	6320
18/10/2010	F6	B	6095
18/10/2010	F6	C	4650
18/10/2010	F7	A	3140
18/10/2010	F7	B	6770
18/10/2010	F7	C	6333
18/10/2010	F8	A	3975
18/10/2010	F8	B	4836
18/10/2010	F8	C	4200
18/10/2010	G1	A	2941
18/10/2010	G1	B	5101
18/10/2010	G1	C	5538
18/10/2010	G2	A	5233
18/10/2010	G2	B	6134
18/10/2010	G2	C	4094

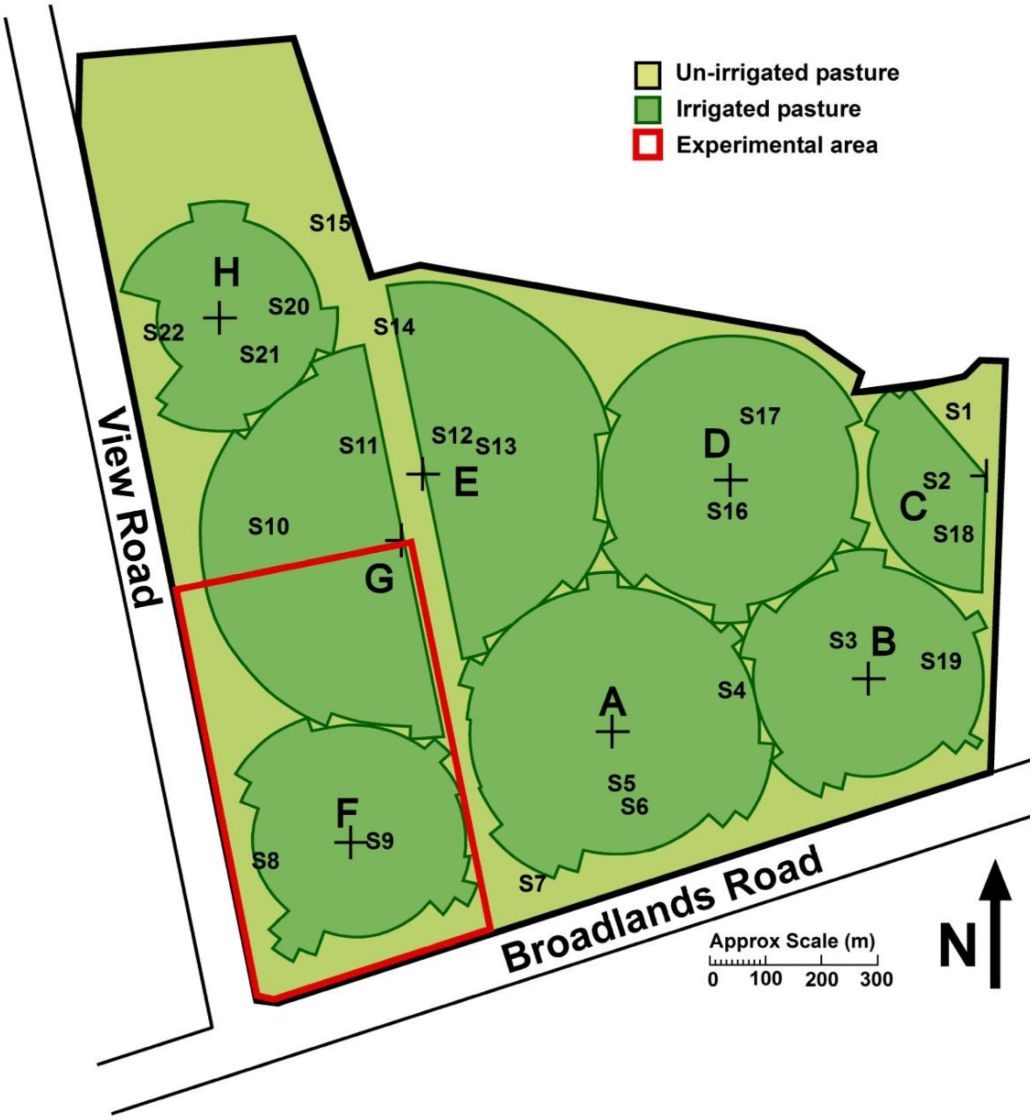
18/10/2010	G3	A	4478
18/10/2010	G3	B	10069
18/10/2010	G3	C	6969
18/10/2010	G4	A	5419
18/10/2010	G4	B	8175
18/10/2010	G4	C	5300
18/10/2010	C1	A	477
18/10/2010	C1	B	477
18/10/2010	C1	C	477
18/10/2010	C2	A	344
18/10/2010	C2	B	344
18/10/2010	C2	C	344
18/10/2010	C3	A	411
18/10/2010	C3	B	411
18/10/2010	C3	C	411
18/10/2010	C4	A	556
18/10/2010	C4	B	556
18/10/2010	C4	C	556
15/12/2010	F1	A	3299
15/12/2010	F1	B	4120
15/12/2010	F1	C	5074
15/12/2010	F2	A	5286
15/12/2010	F2	B	2610
15/12/2010	F2	C	3206
15/12/2010	F3	A	4346
15/12/2010	F3	B	4995
15/12/2010	F3	C	3922
15/12/2010	F4	A	6943
15/12/2010	F4	B	3206
15/12/2010	F4	C	1749
15/12/2010	F5	A	6625
15/12/2010	F5	B	5127
15/12/2010	F5	C	2517
15/12/2010	F6	A	3458
15/12/2010	F6	B	2372
15/12/2010	F6	C	3352
15/12/2010	F7	A	5419
15/12/2010	F7	B	3564
15/12/2010	F7	C	4624
15/12/2010	F8	A	4571
15/12/2010	F8	B	4028
15/12/2010	F8	C	3670
15/12/2010	G1	A	2160
15/12/2010	G1	B	1338
15/12/2010	G1	C	1872
15/12/2010	G2	A	4147
15/12/2010	G2	B	3855
15/12/2010	G2	C	2902
15/12/2010	G3	A	2981
15/12/2010	G3	B	4650
15/12/2010	G3	C	4664
15/12/2010	G4	A	3524
15/12/2010	G4	B	3789
15/12/2010	G4	C	3922
15/12/2010	C1	A	556
15/12/2010	C1	B	556
15/12/2010	C1	C	556
15/12/2010	C2	A	755
15/12/2010	C2	B	755
15/12/2010	C2	C	755
15/12/2010	C3	A	185
15/12/2010	C3	B	185
15/12/2010	C3	C	185
15/12/2010	C4	A	450
15/12/2010	C4	B	450
15/12/2010	C4	C	450

Appendix 6 - Pasture nitrogen measurements

Date	**Sector**	**Mean%N**	**TN kg/ha**
29/01/2010	F1	1.6	77
29/01/2010	F2	2.0	90
29/01/2010	F3	1.7	73
29/01/2010	F4	2.2	80
29/01/2010	F5	1.7	84
29/01/2010	F6	2.2	98
29/01/2010	F7	2.1	95
29/01/2010	F8	1.7	140
29/01/2010	G1	1.7	94
29/01/2010	G2	1.5	86
29/01/2010	G3	2.0	73
29/01/2010	G4	1.9	97
29/01/2010	C1	1.0	12
29/01/2010	C2	1.0	7
29/01/2010	C3	1.3	5
29/01/2010	C4	1.3	5
30/03/2010	F1	2.1	29
30/03/2010	F2	2.3	49
30/03/2010	F3	2.1	37
30/03/2010	F4	2.4	46
30/03/2010	F5	2.1	30
30/03/2010	F6	2.3	75
30/03/2010	F7	2.1	53
30/03/2010	F8	2.5	42
30/03/2010	G1	2.5	60
30/03/2010	G2	2.3	32
30/03/2010	G3	2.6	74
30/03/2010	G4	2.3	73
30/03/2010	C1	1.7	6
30/03/2010	C2	1.4	4
30/03/2010	C3	1.6	3
30/03/2010	C4	1.7	3
18/10/2010	F1	1.9	74
18/10/2010	F2	2.6	120
18/10/2010	F3	2.2	85
18/10/2010	F4	2.0	73
18/10/2010	F5	2.2	88
18/10/2010	F6	2.0	115
18/10/2010	F7	2.0	107
18/10/2010	F8	2.0	85
18/10/2010	G1	3.3	151
18/10/2010	G2	2.6	132
18/10/2010	G3	2.8	199
18/10/2010	G4	2.4	152
18/10/2010	C1	1.6	7
18/10/2010	C2	1.6	5
18/10/2010	C3	1.4	6
18/10/2010	C4	1.5	8
15/12/2010	F1	1.8	75
15/12/2010	F2	2.3	85
15/12/2010	F3	1.7	75
15/12/2010	F4	1.9	75
15/12/2010	F5	1.9	90
15/12/2010	F6	1.8	55
15/12/2010	F7	1.9	86
15/12/2010	F8	1.8	74
15/12/2010	G1	2.3	41
15/12/2010	G2	2.1	76
15/12/2010	G3	1.6	66
15/12/2010	G4	2.2	82
15/12/2010	C1	1.3	7
15/12/2010	C2	1.6	12
15/12/2010	C3	1.2	2
15/12/2010	C4	1.4	6

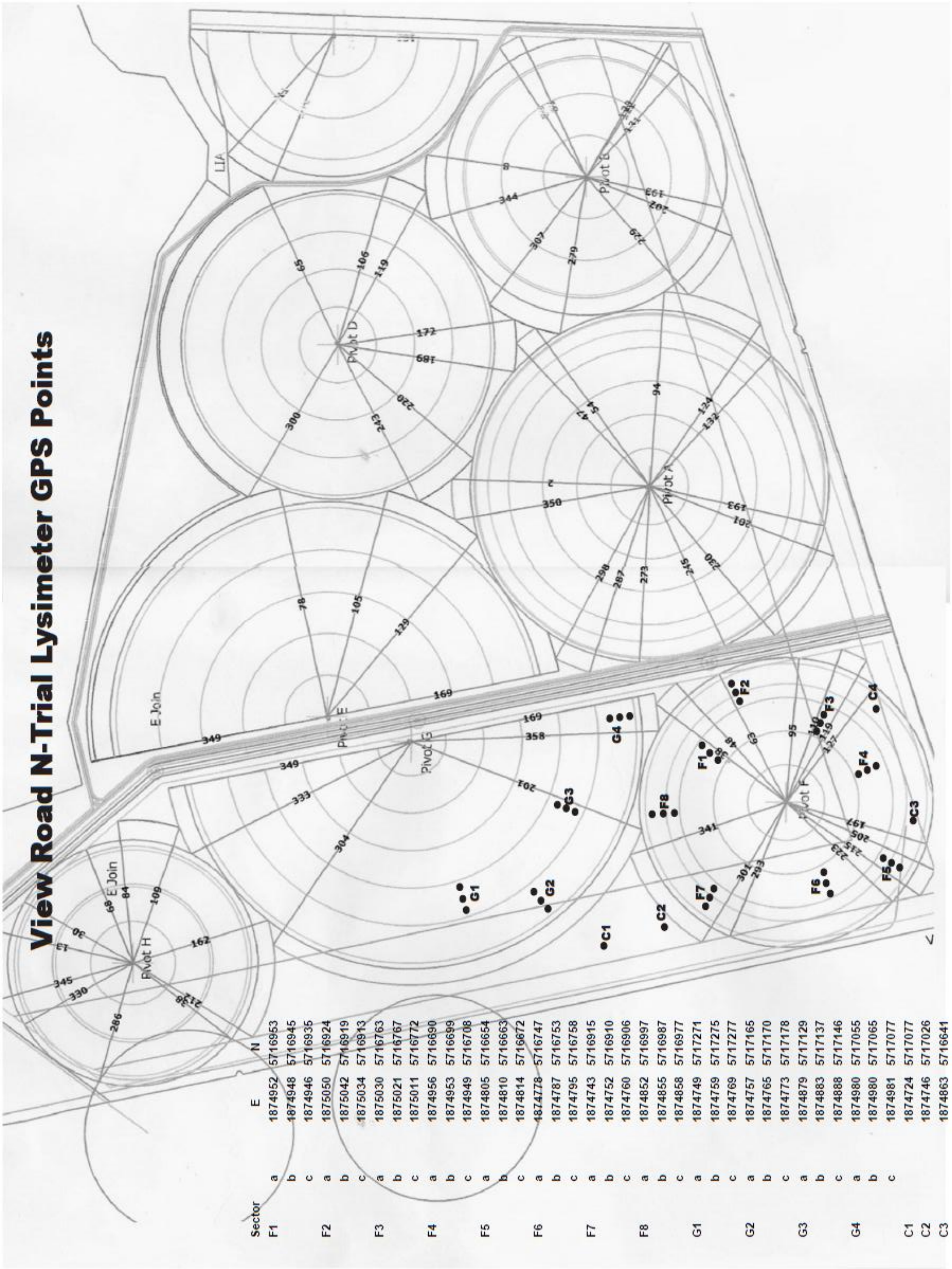
Appendix 7 - Pre-irrigation sample locations

In December 2008, prior to any effluent being irrigated onto the View Road site, some soil samples were taken. Ten cores were taken in a transect using a soil corer to approximately 10 cm depth, then bulked and placed into plastic bags. In total, 22 samples were taken (see below), and returned to the laboratory to be air dried. The air-dried samples were then sealed in plastic bags and stored in the University of Waikato soil laboratory. The approximate location of each sample is shown in the figure below.



Appendix 8 - Lysimeter locations

Using a hand-help GPS, the location of each lysimeter was recorded.



Sector		E	N
F1	a	1874952	5716953
	b	1874948	5716945
	c	1874946	5716935
F2	a	1875050	5716924
	b	1875042	5716919
	c	1875034	5716913
F3	a	1875030	5716763
	b	1875021	5716767
	c	1875011	5716772
F4	a	1874956	5716690
	b	1874953	5716699
	c	1874949	5716708
F5	a	1874805	5716654
	b	1874810	5716663
	c	1874814	5716672
F6	a	1874778	5716747
	b	1874787	5716753
	c	1874795	5716758
F7	a	1874743	5716915
	b	1874752	5716910
	c	1874760	5716906
F8	a	1874852	5716997
	b	1874855	5716987
	c	1874858	5716977
G1	a	1874749	5717271
	b	1874759	5717275
	c	1874769	5717277
G2	a	1874757	5717165
	b	1874765	5717170
	c	1874773	5717178
G3	a	1874879	5717129
	b	1874883	5717137
	c	1874888	5717146
G4	a	1874980	5717055
	b	1874980	5717065
	c	1874981	5717077
C1		1874724	5717077
C2		1874746	5717026
C3		1874863	5716641
C4		1875025	5716692

Appendix 9 - Effluent nitrogen

						Pivot F		Pivot G	
	TDC Wk	Source used	Value used	TDC	Composite	mm/day	(TN kg/ha)	mm/day	(TN kg/ha)
8/12/09	40.94	TDC Wk	40.94	40.94		0.0	0.00	0.0	0.00
9/12/09		TDC Wk	40.94	40.94		5.0	2.03	4.8	1.98
10/12/09		TDC Wk	40.94	40.94		5.0	2.04	4.6	1.89
11/12/09		TDC Wk	40.94	40.94		2.1	0.84	4.9	1.99
12/12/09		TDC Wk	40.94	40.94		7.9	3.22	9.8	4.00
13/12/09		TDC Wk	40.94	40.94		5.0	2.03	4.9	1.99
14/12/09		TDC Wk	40.94	40.94		4.9	2.02	4.9	1.99
15/12/09		TDC Wk	40.94	40.94		4.9	2.02	5.0	2.03
16/12/09	35.30	TDC Wk	35.30	35.30		5.0	1.75	4.8	1.71
17/12/09		TDC Wk	35.30	35.30		5.0	1.75	4.9	1.73
18/12/09		TDC Wk	35.30	35.30		0.0	0.00	0.0	0.00
19/12/09		TDC Wk	35.30	35.30		0.0	0.00	0.0	0.00
20/12/09		TDC Wk	35.30	35.30		7.2	2.54	6.6	2.35
21/12/09		TDC Wk	35.30	35.30		4.9	1.74	4.8	1.69
22/12/09		TDC Wk	35.30	35.30		4.9	1.75	4.9	1.72
23/12/09	42.55	TDC Wk	42.55	42.55		5.0	2.11	4.8	2.04
24/12/09		TDC Wk	42.55	42.55		4.9	2.11	4.7	2.01
25/12/09		TDC Wk	42.55	42.55		5.0	2.11	4.5	1.90
26/12/09		TDC Wk	42.55	42.55		0.0	0.00	0.0	0.00
27/12/09		TDC Wk	42.55	42.55		4.9	2.08	4.8	2.03
28/12/09		TDC Wk	42.55	42.55		4.9	2.09	4.7	2.01
29/12/09		TDC Wk	42.55	42.55		0.0	0.00	0.0	0.00
30/12/09	46.01	TDC Wk	46.01	46.01		4.9	2.25	4.8	2.21
31/12/09		TDC Wk	46.01	46.01		4.9	2.26	4.7	2.16
1/01/10		TDC Wk	46.01	46.01		4.9	2.26	4.8	2.20
2/01/10		TDC Wk	46.01	46.01		4.9	2.25	4.8	2.22
3/01/10		TDC Wk	46.01	46.01		4.8	2.20	4.8	2.21
4/01/10		TDC Wk	46.01	46.01		4.8	2.20	4.8	2.21
5/01/10		TDC Wk	46.01	46.01		4.7	2.15	4.8	2.21
6/01/10	41.01	TDC Wk	41.01	41.01		4.7	1.92	4.7	1.92
7/01/10		TDC Wk	41.01	41.01		4.7	1.92	4.8	1.97
8/01/10		TDC Wk	41.01	41.01		4.6	1.90	4.7	1.91
9/01/10		TDC Wk	41.01	41.01		4.6	1.90	4.8	1.96
10/01/10		TDC Wk	41.01	41.01		4.6	1.90	4.7	1.93
11/01/10		TDC Wk	41.01	41.01		4.8	1.96	4.8	1.96
12/01/10		TDC Wk	41.01	41.01		4.7	1.91	4.8	1.95
13/01/10	43.51	TDC Wk	43.51	43.51		0.0	0.00	0.0	0.00
14/01/10		TDC Wk	43.51	43.51		0.0	0.00	0.0	0.00
15/01/10		TDC Wk	43.51	43.51		0.0	0.00	0.0	0.00
16/01/10		TDC Wk	43.51	43.51		0.0	0.00	0.0	0.00
17/01/10		TDC Wk	43.51	43.51		0.0	0.00	0.0	0.00
18/01/10		TDC Wk	43.51	43.51		0.0	0.00	0.0	0.00
19/01/10		TDC Wk	43.51	43.51		0.0	0.00	0.0	0.00
20/01/10	36.52	TDC Wk	36.52	36.52		0.0	0.00	0.0	0.00
21/01/10		TDC Wk	36.52	36.52		0.0	0.00	0.0	0.00
22/01/10		TDC Wk	36.52	36.52		0.0	0.00	0.0	0.00
23/01/10		TDC Wk	36.52	36.52		0.0	0.00	0.0	0.00
24/01/10		TDC Wk	36.52	36.52		0.0	0.00	0.0	0.00
25/01/10		TDC Wk	36.52	36.52		0.0	0.00	0.0	0.00
26/01/10		TDC Wk	36.52	36.52		0.0	0.00	0.0	0.00
27/01/10	37.20	TDC Wk	37.20	37.20		0.0	0.00	0.0	0.00
28/01/10		TDC Wk	37.20	37.20		0.0	0.00	0.0	0.00
29/01/10		TDC Wk	37.20	37.20		0.0	0.00	0.0	0.00
30/01/10		TDC Wk	37.20	37.20		0.0	0.00	0.0	0.00
31/01/10		TDC Wk	37.20	37.20		0.0	0.00	0.0	0.00
1/02/10		TDC Wk	37.20	37.20		0.0	0.00	0.0	0.00
2/02/10	53.20	TDC Wk	53.20	53.20		0.0	0.00	0.0	0.00
3/02/10		TDC Wk	53.20	53.20		0.0	0.00	0.0	0.00
4/02/10		TDC Wk	53.20	53.20		0.0	0.00	0.0	0.00
5/02/10		TDC Wk	53.20	53.20		0.0	0.00	0.0	0.00
6/02/10		TDC Wk	53.20	53.20		0.0	0.00	0.0	0.00
7/02/10		TDC Wk	53.20	53.20		0.0	0.00	0.0	0.00
8/02/10		TDC Wk	53.20	53.20		7.6	4.05	2.5	1.31
9/02/10		TDC Wk	53.20	53.20		1.8	0.93	4.8	2.57
10/02/10	39.40	TDC Wk	39.40	39.40		4.7	1.85	4.8	1.89

11/02/10		TDC Wk	39.40	39.40		4.7	1.84	4.3	1.69
12/02/10		TDC Wk	39.40	39.40		0.0	0.00	0.0	0.00
13/02/10		TDC Wk	39.40	39.40		0.0	0.00	0.0	0.00
14/02/10		TDC Wk	39.40	39.40		0.0	0.00	0.0	0.00
15/02/10		TDC Wk	39.40	39.40		0.0	0.00	0.0	0.00
16/02/10		TDC Wk	39.40	39.40		4.7	1.84	4.6	1.83
17/02/10	44.40	TDC Wk	44.40	44.40		4.9	2.17	4.7	2.07
18/02/10		TDC Wk	44.40	44.40		0.0	0.00	0.0	0.00
19/02/10		TDC Wk	44.40	44.40		4.7	2.10	4.7	2.07
20/02/10		TDC Wk	44.40	44.40		4.8	2.14	4.6	2.06
21/02/10		TDC Wk	44.40	44.40		4.7	2.08	4.7	2.09
22/02/10		TDC Wk	44.40	44.40		4.6	2.06	4.6	2.05
23/02/10		TDC Wk	44.40	44.40		4.7	2.11	4.7	2.08
24/02/10	38.05	TDC Wk	38.05	38.05		4.8	1.84	4.7	1.78
25/02/10		TDC Wk	38.05	38.05		4.7	1.80	4.7	1.78
26/02/10		TDC Wk	38.05	38.05		4.8	1.85	4.6	1.77
27/02/10		TDC Wk	38.05	38.05		4.8	1.83	4.6	1.76
28/02/10		TDC Wk	38.05	38.05		4.6	1.77	4.4	1.68
1/03/10		TDC Wk	38.05	38.05		0.0	0.00	0.0	0.00
2/03/10		TDC Wk	38.05	38.05		4.6	1.76	4.5	1.73
3/03/10	36.81	TDC Wk	36.81	36.81		2.8	1.02	2.9	1.06
4/03/10		TDC Wk	36.81	36.81		0.0	0.00	0.0	0.00
5/03/10		TDC Wk	36.81	36.81		0.0	0.00	0.0	0.00
6/03/10		TDC Wk	36.81	36.81		4.7	1.72	0.0	0.00
7/03/10		TDC Wk	36.81	36.81		4.7	1.72	0.0	0.00
8/03/10		TDC Wk	36.81	36.81		4.7	1.72	0.0	0.00
9/03/10		TDC Wk	36.81	36.81		4.6	1.70	4.6	1.68
10/03/10	42.70	TDC Wk	42.70	42.70		0.0	0.00	4.6	1.95
11/03/10		TDC Wk	42.70	42.70		0.0	0.00	4.6	1.96
12/03/10		TDC Wk	42.70	42.70		7.7	3.29	4.6	1.97
13/03/10		TDC Wk	42.70	42.70		14.8	6.32	4.6	1.97
14/03/10		TDC Wk	42.70	42.70		4.6	1.98	4.5	1.91
15/03/10		TDC Wk	42.70	42.70		4.6	1.97	4.6	1.96
16/03/10		TDC Wk	42.70	42.70		0.0	0.00	4.6	1.98
17/03/10	32.80	TDC Wk	32.80	32.80		4.7	1.54	4.6	1.52
18/03/10		TDC Wk	32.80	32.80		4.6	1.50	4.6	1.50
19/03/10		TDC Wk	32.80	32.80		4.7	1.54	4.6	1.50
20/03/10		TDC Wk	32.80	32.80		4.6	1.53	4.6	1.51
21/03/10		TDC Wk	32.80	32.80		4.6	1.52	4.6	1.50
22/03/10		TDC Wk	32.80	32.80		4.8	1.56	4.6	1.51
23/03/10		TDC Wk	32.80	32.80		0.0	0.00	0.0	0.00
24/03/10	40.06	TDC Wk	40.06	40.06		4.6	1.83	4.5	1.80
25/03/10		TDC Wk	40.06	40.06		0.0	0.00	0.0	0.00
26/03/10		TDC Wk	40.06	40.06		0.0	0.00	0.0	0.00
27/03/10		TDC Wk	40.06	40.06		0.0	0.00	0.0	0.00
28/03/10		TDC Wk	40.06	40.06		0.0	0.00	0.0	0.00
29/03/10		TDC Wk	40.06	40.06		0.0	0.00	0.0	0.00
30/03/10		TDC Wk	40.06	40.06		0.0	0.00	0.0	0.00
31/03/10	36.00	TDC Wk	36.00	36.00		0.0	0.00	0.0	0.00
1/04/10		TDC Wk	36.00	36.00		0.0	0.00	0.0	0.00
2/04/10		TDC Wk	36.00	36.00		0.0	0.00	0.0	0.00
3/04/10		TDC Wk	36.00	36.00		0.0	0.00	0.0	0.00
4/04/10		TDC Wk	36.00	36.00		0.0	0.00	0.0	0.00
5/04/10		TDC Wk	36.00	36.00		0.0	0.00	0.0	0.00
6/04/10		TDC Wk	36.00	36.00		4.7	1.71	0.0	0.02
7/04/10	32.39	TDC Wk	32.39	32.39		0.0	0.00	0.0	0.00
8/04/10		TDC Wk	32.39	32.39		5.0	1.63	0.2	0.05
9/04/10		TDC Wk	32.39	32.39		4.8	1.54	4.5	1.46
10/04/10		TDC Wk	32.39	32.39		0.0	0.00	0.0	0.00
11/04/10		TDC Wk	32.39	32.39		4.7	1.52	4.3	1.40
12/04/10		TDC Wk	32.39	32.39		0.0	0.00	0.0	0.00
13/04/10		TDC Wk	32.39	32.39		4.7	1.52	4.5	1.46
14/04/10	34.45	TDC Wk	34.45	34.45		0.0	0.00	0.0	0.00
15/04/10		TDC Wk	34.45	34.45		4.7	1.62	4.5	1.55
16/04/10		TDC Wk	34.45	34.45		4.7	1.61	4.5	1.55
17/04/10		TDC Wk	34.45	34.45		3.5	1.19	4.0	1.38
18/04/10		TDC Wk	34.45	34.45		1.3	0.46	0.5	0.17
19/04/10		TDC Wk	34.45	34.45		1.9	0.64	1.8	0.63
20/04/10		TDC Wk	34.45	34.45		0.0	0.00	0.0	0.00
21/04/10	44.20	TDC Wk	44.20	44.20		3.0	1.30	2.0	0.88

22/04/10		TDC Wk	44.20	44.20		4.6	2.05	4.4	1.96
23/04/10		TDC Wk	44.20	44.20		0.0	0.00	0.0	0.00
24/04/10		TDC Wk	44.20	44.20		4.6	2.05	4.3	1.91
25/04/10		TDC Wk	44.20	44.20		4.6	2.05	4.4	1.94
26/04/10		TDC Wk	44.20	44.20		0.0	0.00	4.4	1.94
27/04/10		TDC Wk	44.20	44.20		0.0	0.00	0.0	0.00
28/04/10	35.50	TDC Wk	35.50	35.50		4.6	1.64	4.4	1.57
29/04/10		TDC Wk	35.50	35.50		4.6	1.64	4.4	1.56
30/04/10		TDC Wk	35.50	35.50		4.6	1.64	4.4	1.57
1/05/10		TDC Wk	35.50	35.50		4.6	1.65	4.4	1.56
2/05/10		TDC Wk	35.50	35.50		2.0	0.71	4.4	1.57
3/05/10		TDC Wk	35.50	35.50		0.0	0.00	0.0	0.00
4/05/10		TDC Wk	35.50	35.50		4.8	1.71	4.4	1.57
5/05/10	36.10	TDC Wk	36.10	36.10		6.9	2.50	4.6	1.64
6/05/10		TDC Wk	36.10	36.10		4.3	1.56	4.5	1.63
7/05/10		TDC Wk	36.10	36.10		0.5	0.19	0.0	0.00
8/05/10		TDC Wk	36.10	36.10		4.2	1.53	4.5	1.63
9/05/10		TDC Wk	36.10	36.10		4.9	1.77	4.5	1.63
10/05/10		TDC Wk	36.10	36.10		10.1	3.63	9.0	3.24
11/05/10		TDC Wk	36.10	36.10		12.1	4.36	4.5	1.62
12/05/10	38.10	TDC Wk	38.10	38.10		0.5	0.18	0.0	0.00
13/05/10		TDC Wk	38.10	38.10		0.0	0.00	0.0	0.00
14/05/10		TDC Wk	38.10	38.10		0.0	0.00	0.0	0.00
15/05/10		TDC Wk	38.10	38.10		4.7	1.78	4.6	1.75
16/05/10		TDC Wk	38.10	38.10		4.8	1.81	4.6	1.75
17/05/10		TDC Wk	38.10	38.10		4.4	1.66	4.6	1.74
18/05/10		TDC Wk	38.10	38.10		0.5	0.18	0.0	0.00
19/05/10	39.40	TDC Wk	39.40	39.40		3.7	1.46	4.5	1.78
20/05/10		TDC Wk	39.40	39.40		1.2	0.46	0.0	0.02
21/05/10		TDC Wk	39.40	39.40		0.0	0.00	0.0	0.00
22/05/10		TDC Wk	39.40	39.40		0.0	0.00	0.0	0.00
23/05/10		TDC Wk	39.40	39.40		4.7	1.86	4.5	1.76
24/05/10		TDC Wk	39.40	39.40		0.0	0.00	0.0	0.00
25/05/10		TDC Wk	39.40	39.40		0.0	0.00	0.0	0.00
26/05/10	30.90	TDC Wk	30.90	30.90		0.0	0.00	0.0	0.00
27/05/10		TDC Wk	30.90	30.90		0.0	0.00	8.0	2.47
28/05/10		TDC Wk	30.90	30.90		0.0	0.00	4.6	1.42
29/05/10		TDC Wk	30.90	30.90		0.0	0.00	0.0	0.00
30/05/10		TDC Wk	30.90	30.90		0.0	0.00	4.5	1.40
31/05/10		TDC Wk	30.90	30.90		0.0	0.00	0.0	0.00
1/06/10		TDC Wk	30.90	30.90		0.0	0.00	4.6	1.41
2/06/10	40.70	TDC Wk	40.70	40.70		0.0	0.00	3.1	1.24
3/06/10		TDC Wk	40.70	40.70		4.3	1.74	5.8	2.37
4/06/10		TDC Wk	40.70	40.70		0.5	0.20	0.0	0.00
5/06/10		TDC Wk	40.70	40.70		4.3	1.74	4.5	1.82
6/06/10		TDC Wk	40.70	40.70		4.7	1.92	4.5	1.82
7/06/10		TDC Wk	40.70	40.70		4.7	1.92	4.4	1.80
8/06/10		TDC Wk	40.70	40.70		4.7	1.91	4.5	1.83
9/06/10	41.30	GT Sp	41.30	41.30	41.30	2.4	0.99	4.5	1.84
10/06/10		TDC Wk	41.30	41.30		6.9	2.86	4.4	1.81
11/06/10		TDC Wk	41.30	41.30		4.5	1.87	4.4	1.83
12/06/10		TDC Wk	41.30	41.30		9.6	3.98	8.9	3.70
13/06/10		TDC Wk	41.30	41.30		2.0	0.84	4.4	1.82
14/06/10		GT Sp	39.70	41.30	39.70	0.1	0.04	0.0	0.00
15/06/10		EST	39.70	41.30		4.2	1.66	4.4	1.76
16/06/10	54.40	TDC Wk	54.40	54.40		2.6	1.40	4.4	2.41
17/06/10		TDC Wk	54.40	54.40		0.0	0.00	4.5	2.43
18/06/10		GT Wk	45.7	54.40	45.7	0.2	0.07	4.5	2.04
19/06/10		GT Wk	45.7	54.40	45.7	0.0	0.00	4.4	2.03
20/06/10		GT Wk	45.7	54.40	45.7	0.0	0.00	4.4	2.02
21/06/10		GT Wk	45.7	54.40	45.7	0.0	0.00	4.4	2.02
22/06/10		GT Wk	45.7	54.40	45.7	0.0	0.00	0.0	0.00
23/06/10		GT Wk	45.7	54.40	45.7	0.0	0.00	4.5	2.04
24/06/10		GT Wk	45.7	54.40	45.7	0.0	0.00	4.4	2.02
25/06/10		GT Wk	47.1	54.40	47.1	0.0	0.00	0.0	0.00
26/06/10		GT Wk	47.1	54.40	47.1	0.0	0.00	4.4	2.09
27/06/10		GT Wk	47.1	54.40	47.1	0.0	0.00	0.0	0.00
28/06/10		GT Wk	47.1	54.40	47.1	0.0	0.00	4.4	2.08
29/06/10		GT Wk	47.1	54.40	47.1	0.0	0.00	4.5	2.11
30/06/10	42.40	GT Wk	47.1	42.40	47.1	0.0	0.00	4.4	2.09

1/07/10		GT Sp	48.6	42.40	48.6	0.0	0.00	4.5	2.16
2/07/10		GT Wk	46.5	42.40	46.5	0.0	0.00	0.0	0.00
3/07/10		GT Wk	46.5	42.40	46.5	0.0	0.00	4.2	1.97
4/07/10		GT Wk	46.5	42.40	46.5	0.0	0.00	4.5	2.08
5/07/10		GT Wk	46.5	42.40	46.5	0.0	0.00	0.1	0.07
6/07/10		GT Wk	46.5	42.40	46.5	0.0	0.00	4.4	2.04
7/07/10	54.45	GT Wk	46.5	54.45	46.5	0.0	0.00	4.5	2.10
8/07/10		GT Wk	46.5	54.45	46.5	0.0	0.00	4.2	1.96
9/07/10		TDC Wk	54.45	54.45		0.0	0.00	4.9	2.68
10/07/10		TDC Wk	54.45	54.45		0.0	0.00	4.0	2.16
11/07/10		TDC Wk	54.45	54.45		0.0	0.00	0.6	0.30
12/07/10		TDC Wk	54.45	54.45		0.0	0.00	4.6	2.51
13/07/10		TDC Wk	54.45	54.45		0.0	0.00	4.5	2.45
14/07/10	42.75	TDC Wk	42.75	42.75		0.0	0.00	0.0	0.00
15/07/10		TDC Wk	42.75	42.75		0.0	0.00	0.5	0.20
16/07/10		TDC Wk	42.75	42.75		0.0	0.00	0.0	0.00
17/07/10		GT Sp	47.7	42.75	47.7	0.0	0.00	4.5	2.14
18/07/10		EST	45.8	42.75		0.0	0.00	0.0	0.00
19/07/10		EST	45.8	42.75		0.0	0.00	4.5	2.07
20/07/10		EST	45.8	42.75		0.0	0.00	0.0	0.00
21/07/10	43.30	EST	45.8	43.30		0.0	0.00	4.5	2.06
22/07/10		GT Sp	43.9	43.30	43.9	0.0	0.00	4.5	1.97
23/07/10		TDC Wk	43.30	43.30		0.0	0.00	4.4	1.93
24/07/10		TDC Wk	43.3	43.30		0.0	0.00	0.0	0.00
25/07/10		TDC Wk	43.3	43.30		0.0	0.00	4.5	1.96
26/07/10		TDC Wk	43.3	43.30		0.0	0.00	4.5	1.96
27/07/10		TDC Wk	43.3	43.30		0.0	0.00	0.0	0.00
28/07/10	39.20	TDC Wk	39.20	39.20		0.0	0.00	4.6	1.78
29/07/10		TDC Wk	39.2	39.20		0.0	0.00	0.0	0.00
30/07/10		TDC Wk	39.2	39.20		0.0	0.00	4.5	1.76
31/07/10		TDC Wk	39.2	39.20		0.0	0.00	4.2	1.64
1/08/10		TDC Wk	39.2	39.20		0.0	0.00	4.9	1.91
2/08/10		TDC Wk	39.2	39.20		4.2	2.11	0.0	0.00
3/08/10		TDC Wk	39.2	39.20		2.6	1.28	4.5	1.76
4/08/10	40.20	TDC Wk	40.20	40.20		0.0	0.00	4.5	1.82
5/08/10		TDC Wk	40.2	40.20		0.0	0.00	0.8	0.32
6/08/10		TDC Wk	40.2	40.20		0.0	0.00	0.0	0.00
7/08/10		TDC Wk	40.2	40.20		2.0	1.01	4.5	1.82
8/08/10		TDC Wk	40.2	40.20		0.0	0.00	4.6	1.85
9/08/10		TDC Wk	40.2	40.20		0.0	0.00	0.0	0.00
10/08/10		TDC Wk	40.2	40.20		0.0	0.00	4.5	1.81
11/08/10	44.10	TDC Wk	44.10	44.10		0.0	0.00	4.6	2.01
12/08/10		TDC Wk	44.1	44.10		0.0	0.02	0.0	0.00
13/08/10		TDC Wk	44.1	44.10		0.0	0.00	4.4	1.95
14/08/10		TDC Wk	44.1	44.10		1.9	0.83	4.5	1.99
15/08/10		TDC Wk	44.1	44.10		2.2	0.96	4.5	1.97
16/08/10		TDC Wk	44.1	44.10		0.0	0.00	4.5	1.99
17/08/10		GT Wk	43.5	44.10	43.5	0.0	0.00	0.0	0.00
18/08/10	35.91	GT Wk	43.5	35.91	43.5	2.2	0.95	4.4	1.93
19/08/10		GT Wk	43.5	35.91	43.5	1.5	0.66	0.1	0.02
20/08/10		GT Wk	43.5	35.91	43.5	3.6	1.55	4.5	1.96
21/08/10		GT Wk	43.5	35.91	43.5	3.3	1.42	4.5	1.96
22/08/10		GT Wk	43.5	35.91	43.5	0.0	0.00	0.0	0.00
23/08/10		GT Wk	43.5	35.91	43.5	0.0	0.00	0.0	0.00
24/08/10		GT Wk	51.7	35.91	51.7	1.0	0.50	4.6	2.36
25/08/10	52.00	GT Wk	51.7	52.00	51.7	0.0	0.00	4.5	2.32
26/08/10		GT Wk	51.7	52.00	51.7	0.9	0.48	4.5	2.35
27/08/10		GT Wk	51.7	52.00	51.7	2.2	1.11	4.5	2.31
28/08/10		GT Wk	51.7	52.00	51.7	2.8	1.43	0.0	0.00
29/08/10		GT Wk	51.7	52.00	51.7	4.3	2.20	4.4	2.27
30/08/10		GT Wk	51.7	52.00	51.7	0.5	0.27	6.9	3.57
31/08/10		GT Wk	51.7	52.00	51.7	7.1	3.66	13.5	6.96
1/09/10	42.60	GT Wk	50	42.60	50	1.0	0.48	4.5	2.24
2/09/10		GT Wk	50	42.60	50	3.5	1.73	4.6	2.29
3/09/10		GT Wk	50	42.60	50	0.3	0.16	4.4	2.20
4/09/10		GT Wk	50	42.60	50	4.3	2.14	4.6	2.32
5/09/10		GT Wk	50	42.60	50	2.2	1.12	4.5	2.25
6/09/10		GT Wk	50	42.60	50	4.7	2.33	4.4	2.22
7/09/10		GT Wk	50	42.60	50	2.1	1.04	4.5	2.23
8/09/10	50.00	TDC Wk	50.00	50.00		0.0	0.00	4.5	2.26

9/09/10		TDC Wk	50	50.00		0.0	0.00	4.4	2.21
10/09/10		TDC Wk	50	50.00		0.0	0.00	4.5	2.26
11/09/10		TDC Wk	50	50.00		0.0	0.00	4.4	2.21
12/09/10		TDC Wk	50	50.00		0.0	0.00	4.5	2.23
13/09/10		TDC Wk	50	50.00		0.0	0.00	4.4	2.20
14/09/10		TDC Wk	50	50.00		0.0	0.00	4.4	2.22
15/09/10	44.50	TDC Wk	44.5	44.50		2.8	1.25	0.0	0.00
16/09/10		TDC Wk	44.5	44.50		4.3	1.89	4.4	1.94
17/09/10		GT Wk	44.4	44.50	44.4	0.5	0.24	0.0	0.00
18/09/10		GT Wk	44.4	44.50	44.4	0.0	0.00	0.0	0.00
19/09/10		GT Wk	44.4	44.50	44.4	0.0	0.00	4.5	1.98
20/09/10		GT Wk	44.4	44.50	44.4	3.9	1.73	4.5	1.98
21/09/10		GT Wk	44.4	44.50	44.4	4.8	2.14	4.2	1.86
22/09/10	37.48	GT Wk	44.4	37.48	44.4	4.7	2.09	4.1	1.80
23/09/10		GT Wk	44.4	37.48	44.4	4.7	2.09	5.2	2.33
24/09/10		GT Wk	44.4	37.48	44.4	4.9	2.17	4.4	1.97
25/09/10		EST	44.4	37.48		4.8	2.12	4.3	1.91
26/09/10		EST	44.4	37.48		5.1	2.25	4.4	1.94
27/09/10		EST	44.4	37.48		0.2	0.08	5.0	2.22
28/09/10		EST	44.4	37.48		4.4	1.95	4.4	1.95
29/09/10	50.19	TDC Wk	50.19	50.19		4.0	2.03	4.1	2.07
30/09/10		TDC Wk	50.19	50.19		4.8	2.42	4.5	2.28
1/10/10		TDC Wk	50.19	50.19		4.6	2.32	4.4	2.21
2/10/10		TDC Wk	50.19	50.19		5.3	2.68	4.4	2.22
3/10/10		TDC Wk	50.19	50.19		4.6	2.32	4.3	2.17
4/10/10		TDC Wk	50.19	50.19		4.6	2.33	4.4	2.20
5/10/10		GT Wk	49	50.19	49	4.2	2.05	4.4	2.16
6/10/10	58.10	GT Wk	49	58.10	49	5.3	2.61	4.4	2.14
7/10/10		GT Wk	49	58.10	49	4.6	2.24	4.3	2.09
8/10/10		GT Wk	49	58.10	49	4.8	2.33	4.3	2.12
9/10/10		GT Wk	49	58.10	49	0.5	0.23	0.0	0.00
10/10/10		GT Wk	49	58.10	49	4.3	2.10	4.3	2.10
11/10/10		GT Wk	49	58.10	49	0.4	0.19	0.0	0.00
12/10/10	54.00	GT Wk	51.5	54.00	51.5	0.0	0.00	0.0	0.00
13/10/10		GT Wk	51.5	54.00	51.5	0.0	0.00	0.0	0.00
14/10/10		GT Wk	51.5	54.00	51.5	0.0	0.00	0.0	0.00
15/10/10		GT Wk	51.5	54.00	51.5	0.0	0.00	0.0	0.00
16/10/10		GT Wk	51.5	54.00	51.5	0.0	0.00	0.0	0.00
17/10/10		GT Wk	51.5	54.00	51.5	0.0	0.00	0.0	0.00
18/10/10		GT Wk	51.5	54.00	51.5	0.0	0.00	0.0	0.00
19/10/10		GT Wk	46.2	54.00	46.2	0.0	0.00	0.0	0.00
20/10/10	47.60	GT Wk	46.2	47.60	46.2	0.0	0.00	0.0	0.00
21/10/10		GT Wk	46.2	47.60	46.2	0.0	0.00	0.0	0.00
22/10/10		GT Wk	46.2	47.60	46.2	0.0	0.00	0.0	0.00
23/10/10		GT Wk	46.2	47.60	46.2	0.0	0.00	0.0	0.00
24/10/10		GT Wk	46.2	47.60	46.2	0.0	0.00	0.0	0.00
25/10/10		GT Wk	46.2	47.60	46.2	0.0	0.00	0.0	0.00
26/10/10		GT Wk	53.9	47.60	53.9	3.8	2.04	0.0	0.00
27/10/10	50.73	GT Wk	53.9	50.73	53.9	9.6	5.15	4.5	2.42
28/10/10		GT Wk	53.9	50.73	53.9	5.3	2.86	4.4	2.37
29/10/10		GT Wk	53.9	50.73	53.9	4.6	2.49	4.4	2.38
30/10/10		GT Wk	53.9	50.73	53.9	4.8	2.56	4.4	2.39
31/10/10		GT Wk	53.9	50.73	53.9	4.8	2.58	4.5	2.41
1/11/10		GT Wk	53.9	50.73	53.9	4.77	2.57	4.4	2.38
2/11/10		GT Wk	53.9	50.73	53.9	4.80	2.59	4.5	2.42
3/11/10	39.86	GT Wk	41.6	39.86	41.6	4.79	1.99	4.4	1.82
4/11/10		GT Wk	41.6	39.86	41.6	4.35	1.81	4.4	1.85
5/11/10		GT Wk	41.6	39.86	41.6	5.59	2.32	4.4	1.82
6/11/10		GT Wk	41.6	39.86	41.6	4.63	1.92	0.0	0.00
7/11/10		GT Wk	41.6	39.86	41.6	4.24	1.76	0.0	0.00
8/11/10		GT Wk	41.6	39.86	41.6	0.34	0.14	0.0	0.00
9/11/10		GT Wk	41.6	39.86	41.6	0	0.00	4.3	1.78
10/11/10	41.98	GT Wk	41.6	41.98	41.6	0	0.00	8.7	3.63
11/11/10		GT Wk	48.8	41.98	48.8	4.76	2.32	0.0	0.00
12/11/10		GT Wk	48.8	41.98	48.8	9.25	4.51	8.73	4.26
13/11/10		GT Wk	48.8	41.98	48.8	0.15	0.07	0.00	0.00
14/11/10		GT Wk	48.8	41.98	48.8	0.00	0.00	0.00	0.00
15/11/10		GT Wk	48.8	41.98	48.8	0.00	0.00	4.37	2.13
16/11/10		GT Wk	48.8	41.98	48.8	0.00	0.00	0.00	0.00
17/11/10	37.37	GT Wk	48.8	37.37	48.8	4.18	2.04	4.37	2.13

18/11/10		GT Wk	48.8	37.37	48.8	5.11	2.49	4.21	2.06
19/11/10		GT Wk	48.5	37.37	48.5	0.44	0.21	0.00	0.00
20/11/10		GT Wk	48.5	37.37	48.5	4.32	2.10	4.01	1.94
21/11/10		GT Wk	48.5	37.37	48.5	4.92	2.39	0.02	0.01
22/11/10		GT Wk	48.5	37.37	48.5	0.47	0.23	0.00	0.00
23/11/10		GT Wk	48.5	37.37	48.5	4.86	2.36	4.40	2.13
24/11/10	38.83	GT Wk	48.5	38.83	48.5	0.00	0.00	0.00	0.00
25/11/10		GT Wk	48.5	38.83	48.5	4.03	1.95	4.24	2.06
26/11/10		GT Wk	48.5	38.83	48.5	4.81	2.33	4.16	2.02
27/11/10		EST	48.5	38.83		4.63	2.24	4.17	2.02
28/11/10		EST	48.5	38.83		1.02	0.50	0.04	0.02
29/11/10		EST	48.5	38.83		4.42	2.14	4.22	2.05
30/11/10		EST	48.5	38.83		0.41	0.20	0.00	0.00
1/12/10	38.20	EST	48.5	38.20		4.84	2.35	0.75	0.36
2/12/10		EST	48.5	38.20		3.95	1.92	0.04	0.02
3/12/10		EST	48.5	38.20		5.25	2.55	4.12	2.00
4/12/10		EST	48.5	38.20		0.49	0.24	0.00	0.00
5/12/10		EST	48.5	38.20		4.02	1.95	4.25	2.06
6/12/10		EST	48.5	38.20		0.80	0.39	0.00	0.00
7/12/10		EST	48.5	38.20		4.89	2.37	4.42	2.14
8/12/10		EST	48.5	38.20		0.00	0.00	0.00	0.00
9/12/10		EST	48.5	38.20		4.79	2.32	4.34	2.10
10/12/10		EST	48.5	38.20		0.06	0.03	0.00	0.00
11/12/10		EST	48.5	38.20		0.00	0.00	0.00	0.00
12/12/10		EST	48.5	38.20		1.56	0.76	4.38	2.12
13/12/10		EST	48.5	38.20		0.00	0.00	0.00	0.00
14/12/10		EST	48.5	38.20		0.00	0.00	0.00	0.00
15/12/10		EST	48.5	38.20		0.00	0.00	0.00	0.00

Appendix 10 - Rain gauge data

Period:	16-03-10 to 31-03-10						
	A	B	C		MEAN	EFFLUENT APPLIED	
Rainfall	23	22	23.5	21.5	23		%
F1	51	51.5	50		51	28	107
F2	47	63	58		56	34	126
F3	23.5	50.5	49		41	19	70
F4	56	58.5	57.5		57	35	131
F5	39.5	26.5	50		39	16	61
F6	57	56	53		55	33	124
F7	24	58	58.5		47	24	92
F8	31	51	56		46	24	89
G1	62	62	62.5		62	40	116
G2	45	51.5	51.5		49	27	78
G3	56	58	56		57	34	100
G4	47	66	64		59	37	106
Period:	31-03-10 to 29-04-10						
	A	B	C		MEAN	EFFLUENT APPLIED	
Rainfall	27	27	27	28.5	27		%
F1	77	77	75		76	49	95
F2	58	98	100		85	58	113
F3	77	80	77		78	51	99
F4	92	94	89		92	64	125
F5	53	33	82		56	29	56
F6	85	89	85		86	59	115
F7	45	94	96		78	51	99
F8	55	87	92		78	51	99
G1	84	86	87		86	58	105
G2	61	73	76		70	43	77
G3	86	86	81		84	57	103
G4	76	98	101		92	64	116
Period:	27-05-10 to 09-06-10						
	A	B	C		MEAN	EFFLUENT APPLIED	
Rainfall	92	94	92	91	92		%
F1	120	0	114		117	25	57
F2	128	124	129		127	35	80
F3	160	160	160		160	68	156
F4	160	160	160		160	68	156
F5	112	113	112		112	20	46
F6	160	160	160		160	68	156
F7	124	120	127		124	31	73
F8	125	122	126		124	32	74
G1	132	132	133		132	40	102
G2	116	122	124		121	28	72
G3	126	128	126		127	34	87
G4	126	160	155		147	55	139
Period:	09-06-10 to 22-06-10						
	A	B	C		MEAN	EFFLUENT APPLIED	
Rainfall	79	79	80	80	80		%
F1	121	0	114		118	38	102
F2	121	123	132		125	46	123
F3	0	0	89		89		134
F4	0	0	0		0		134
F5	106	108	104		106	27	71
F6	0	0	0		0		140
F7	117	114	124		118	39	104
F8	113	112	124		116	37	99
G1	155	158	158		157	78	112
G2	122	136	143		134	54	78
G3	147	153	147		149	70	100
G4	139	165	165		156	77	111

Period:	18-08-10 to 08-09-10						
	A	B	C		MEAN	EFFLUENT APPLIED	
Rainfall	62	63	64	63	63		%
F1	113	0	110		112	49	118
F2	108	104	117		110	47	114
F3	108	109	0		109	46	111
F4	110	111	105		109	46	111
F5	112	96	93		100	37	91
F6	113	115	0		114	51	124
F7	64	65	102		77	14	34
F8	104	100	104		103	40	97
G1	full	full	full		160	97	112
G2	120	138	142		133	70	81
G3	141	150	147		146	83	96
G4	140	full	full		160	97	112
Period:	17-11-10 to 26-11-10						
	A	B	C		MEAN	EFFLUENT APPLIED	
Rainfall	11	10	11	10	11		%
F1					39	29	83
F2					51	41	118
F3					40	30	86
F4					47	37	106
F5	45	41	38		41	31	90
F6					49	39	112
F7	51	49	44		48	38	109
F8					44	34	97
G1					42	32	112
G2	30	35	34		33	23	80
G3					39	29	101
G4	33	44	44		40	30	106
Period:	to 14/12/10						
	A	B	C		MEAN	EFFLUENT APPLIED	
Rainfall	0	0	0	0	0		%
F1					33	33	100
F2					41	41	124
F3					29	29	88
F4					33	33	100
F5	28	27	22		26	26	78
F6					36	36	109
F7	38	36	38		37	37	113
F8					29	29	88
G1					30	30	107
G2	22	23	23		23	23	81
G3					25	25	89
G4	25	38	41		35	35	123

Appendix 11 – View Road groundwater monitoring bore locations

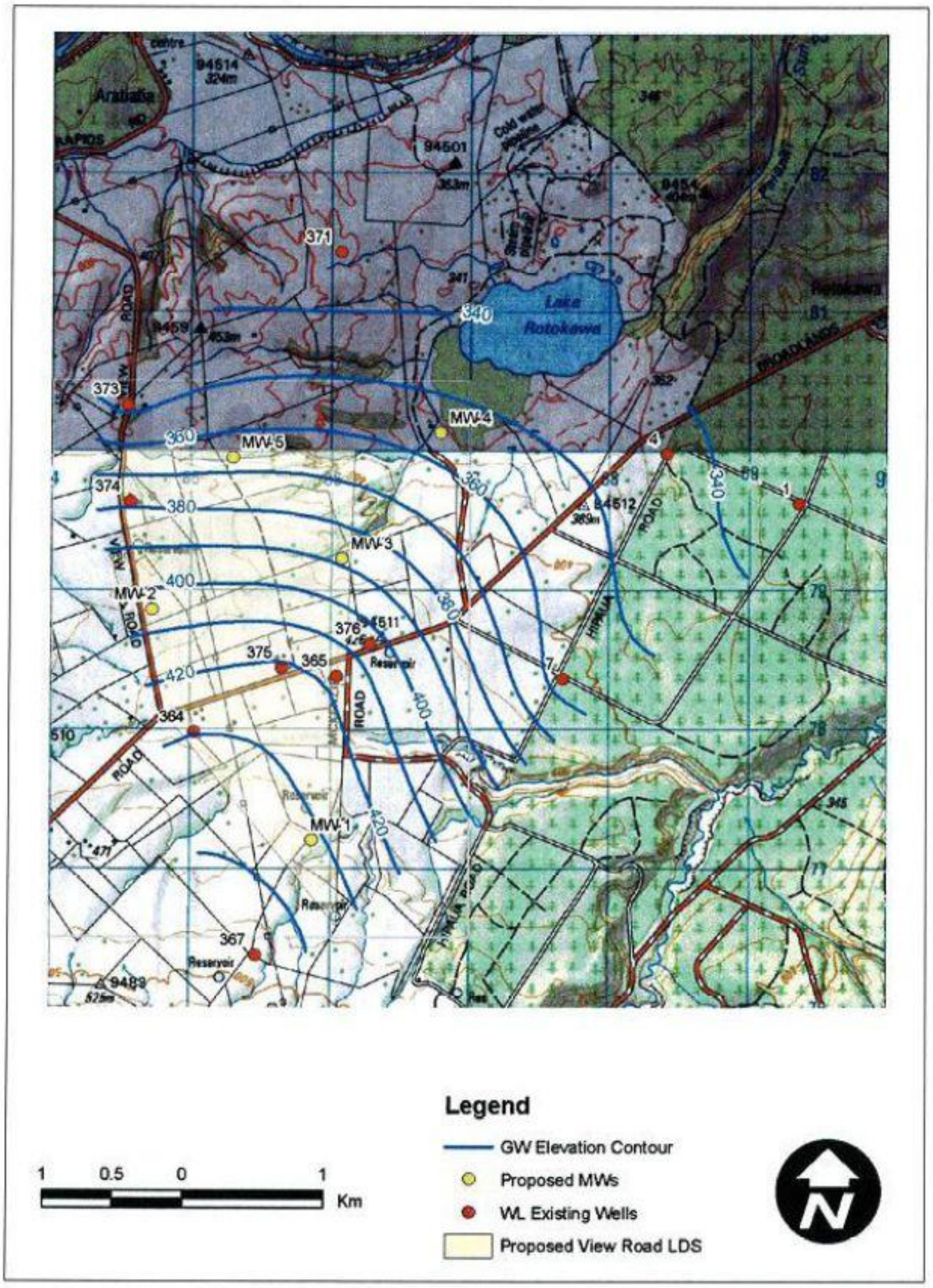


Figure 5. Proposed New Monitoring Well Locations*.

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