EFFECTS OF LAND USE CHANGE ON SOIL AND WATER QUALITY AND PLANT SPECIES COMPOSITION OF CEDARA WETLANDS

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ABBREVIATIONS

ANOVA -Analysis of Variance
CEC – Cation Exchange Capacity
DEAT- Department of Environmental Affairs and Tourism
DWAF – Department Of Water Affairs and Forestry
LSD – Least of Significant differences
NEMA –National Environmental Management Act of South African
RSA – Republic of South Africa
SE – Standard error

ABSTRACT

Wetlands are vital in the provision of ecosystem services and land use change could affect their functioning and health. Disposal of organic waste slurries on wetlands could result in high nutrient loads, whereas drainage for agriculture, could adversely affect their characteristics, particularly soil properties. The purpose of this study was to assess the effects of land use changes on soil chemical properties, water quality and plant species composition of three wetlands at Cedara. One wetland was used for discharge of sewage effluent and dairy slurry; another was drained using ridge/furrow system and used for pasture production, while the third, undisturbed wetland, was used as the control. A soil survey was carried out to identify soil forms and soil sampling was done on transects at 0–20, 20–40, 40–60 and 60–100 cm depths, and the samples were analysed for pH, clay content, total C and N, CEC, exchangeable K, Ca, Na, Mg, available Mn, Zn, Cu and P. Water samples, taken during different seasons from upstream, midstream and downstream positions, were analysed for quality parameters. Grass species were identified for species composition. Wetland areal extends were greater when soil properties were used to delineate wetland bounderies than when diagnostic plant species were used. The dominant soil form in all wetlands was Katspruit, with Pinedene, Clovelly, Griffin and Hutton on the edges. Soils in all wetlands were acidic, with the drained wetland having higher pH, Ca and Mg concentrations. The dairy/sewage wetland had significantly higher P, Zn and Cu than the ridge/furrow drained wetland while the undisturbed wetland had the least. The undisturbed wetland had higher total C, N and available Mn concentrations than the other two. In the water samples pH, Ca, Mg and P was higher in the ridge/furrow drained wetland than the others. The undisturbed wetland had higher species composition and had more wetland plant species than the other wetlands which mostly had pasture grasses. The findings suggested that land use change will reduce soil C and N and available Mn, and modify the concentrations of available P and micronutrients and bases in the soil, impair water quality and ultimately result in loss of wetland plant species diversity.

***Keywords*:** Drainage, dairy slurry, sewage waste, total carbon, phosphorus, micronutrients

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CHAPTER ONE: INTRODUCTION

1.1 Background

Wetland utilization and degradation are driven by a number of reasons in South Africa and other developing countries. Among the most prominent reasons, in South Africa, are limited water supplies and arable land. The annual average rainfall in South Africa is less than 500mm, a figure way below the world average of 860 mm (Basson et al., 1997). Such a low rainfall makes the country water scarce, and the challenge is further exacerbated by the fact that most of the available water resources are degraded by pollution and soil erosion, mainly due to human activities (Dini et al, 1998). The water resources, e.g. lakes, rivers, and wetlands, lose their functionality, resulting in species extinction and loss of ecosystem services, such as nutrient cycling, heavy metal retention, and flood control (Basson *et al.*, 1997). Almost 60% of river ecosystems are threatened, with 25% of these critically endangered (Kotze *et al.*, 1995). Wetland ecosystems, in particular, are of even greater concern with about 65% of them being identified as threatened, including a staggering 48% critically endangered (DWAF, 2012). This is a great concern especially in light of the irreplaceable core functions and benefits of these systems. Pollution, coupled with erosion and others factors, remain the key environmental problems facing South Africa‟s water resources.

Major sources of pollution include domestic and industrial effluent from urban areas, eroded soil and other material dislodged by runoff containing chemicals, herbicides and suspended sediments from agricultural lands (Wall, 2010; Kotze, 2000). The consequences of these processes include the silting up of dams and reservoirs, leading to a loss of storage capacity, poor water quality leading to increased purification costs, reduced oxygen levels, and loss of aquatic life. Nutrients such as nitrogen (N) and phosphorus (P) eroded from agricultural fields into water sources affect the health and reproduction of aquatic species, posing a serious threat to biological diversity. Wetlands play a significant role in reducing the impact of such degradation and pollution on water resources (Hamme, 1989; Raisen and Mitere, 1995; Wood, 1999; Mitsch, 2000).

Wetlands, and their specialized vegetation, act as natural filters by trapping sediments and pollutants, thus improving the quality of runoff water from urban and agricultural (Kotze, 2000). Additionally, wetland habitats support a diversity of species; invertebrates, insects, plants, reptiles and vertebrates. However, the function of most wetlands to date has been hampered by human activities.

Most wetlands globally, have been destroyed or damaged to the point where they are dysfunctional (Schuyt and Brander, 2004). Overgrazing, road construction, and conversion to forestry and agriculture have highly contributed to wetland degradation (Kotze, 2004). Draining and converting wetlands to croplands has been demonstrated to have high impacts on wetland characteristics and functioning, leading to degradation (Willrich and Smith, 1970; Kotze and Breen, 2000). Problems related to water quality, nutrient losses from soils, erosion, and ecosystem destruction are often identified as being a result of wetland drainage (Holden *et al*., 2004). The lowering of the water table following drainage leads to a number of processes taking place within the soil that affects both its physical and chemical properties. Bulk density may increase by up to 63% due to accelerated mineralization of organic matter in the upper 40 cm within a few years of drainage (Silins and Rothwell, 1998). It may also result in the collapse of readily drainable macropores, which are ordinarily important pathways for runoff generation and retention in wetlands **(**Holdena *et al*., 2004**)**.

Drainage and subsequent lowering of the water table has been hypothesized to change wetlands from carbon sinks to carbon sources to the atmosphere as a result of increased oxidation of organic matter (Holdena *et al*., 2004). The exchangeable cation content in drained wetlands has been reported to be lower than in undisturbed wetlands and total concentrations of N and P often increase whereas K always decreases in the topsoil (0–20 cm) of wetlands after drainage (Laiho *et al*., 1998; Sundstrom *et al*., 2000).

In South Africa, 50% of wetlands have been destroyed, largely due to agricultural expansion and overgrazing in the last several decades (Kotze *et al*., 1995). Many wetlands in KwaZulu-Natal province were drained and converted to cropping land (mainly for sugarcane, timber and pastures) by implementing ridge and furrow systems based on research in the 1970"s (KZN Department of Agriculture, 1998). More recently, research suggests that the conversion of wetlands into agricultural land has caused the degradation and destruction of the majority of wetlands (Olhan *et al*., 2010; Kotze and Breen, 2000). As a result, efforts are being made to conserve and restore the remaining wetlands in the Province (Kotze, 2000).

There is a growing awareness that restoration is essential to resuscitate ecosystems that have been degraded or destroyed. The conservation of wetlands has been studied extensively globally and in more recent decades, in South Africa. While there is a significant amount of information and a number of studies within KZN, there is little or no information of the wetland situation at Cedara, yet it lies within the Umgeni vlei, which was declared as one of the wetlands of international importance by the Ramsar Convention in 2014.

1.2 Justification of study

A number of wetlands, covering approximately 6227 ha hectares, occur in the Midlands region of KwaZulu-Natal including at Cedara (DWAF, 2004). Cedara, the research farm of the KZN Department of Agriculture and Rural Development, is situated in the KZN Midlands and is used for integrated farming systems research trials, to provide information on sustainable agriculture in the Province. Within the farm, there is infrastructure for Departmental officials and other residents forming a large housing community (Khanya Village). These residents and downstream users depend heavily on existing water resources. Some of the wetlands at Cedara have been drained in order to support farming. There is need to evaluate the cumulative impacts of draining wetlands on wetland ecosystems soil chemical properties and water quality at Cedara wetlands.

Large amounts of organic wastes are produced in high density human settlements and from intensive animal production systems like dairy and piggery. Wetlands are often used to purify the waste waters by trapping pollutants i.e. sediments, excess nutrients (especially nitrogen and phosphorus), heavy metals, disease-causing bacteria and viruses, and synthesized organic pollutants such as pesticides. Dairy slurry and sewage waste are directed to a natural wetland at Cedara. The effects of these changes in land use of the wetlands on soil chemical properties, water quality and plant species need to be understood. Rehabilitation of degraded wetlands will need baseline information and studies on soil and water quality and plant species composition of the different wetlands will provide the necessary baseline information. The information obtained could be used as a basis of restoration and management of degraded Cedara wetlands and to assess effects of efforts to reverse wetland losses in the future.

1.3 Hypothesis

The hypothesis of this study is that changing land use of Cedara wetlands from their natural state for an agricultural purpose and organic waste management has impacted on soil properties, water quality and plant species composition.

1.4 Main Objectives

The primary objective of this research is to evaluate the impact of land use change on soil properties, water quality and plant species diversity of wetlands at Cedara.

1.5 Specific Objectives

i) To determine the effects of land use change on wetland soil chemical properties;
ii) To determine the impact of land use change on wetland water quality;
iii) To determine the impact of land use change on wetland vegetation species composition.

CHAPTER TWO: LITERATURE REVIEW

2.1 Definition and function of wetlands

Literature provides a range of definitions to wetlands. Wetland definition is very important because it helps in their identification and delineation (Dini et al, 1998). The RAMSAR Convention (1971) described wetlands as "areas of marsh, fern, wetland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six metres". Wetlands, as defined by the South African National Water Act, No 36 of 1998, are lands that are transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or land that is periodically covered with shallow water and usually inhabited by hydrophytic vegetation. The wetland soils must display signs of wetness within 50cm of the soil surface. This depth has been chosen because experience internationally has shown that frequent saturation of the top 50cm of soil is necessary to support hydrophytic vegetation.

Some wetlands remain permanently flooded for the entire course of the year, whereas some are seasonally flooded (5-11 months) and some experience temporal saturation (1-4 months) but yet still enough to develop and display the characteristic signs of wetness, typical of wetlands (Braack et al, 2000). This is important to note because wetlands in South Africa are predominantly seasonal, and therefore wetlands of no apparent importance may become significant at certain times (Cowan, 2000).

Regardless of how one can describe what constitutes a wetland, the primary functions of wetlands of providing key ecosystem services to humankind remain the most important asppect. Wetlands act as centres of biodiversity providing habitat for large populations of organisms including invertebrates, insects, plant species, reptiles and vertebrate species (Hails, 1996). They act as "kidneys" of the water cycle, conserving water, regulating runoff, sequestrating carbon and purifying water from pollutants (Blanken and Rouse, 1996; Zhao, 1999; Chen and Lu, 2003; Peregon *et al.*, 2007; Kayranli *et al.*, 2010; Wang *et al.*, 2010). Other functions of wetlands include those which are of direct value for society, providing grazing land for livestock, direct water abstraction, biodiversity and limited cultivation of food crops (Kotze *et al.*, 1995, Walters and Koopman, unpublished). They also reduce the severity of droughts and floods due to their gentle slopes and resistance offered by the dense vegetation they support, spreading of water over a wide area of a wetland (Braack et al, 2000).

2.2 Distribution and uses of wetlands in South Africa

Wetland distribution in South Africa is still insufficiently mapped, although various wetland mapping initiatives have been undertaken in some parts of the country, including the KwaZulu-Natal province (Grundling et al., 2013, Dini, 2004). Studies in several major catchments indicate that wetland loss is in the range of 35 to 50% (Dini, 2004). This makes wetlands the most threatened ecosystems in the world today, despite the functions and values that they hold.

Cowan (2000) also weighs in on the subject and estimates that over half of South African wetlands have been lost already, with those remaining among the most threatened natural areas. Most of these losses are attributed to human activities (Dini et al, 1998). Huge wetland losses have been through drainages for crop and pasture production, poorly managed burning and grazing often resulting in donga erosion, the planting of alien trees, mining, pollution and urban development (DWAF, 2005). This alters the water flow and water quality, and consequently damage the wetland. Predictions assert that continued wetland destruction will effectively result in poor water quality and less reliable supplies, increased and severe flooding, low agricultural produce, and probably more endangered species (DWAF, 2005).

Most South African wetlands have a dominant vegetation of reeds (*Phragmites australis*), Carex species, bulrush (*Typha capensis*), grasses and other sedges (*Cyperus papyrus*), to a lesser extent (Grundling, 2004). The gradual change in the vegetation along a wetland boundary gradient means that the outer parts of the wetland often have a mixture of species that occur widely outside of wetlands (e.g. ngongoni grass [*Aristida junciformis*] and rooigras [*Themedatriandra*]) and species specifically adapted to saturated soil conditions and confined to wetlands (e.g. the sedge *Pycreus macranthus*). The continued destruction of these systems poses serious threats in plant species structure and composition.

2.3 Land use change in wetlands

Wetland utilization is common in South Africa, sometimes justified by the prevailing climatic conditions referred to in the introduction. Braack *et al.* (2000) argue that wetland utilization is possible but such should be done in a sustainable manner with an acceptable impact. However, the last 150 years of wetland transformation and utilization has witnessed a 50% loss of wetlands (O'Connell, 2003, Dini, 2004), as previously alluded to. Most of these wetlands are transformed into other land use types, e.g. arable land (Fernández *et al*., 2010; Zhang *et al*., 2007; Zhao *et al*., 2004). In South Africa many wetlands were transformed by drainage through ridge and furrow system, which was regulated by the Conservation Resource Act (No 43/1983).

Almost all the major wetlands in the upper Mooi and Mgeni catchments have been drained at some stage, with the majority of these drainage networks being established over 60 years ago. Draining was carried out with the purpose of lowering the water table and removing surface water to expand the area of arable land.

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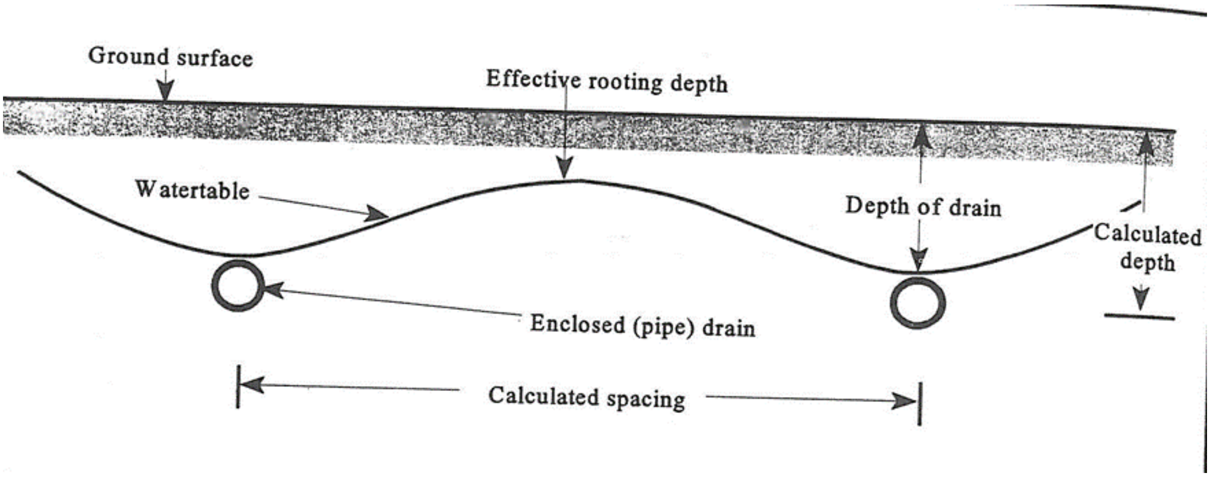

Figure 1: Drainage of wetlands (Conservation of Farmlands in KwaZulu-Natal, 1997)

The drained wetlands have either been planted to pasture or crops such as maize (Kotze 2004; DWAF, 2004). These wetland drainage systems were constructed in what is termed a „herring bone‟ design which involved drains running along either side of the wetlands in order to cut off flow from adjacent slopes (DWAF, 2004). The natural channels were captured at the head of the wetland and flow was concentrated into the main drain which runs directly through the lowest point, normally the middle of the wetland. In addition, smaller cross drains run at an angle from the side drains to the main drain in the centre of the wetland. Crops and pastures were planted in the areas between the drains.

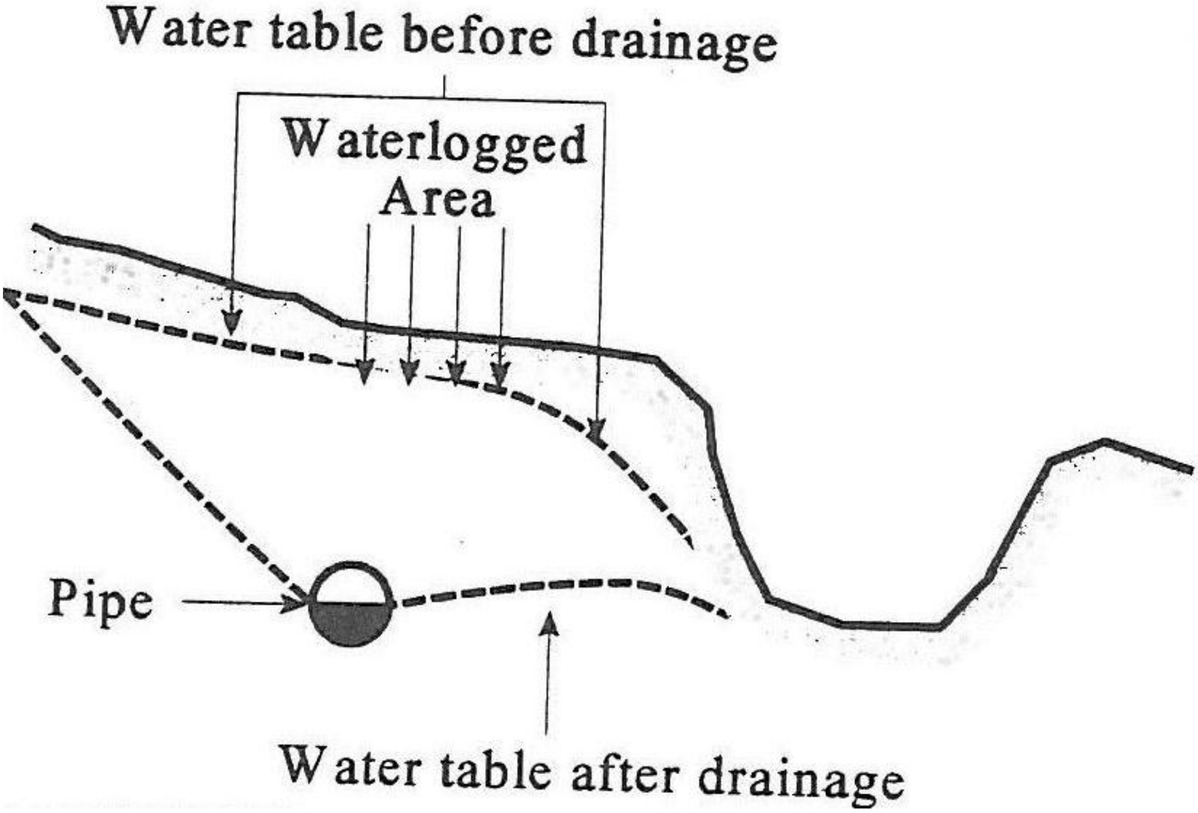

Figure 2: An inceptor drain of wetlands (Conservation of Farmlands in KwaZulu-Natal, 1997)

The „ridge and furrow" technique was used to make wetlands „drier" and thereby useful to farmers. This method involved the creation of parallel ridges and furrows across the length and breadth of wetland. The soil extracted from the furrows was used in building up the ridge so that they were wider than the furrows. The design was aimed to concentrate flow in the furrows and allow pasture species to grow on the higher, wider and drier ridges thereby increasing the area under food for livestock (DWAF, 2004).

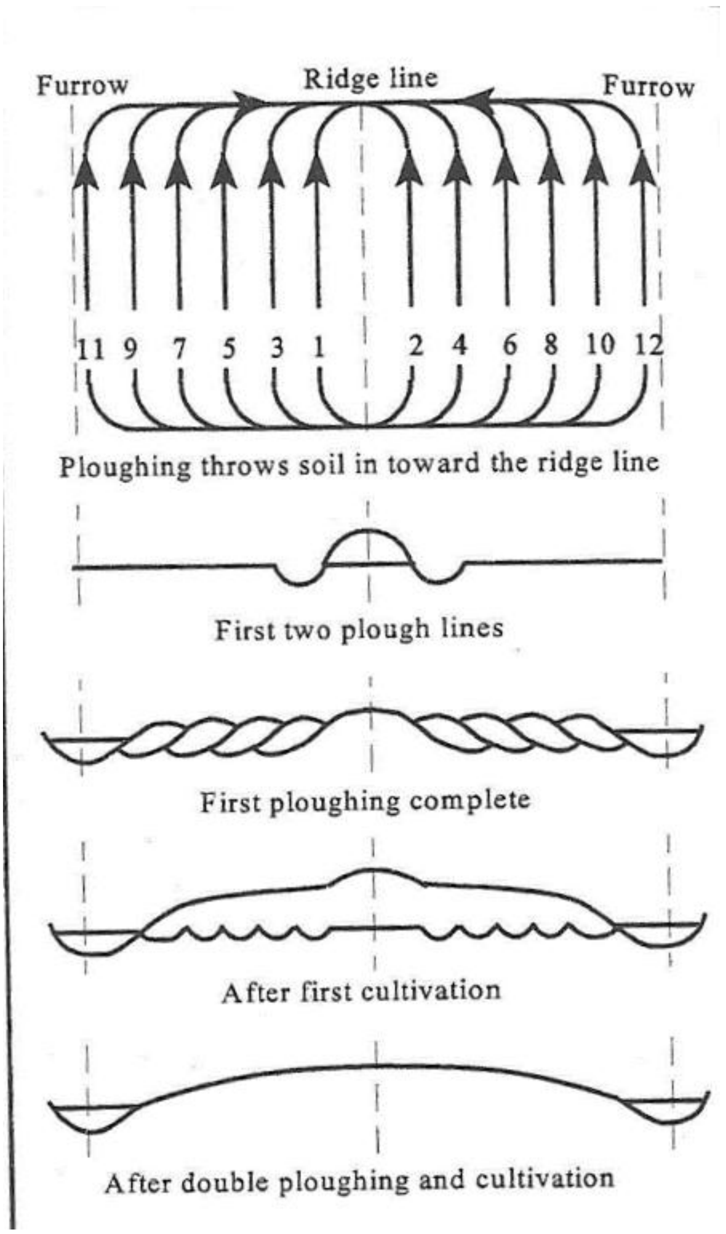

Figure 3: Development of ridge and furrows in a wetland (Conservation of Farmlands in KwaZulu-Natal, 1997)

However, research, internationally and locally, has shown that the changes in land use of those wetland areas have posed serious threats, associated with loss of biodiversity and overall decline in ecosystem services. Wetland use changes have been proven to, not only alter the hydrological regime, but also disturb the natural soil profile of the wetland (O'mar et al., 2014). New regulations in South Africa have since been enacted, with the aim of protecting wetlands.

The current Legislation, the National Environmental Management Act (NEMA) states that land users are forbidden (without successfully obtaining the necessary permission) to drain or cultivate any vlei, marsh or water sponge or portion thereof on their land or to cultivate any land within the flood area of a water course. With regards to wetland drainage existing wet agricultural lands (developed wetlands) the law states that existing drains may not be widened or deepened, and should be kept only if they can be maintained by hand. No erosion may be present in drains or in drained wetlands. Although these laws were passed in 1998, many wetland users are still not aware of them. Continual negligence and lack of knowledge about wetlands will result in degradation and their eventual loss (Mharapara *et al*., 1997). Different land uses, which include cultivation, grazing, and dairy can negatively affect the functionality of these ecosystems.

2.4 Impact of change in land-use on wetlands

Impacts on wetlands result from both „on-site‟ and „off-site‟ activities (Kotze, unknown). On-site activities, meaning at the wetland site itself, include drainage, disturbance through cultivation, roads, infilling, and flooding by dams. On the other hand, off-site activities, referring to those happening in the wetland‟s surrounding catchment, include afforestation, mining and crop production, to mention but a few.

Wetland cultivation for one has become an integral part of the agricultural system as wetland soils generally tend to be chemically fertile (Bell *et al*., 1987). Cultivation of these ecosystems has been said to increase food security, especially in rural communities where people highly depend on agriculture for their survival. Their utilization is due to their wetness and fertility (Matiza, 1992; Mharapara, 1995). Wetlands remain wet further into the dry season and this makes them valuable for agricultural activities in areas where droughts are prevalent (Ingram, 1991). Therefore, hydrological properties of wetlands, in particular their ability to retain water during dry spells are important factors determining their agricultural potential (Mkwanda, 1995). Wetland soils, once drained, can therefore be of high agricultural potential.

Disturbances of the soil associated with open cut drainage ditches and cultivation, however, has many disadvantages and has created significant threats to the sustainability of natural wetlands. Cultivation practices alter wetland characteristics such as mineralization, infiltration capacity, soil moisture retention, rate of runoff and erosion, pH and availability of nutrients. Mineralization processes are significant, particularly in wetlands affected by long term cultivation and different cropping practices (Qualls and Richardson, 2000; Mendelssohn *et al.*, 1999). Organic matter decomposition under drained conditions proceeds from two- (Reddy and Patrick, 1975) to threefold (DeBusk and Reddy, 1998) faster than under flooded conditions. In the absence of molecular oxygen (O_2), such as under flooded soil conditions, other soil nutrient electron acceptors, such as nitrate (NO_3^-), ferric iron (Fe^{3+}), manganic manganese ($Mn^{4+)}$, sulfate (SO_4), and carbon dioxide (CO_2) are used to satisfy microbial respiratory requirements at a low energy value.

Drying or wetland conversion to agricultural use may lead to mineralization and/or immobilization of stored nutrients because of the changes in soil redox status. Changing soil redox status exerts a strong influence on the microbial community, organic matter mineralization rates, and mineral equilibrium (Ponnamperuma, 1972; Rowell, 1981).

Concerns about the effects of change in land use of wetlands as well as agricultural management practices on wetland health have initiated interest in soil quality/health. For example, disposal of dairy slurry on wetlands could result in high nutrient loads which could potentially lead to greenhouse gas emissions (GHG) whereas drainage for agriculture, could adversely affect their characteristics, particularly soil chemical properties.

The conversion of natural wetlands into agricultural land involves three basic processes:
1) the removal of natural vegetation,
2) draining of soils by ditches and ridge and furrows, and
3) annual fertilizer and lime application to increase availability of plant nutrients and pH to levels suited for the intended crop.

Other important developments such as roads can have negative impacts on wetlands. Roads are often constructed through wetlands, thereby dividing them and changing their nature. In addition, the runoff from roads may create unexpected water movement or erosion some distance from the roads, thereby leading to unanticipated impacts on wetlands. The South African National Roads Agency Limited and National Roads Act (SANRAL, 1998, The EIA regulations, The National Water Act aim to regulate these problems.

2.4.1 Land use changes on soil properties

Soil physical properties

Soil aggregate size distribution and stability are important indicators of soil physical quality and these reflect the impact of land use and soil management (Castro Filho et al., 2002). Conversion of wetlands to other land uses (i.e. cultivation or drainage) could result in higher bulk density, lower hydraulic conductivity, and higher susceptibility to soil erosion, thereby acceleration soil degradation and decline in soil organic carbon concentration (Lal, 2003). Cultivation also impacts soil structure, it lowers the clay content through promotion of disaggregation of soil leading to precipitation of clay particles into lower horizons and increased accumulation of fine silt particles on surface (Mulatu et al, 2013, Belay and Hunt, 2000).

Chemical Properties

Soil disturbance arising from processes such as cultivation affect the spatial pattern of soil pH, nutrient concentration and soil organic matter content (Cohen et al., 2008). These may however, vary with the type of land use and soil types (Kowal, 1969; Whitlow, 1983). Soil nutrients in particular play a critical role in the biogeochemistry and primary productivity of wetlands and their content changes can be influenced strongly by land-use types and hydrological conditions.

A number of studies have observed that the exchangeable cation content in drained wetlands is lower than in undisturbed wetlands and total concentrations of N and P often increase whereas K always decreases in the topsoil (0–20 cm) of a wetland after drainage (Laiho *et al.*, 1998; Sundstrom *et al.*, 2000). For example, Sundstrom *et al.* (2000) observed that drainage with 60m ditch spacing led to an increase in concentration of total N and P, a decrease in concentrations of total K, calcium (Ca) and magnesium (Mg) and had little effect on soil pH. as a result of aeration of topsoil, accelerated decomposition and increased nutrient release.
The study further observed an even greater increase in the total N and P in the topsoil, with minor changes for both Ca and Mg, and much less in K, containing only 25–40% of the K that was initially present prior to drainage (Sundstrom *et al.*, 2000). A similar observation was reported in Paavilainen and Päivänen (1995).

The increase in total N concentrations observed in the topsoil of wetland following drainage is due to an increase in the retention of N by microbial immobilization as the plant residues in the wetland decompose and total N is increased per unit volume of wetland (Wells and Williams, 1996), which also results in a lowering of the C:N ratio. However, many studies have also observed that drainage and the consequent lowering of the water table results in an increase in N mineralization (Williams, 1974; Williams and Wheatley, 1988), in response to an increase in oxygen and the number of ammonifying and nitrifying bacteria. Williams and Wheatley (1988) observed that on lowering the water table from 0 to 50 cm the mean content of available mineral N in the wetland profile increased by a factor of 1.5. The response of N mineralization to water table lowering, however, is not always predictable. For example, Williams (1974) observed that lowering the water table to 18 cm significantly decreased the amount of N mineralized in the top 10 cm of wetland but that further lowering of the water table to 34 cm increased mineralization in the top 10 cm.

Mineralization–immobilization responses of soil N to wetland land drainage depend largely on the change in wetland decomposition rate, which is regulated by environmental (temperature, pH) and soil factors (decomposition, organic matter quality, nutrient content). Although lowering the water table should eliminate poor aeration as the foremost limitation to mineralization, the improved aeration may have little impact on mineralization rates if temperature, pH or nutritional constraints still inhibit microbial activity. Humphrey and Pluth (1996) observed that N mineralization rates did not respond to drainage in wetland at pH 4.0 but were significantly stimulated in wetland at pH 7.2.

2.4.2 Land use change on water quality

Natural wetlands have been known for decades to improve water quality. Natural processes within wetlands (e.g. sedimentation, biological assimilation, plant filtration) function to improve water quality by serving as a sink for pollutants such as excess nutrients and heavy metals (Saunders and Kalff, 2001; Walker and Hurl, 2002). As a result, constructed wetlands are being increasingly used as natural alternative systems for wastewater treatment.

Any change in land use of wetlands alters the texture and composition of the land surface and therefore influences water quality (Belke, 2007). In the case of wetland cultivation, run-off contaminated by fertilizers and biocides can drastically increase the nutrient levels of recipient wetlands, disrupting their ecosystem processes (Jeffries and Mills, 1990; Gopal,

2003) and reduces the quality of wetland waters. Nutrients like N and P are essential for plant and animal growth. However, excessive amounts of these nutrients may result in accelerated growth of algae, which may essentially block sunlight needed by plants and other aquatic life in wetlands. On the other hand drainage of wetlands promotes erosion of sediments (sand, silt, clay and plant material) resulting in high turbidity. Excessive turbidity causes problems for drinking water quality, impeding light transmission thus hampers photosynthesis thereby suppressing primary production and reducing oxygen levels, which in turn affects biota distribution and habitat selection (Dörgeloh, 1995, Hart, 1999, Mashele, 2013).

Land use change, which involves the conversion of wetlands to other uses such as pastures, presents a real and pervasive threat to the biodiversity of wetland ecosystems. Water pollution derived from these land use changes has become a major concern (Mitsch and Gosselink, 2000). Major pollutants in agricultural systems are derived from upstream applications of fertilizers, dairy, dairy washings containing high amounts of both organic and inorganic salts affecting water quality. Runoff water from irrigated pastures, creates a significant form of non-point source pollution, contributing to water quality impairment due to an overabundance of nutrients and/or toxicity of pesticides with special emphasis on, salinity which can affect plant growth (Lissner et al., 1999) and nitrogen mineralization (Irshad *et al*., 2005). Upstream agricultural intensification often includes a substantial increase in the rates of nitrogen (N) fertilizer application, which improves yields but has deleterious consequences for downstream aquatic systems, where nutrient loading can drive eutrophication (Howarth *et al*. 1996; Vitousek *et al*. 1997; Boesch *et al*. 2001; Jenkinson, 2001). For example, livestock grazing close to or on the wetland can contribute to soil erosion and therefore enhance sediment accumulation into the wetland, which carry nutrients, thereby contributing to eutrophication through phosphate inputs (DEAT, 2006; Kotze and Breen, 1994; Novotny, 2003).

Generally, wetlands are characterised by an increase in NH_4^+ in soil pore water (Patric and Mahapatra, 1968). The anaerobic conditions in wetlands prevent nitrification, thus more ammonia accumulates in wetlands. Drainage of wetlands to pasture, for example, could increase redox potential, resulting in reduction of ammonium (NH_4^+) concentrations as a result of nitrification (Patric and Mahapatra). Those nitrate could then be washed out of the pore spaces of a soil profile into the streams of the wetlands. In addition to changes in species of N, availability of Fe and Mn could also be affected by their oxidation, due to increases in redox potential.

Wetlands have been considered as low cost alternatives for treating polluted waters but this is no longer possible as many of them have been destroyed by, for example drainage ditches, ridge and furrow systems (Page *et al*., 2010; Moore *et al*., 2009; Seo *et al*., 2005; Schulz et al., 2003; Sherrard et al., 2004). Studies reveal that wetland filtration systems, for example, could reduce up to 30–67% total phosphorous (TP) and 30–52% total nitrogen (TN) of the eutrophic water (Coveney *et al*., 2002). Water quality can however, vary with season and can be significantly affected by precipitation events (Spellman and Drinan, 2000). In order to help control the impact of land uses on surface water bodies, policies and monitoring programs are utilized to determine the quality of the water and potential sources of contamination (DWAF, 1997). Several water quality parameters are measured, including temperature and suspended solids (physical) pH, phosphorous, nitrogen (chemical).

2.4.3 Land use change on plant species composition

Land-use changes in wetlands can result in direct ecosystem loss, as well as fragmentation causing decreases in wetland quality and increases in wetland stress. Wetland loss directly results in low diversity of wetland plant species and loss of ecosystem services performed, such as nutrient cycling, heavy metal retention, and flood control. Wetland drainage and cultivation have resulted in major impacts on wetland hydrology (Dixon, 2002) which is one of the strongest determinant for wetland vegetation, composition and diversity. An alteration in water regime of wetlands affects wetland dependent species and may result in loss of wetland biodiversity (Collins, 2005).

Wetland plants are commonly defined as those “growing in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content” (Cowardin et al., 1979). This term includes both herbaceous (vascular and nonvascular) and woody species. Wetland plants may be floating, floating-leaved, submerged, or emergent and may complete their life cycle in still or flowing water, or on inundated or non-inundated hydric soils (Cronk and Fennessy, 2001). Wetland plants play a crucial role in water quality. They remove nutrients through uptake and accumulation in tissues, and also act as a nutrient pump by moving compounds from the sediment and into the water column.

Wetland plants are excellent indicators of wetland condition for many reasons including their relatively high levels of species richness, rapid growth rates, and direct response to environmental change. Land use change in a wetland has the potential to degrade its ecosystems by causing a shift in plant community composition. Individual species respond differently to a wide range of stressors and thus, as environmental conditions change, a shift in the plant community composition would be observed. Furthermore, wetland cultivation influences community structure and species composition (Fungai, 2006). This is important to note because if the structure and composition is altered, following land use changes or cultivation, one might witness a decline or even disappearance of natural wetland vegetation and invasion of non-wetland vegetation as observed by Dixon (2001), leading to wetland degradation. Mulatu *et al*. (2014) reported interesting observations in terms of species composition changes related to cultivating wetlands. They compared cultivated and uncultivated sites, and measured species dominance. Their findings show the dominance of species belonging to the Cyperaceae family in the uncultivated sites and that of species belonging to the Lamiaceae family in the cultivated sites. This makes evident the impact of land use change in species structure and composition.

2.5 Conclusion

Wetlands have been subject to artificial drainage for many years, mostly in response to demand for agricultural land. However, there have been several environmental problems associated with the drainage of wetlands, which include changes in soil properties, water quality and plant species composition. During wetland drainage, the water table is lowered. The lowering of the water table following drainage leads to a number of processes taking place within the soil profile that affects both its physical and chemical properties thus affecting wetland functions. Current interest has been on the restoration of previously drained wetlands as the first line of defence to mitigate unavoidable wetland loss, there is therefore a serious need to understand the historical condition and chemical and/or biological functions of ecosystems following a conversion from wetlands to agricultural use in South Africa

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study area

The study was conducted on three wetlands situated on Cedara Research Farm of KwaZulu-Natal Department of Agriculture and Rural Development (29^{o}32' 27.6" S, 30^{o}15'57.6" E), north of Pietermaritzburg, South Africa (Figure 1). The area lies in the Moist Midlands Mistbelt Region, with an average summer temperatures of 26 ^{o}C, winter temperatures of 22^{o}C and average annual rainfall of 800 mm/year (ARC, 2012). Generally, the soils are predominantly Hutton on the well-drained slopes, shallow Glenrosa on the steep north-facing slopes and acid, hydromophic soils of the Katspruit form (Scotney, 1987) in the valley bottoms. These wetlands occupy the basins underlain by Karoo dolerite (Smith, 1953) but their soils vary widely with regards to texture, SOC content and pH. Their main floral components are sedges (*Carex cernua*) and grasses (*Aristida junciformis*) (Craven, 1987).

Three wetlands were studied. One wetland (5.1 ha), drained and receives sewage wastes and dairy slurry (Wetland A), another (13.0 ha) has been drained for cultivated pastures by ridge and furrow (Wetland B) (Figure 1; Table 1), while the third (4.7 ha) has had minimal disturbance (Wetland C) and was used as a reference (control) wetland for this study. Wetlands B C drained from the same hillslope and thus had the same upstream conditions, with the stream flowing through Wetland C also passes through Wetland B. Wetland B was downstream of Wetland C. Although Wetland A had a different catchment area, it drained from generally similar conditions, except that it also received sewage and dairy wastes.

Using boundaries derived from a previous study and on-site observations, the preliminary extents of the wetland areas were demarcated, as part of the desktop exercise. These were then used as a guideline in the subsequent data collection for soil chemical analysis, grass species identification and water sampling (See Figure 5&6).

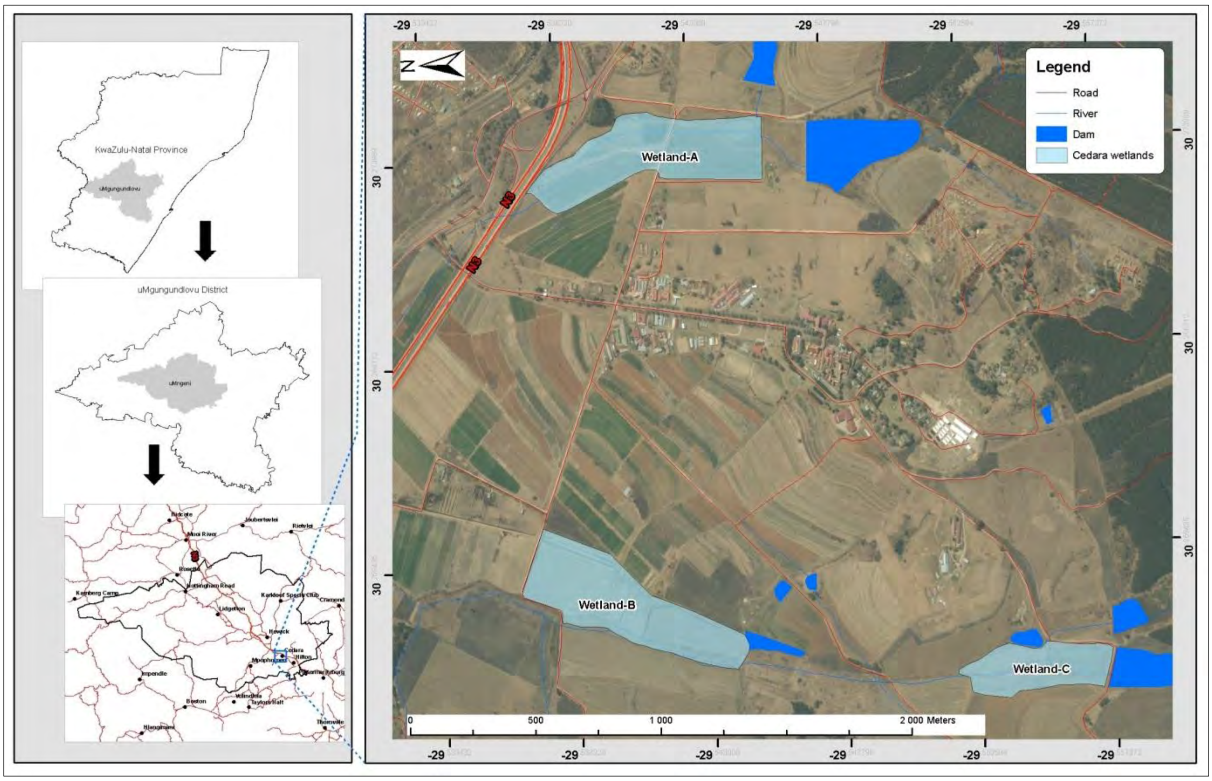

Figure 4: Location of the three wetlands used as study sites at Cedara Research Farm

Table 1: General characteristics of the wetlands studied

Wetland	Wetland A	Wetland B	Wetland C
Current land use	Sewage effluent &Dairy	Drained by Ridge/Furrow	Undisturbed
Location	29°32'19" S 30°16'22" E	29°32'20" S 30°15'30" E	29°33'25" S 30°15'17" E
Year of disturbance	Pastures were grown since 1971/2 to-date	Ridge since 1970 to-date	Cultivation of the wetland was stopped in 1987 since then, grasses have been growing naturally. The site was declared a conservation site of natural significance in 1994
Area (ha)	5.1	4.7	13.0
Vegetation type	Vegetation in the wetland is not uniform. The portion near the sewage between transect 1&2 has been abandoned for the past 2 years. Annual grasses (unmonitored) have been growing. The rest of the area is occupied by sedges, fescue, *Paspalum*, rye and clover grasses	Red & white clover, forbes & sedges, *Eragrotis planda, Cynadon dactylon, Sparobulus africans, Paspalum notatum, Paspalum dilatatum*	Between transect 1& 2 from the big dam, natural wetland grasses are growing. From transect 2 towards transect 3, natural grasses are growing. Growing of pasture was stopped in 1986/7 specifically on the side near the dam because the site was found to be cold. Since 1987 the grasses have been growing naturally
Current condition	Dairy, Pasture, Nearby sewage works, Road cutting through wetland	Veld (Pasture)	Half veld, other half active wetland, Road cutting through wetland

3.2 Soil survey and delineation of wetlands

A soil survey was conducted to establish soil forms and their distributions using soil augers and the soils were classified using the soil keys from the South African Soil Classification System (Soil Classification Working Group, 1991). Procedures outlined in the "Guidelines for the delineation of wetland and riparian zones" (DWAF, 2005) were also followed. Assessment was done based on soil colour, presence of mottles, effective depth, rooting depth, texture and structure. The idea of the soil survey was to identify the soils and their areal extents so that properties of the same soils were compared across wetlands (See figure 5).

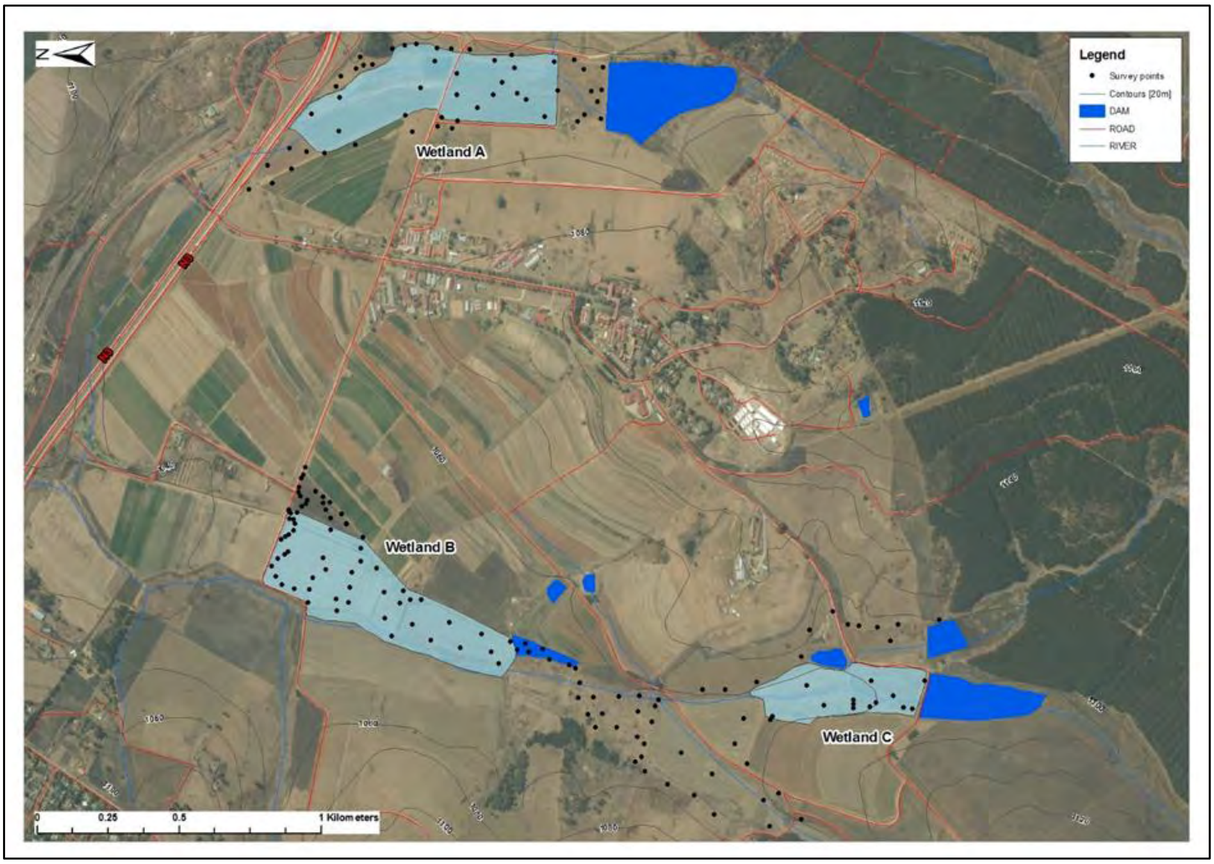

Figure 5: Soil survey points

3.3 Soil sampling

Soil sampling for chemical analysis in soils consisted of cross sectional transects of each preliminary wetland area (4 or 5 depending on size of the wetland), which were about 200 m apart (Figure 2). The number of transects was ultimately determined by the soil variability found. These transects were conducted by auger sampling at 0 – 20, 20 – 40, 40 – 60, and 60 – 100 cm depths. Distance between auger points was about 50 m. All points were accurately located by GPS (Trimble GeoXT). The soils samples were air dried, sieved through a 2 mm and analysed for pH (water), total N and C, CEC, K, Ca, P, Na, Mg, Mn, Zn, Cu. Soil samples for NH_4^+-N and NO_3^--N were kept at 4◦C prior to soil solution extraction and analyses.

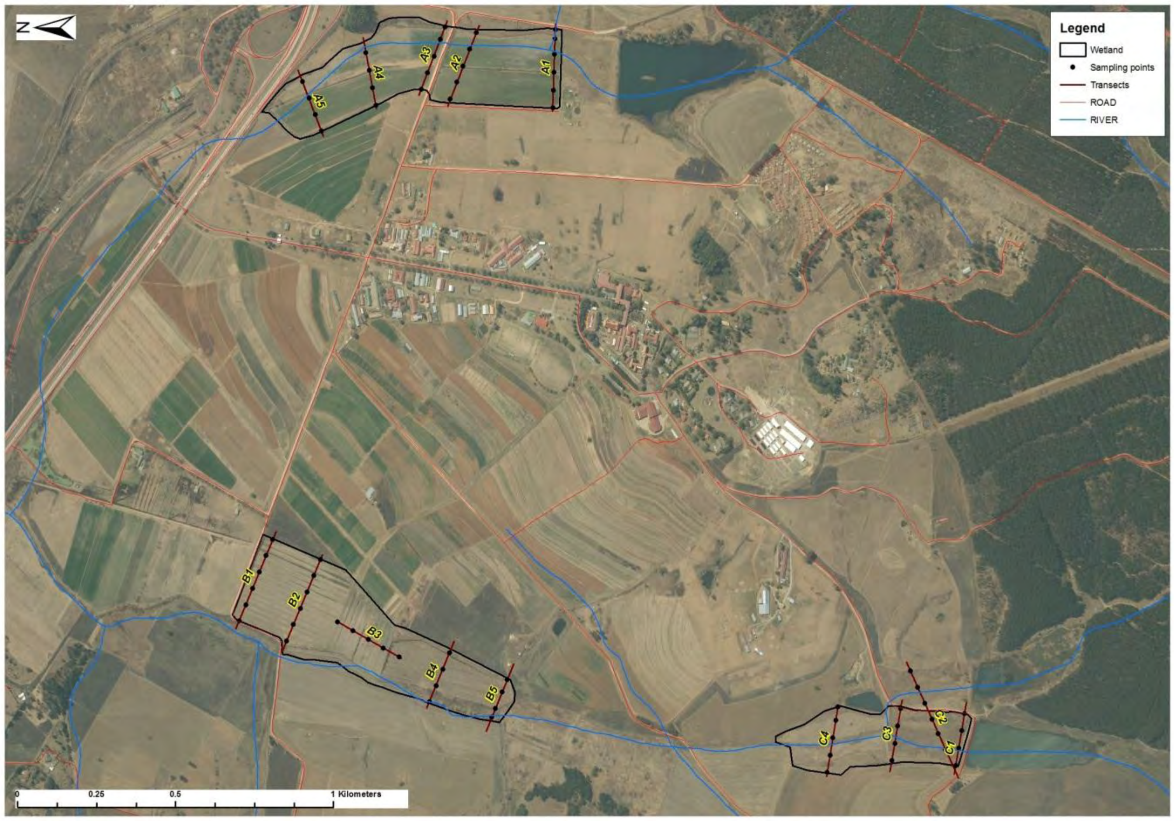

Figure 6: Soil sampling points for chemical analysis on the wetlands

3.4 Water sampling

Water samples were collected on streams in all the wetland-sites, once each month during the Summer (December, January, February), Winter (June, July, August), Spring (September, October, November) seasons of 2012-13, using the grab method of sampling at entry (upstream), mid-point (midstream) and at exit (downstream) of wetland. The samples were taken at points equidistant from each other as practically as possible in each wetland. The intention was to obtain data over as wide a range as possible. In this way, dilution as a result of a large rainfall event would have minimal effect on the overall results. A GPS was used to record coordinates of each sampling point. However, some water samples could not be collected during some seasons because parts of the streams were dry. The descriptions of the sampling points are given in Figure 3 and Table 2 below.

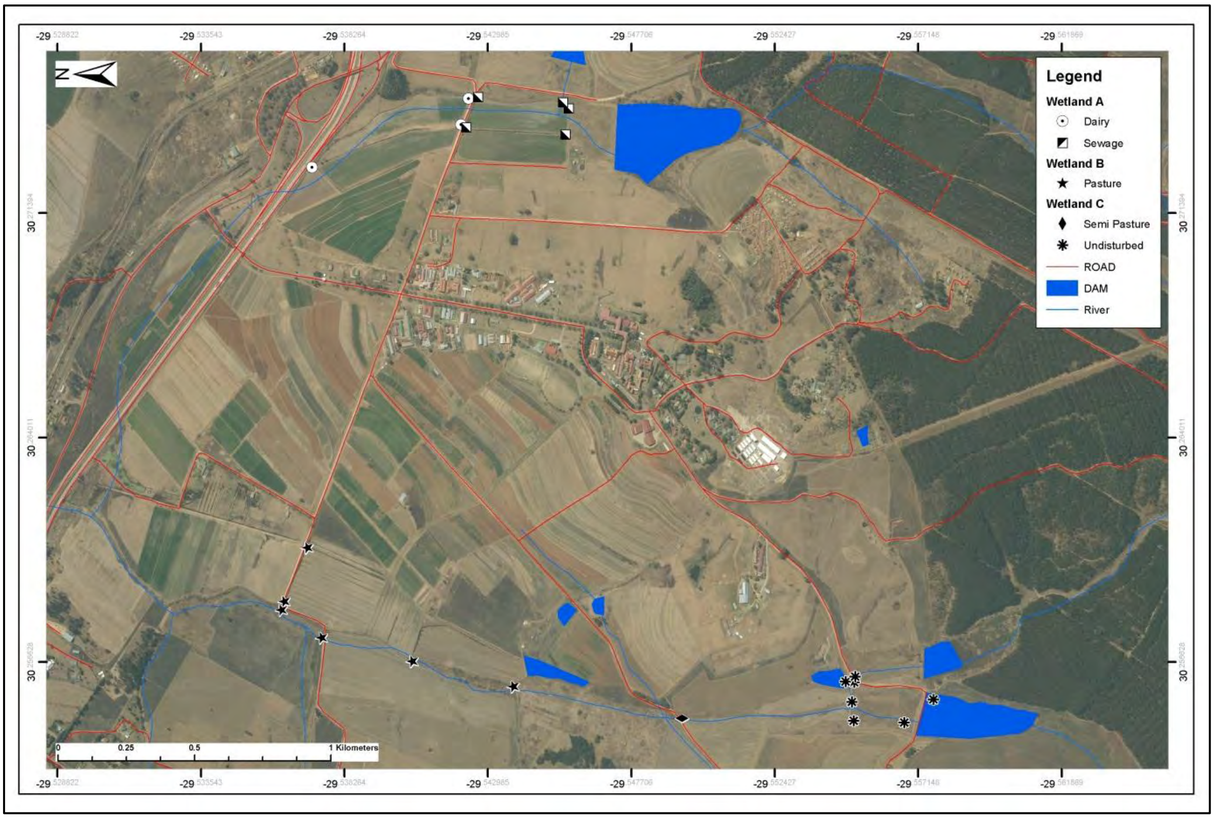

Figure 7: Water sampling points on the Cedara wetlands

Table 2: Description of water sampling points

Land use	Position	Description
Dairy and sewage effluent	Upstream	The catchment area is mainly covered by grass, near a sewage plant and dam wall and outlet from the upper stream, drainage system begins (weir)
	Midstream	Near the road and runoff from dairy washes off is the drained from the dairy into the system
	Downstream	Runoff from dairy and pasture
Drained by Ridge/Furrow	Upstream	Natural wetland
	Midstream	Pastures
	Downstream	Pastures
Undisturbed	Upstream	Natural wetland
	Midstream	Bit of pasture and runoff from agricultural land upslope
	Downstream	Natural wetland

3.5 Grass species sampling

Plant composition was surveyed in wetlands, using step-point surveys, along the same transects as those for sampling soils (Figure 2). The survey was conducted in September (warm season) at vegetative stage of plant species. The surveys were conducted by transect walks and identifying a single plant species at each step, representing a point-cover estimate (Evans and Love, 1957). Percent cover for species, bare ground and water was calculated by adding encounters for any given object from all transects together and diving the number of encounters by the total number of steps.

$$Cover\ of\ species\ A = \frac{\text{number of hits Spp A}*100}{\text{total number of points}} \qquad \text{(Evans and Love, 1957)}$$

In addition to soil guidelines for delineation of wetland boundaries and wetland zones, DWAF (1999) guidelines were also used to classify wetland indicator status of plants consisting of obligate wetland (ow) species (> 99% occurrence in wetlands), facultative wetland (fw) species (67-99% occurrence in wetlands), facultative (f) species (grow both in wetlands and non-wetland areas), facultative dryland (fd) species (grow in non-wetland areas).

3.6 Laboratory analyses

3.6.1 Soils analyses

Soil analyses were conducted at the Cedara Research and Technology Development: Analytical Services Laboratory, KZN. Total Phosphorus (P) was determined in the UV Spectrophotometer after extraction by wet digestion using concentrated sulphuric acid, selenium, lithium sulphate and hydrogen peroxide mixture as described by Anderson and Ingram (1996). Total N and C were determined using the Dumas dry matter combustion analyser LECO CNS-2000 (LECO Corp., St. Joseph, Michigan, USA).

Extractable P, available Calcium (Ca), Magnesium (Mg), Potassium (K), Manganese (Mn), Copper (Cu) and Sodium (Na) were extracted from samples with NH_4HCO_3 solution. The NH_4HCO_3 reagent was prepared by taking 1M ammonium bicarbonate added to 0.005M DTPA (Soltanpour and Workman, 1979). The pH of the solution was adjusted to 7.6 using an HCl solution. For extraction, 25 mL of solution was added to 2.5 mL of soil, stirred for 10 min and filtered. For K, Mn, and Cu, the filtrate was not diluted while for the others dilution was necessary. Analysis of cations was done on the Atomic Absorption Spectrophotometer (AAS) and that for extractable P was done on the Spectrophotometer. Mineral N (NH_4^+-N and NO_3^--N were extracted from samples with 25ml of KCl.

3.6.2 Water Analysis

Water quality parameters such as pH, electrical conductivity (EC) , NO_3^-, NH_4, turbidity, pH, Ca^{2+}, Mg^{2+}, Na^+, K^+ concentrations were measured at Cedara and Umgeni Water laboratories using standard laboratory methods. The methods used for analysis were the same as those of soil samples. Nephelometric method of turbidity measurement was used based in a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension under the same conditions. Higher the intensity of scattered light the higher the turbidity.

3.7 Statistical analysis

All statistical analyses were conducted using Genstat Release 14.1 for Windows 7 (Lawes Agricultural Trust, 2009). Analysis of Variance (ANOVA) was used to compare wetlands (no separation of soils), individual soil forms across sites at a given depth (e.g. comparing mean pH values of a Katspruit in the drained by ridge/rurrow and sewage sludge/dairy slurry wetlands to an undisturbed wetland at depths of 0-20, 20-40, 40-60, 60-100 cm). For wetland B (Drained by Ridge/Furrow) there was no clovelly soil form so only wetland A and B were compared. Where significant differences occurred, separation of means was done using the standard error (SE) at the 0.05 level of significance. Analysis of variance was also used to evaluate effects of land uses, seasons and sampling positions on water quality parameters. Where no significant interaction effects between any two factors occurred, the results of the main factor effects were presented irrespective of whether they were significant or not.

CHAPTER FOUR: RESULTS

4.1 Wetland boundaries and soil forms found in all wetlands

New wetland boundaries, determined based on the soil survey and classification, focussing on soil colour, texture, wetness (DWAF, 1999), showed that the wetlands covered larger areas than based on the desktop study of 2008 shown in Figure 1. Wetlands B and C were linked by the Katspruit soil form that covered the bulk of the wetlands (Figure 4). Wetland C had a “V” shape (Figure 4).

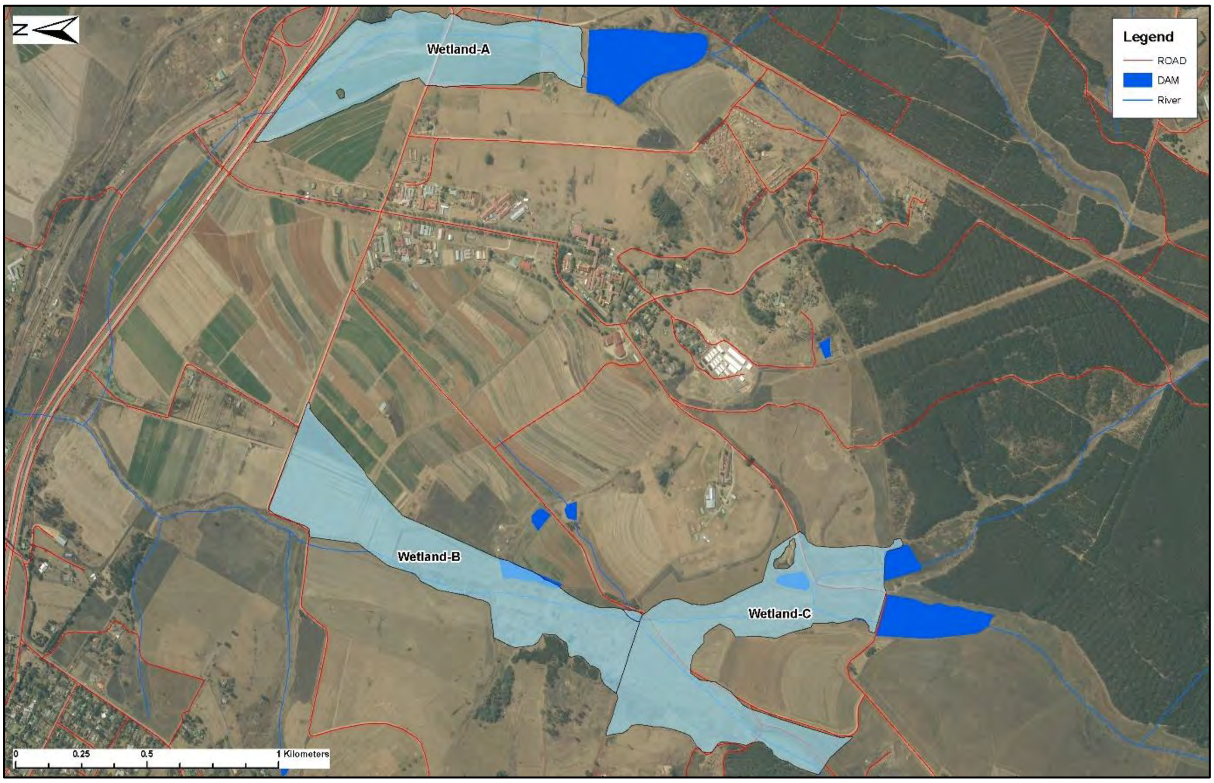

Figure 8: Wetland boundaries based on soil characteristics.

The main soil forms in the wetlands were Katspruit and Pinedene (at 30-40 cm depths below the surface) both affected by wetness, with the well-drained Clovelly, Hutton and Griffin on the edges (Soil Classification Working Group, 1991). While the Katspruit and the Pinedine occurred on all of the wetlands, the Hutton, Griffin and Clovelly forms were found on the edges of wetlands A and C, and not wetland B (Figure 5). Other soils found on wetland B were soils with hardened plinthite, the Dresden and Glencoe forms.

On wetland A (treated with sewage and dairy wastes), the Katspruit and Pinedene occupied 24.4 and 0.4 ha, respectively out of the 29.0 ha of the wetland area (Figure 6). This constituted 85.6 % with surrounding area outside the wetland being occupied by well drained soils classified as Clovelly, Griffin and Hutton forms on the edges. On wetland B (drained by ridge/furrow), wetland soils occupied 100% of the area with Katspruit, Dresden, Glencoe, Pinedene, Willowbrook occupying 30.3, 0.7, 0.3, 0.3 and 0.2 ha, respectively, out of 31.8 ha (Figure 7). On Wetland C (undisturbed), wetland soils occupied 66% of the area (Figure 8), with Katspruit, Pinedene and Fernwood occupying 27.1, 4.5 and 2.5ha, respectively, out of 51.3 ha. The surrounding soil forms were deep well drained soils of Clovelly, Griffin and Hutton forms and the shallow soil of the Glenrosa form occupying the edges of the wetland.

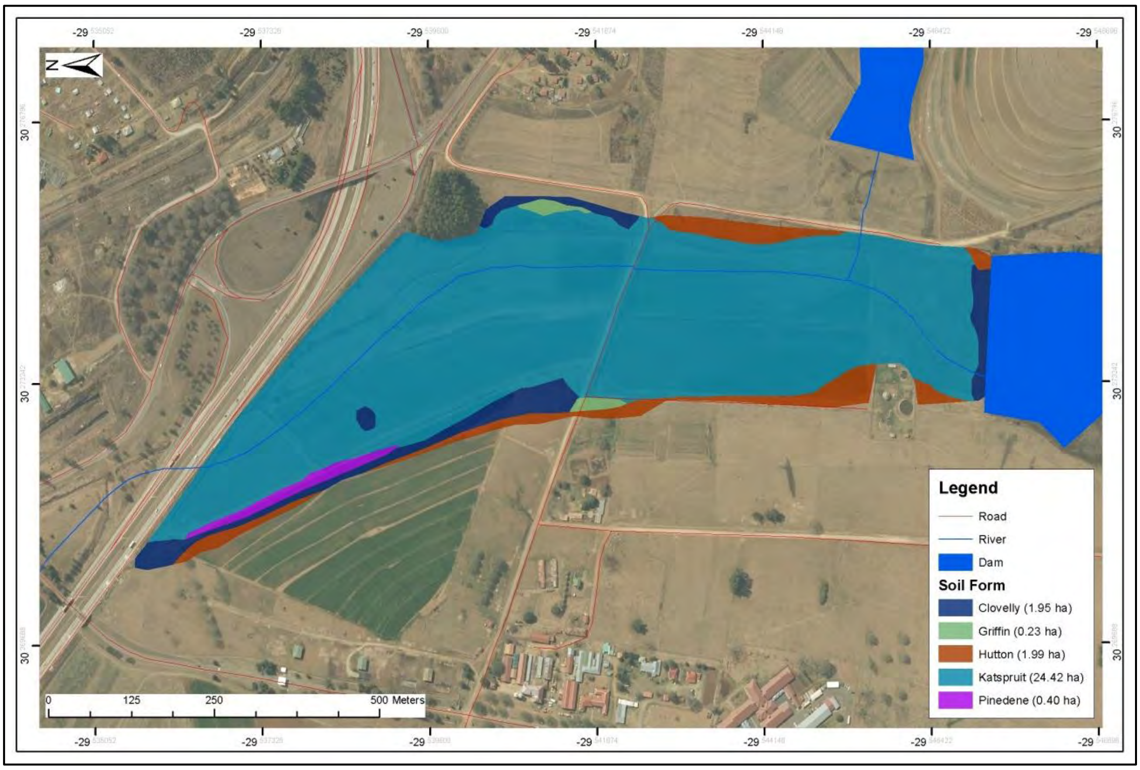

Figure 9: Distribution of soil forms on the wetland treated with organic waste

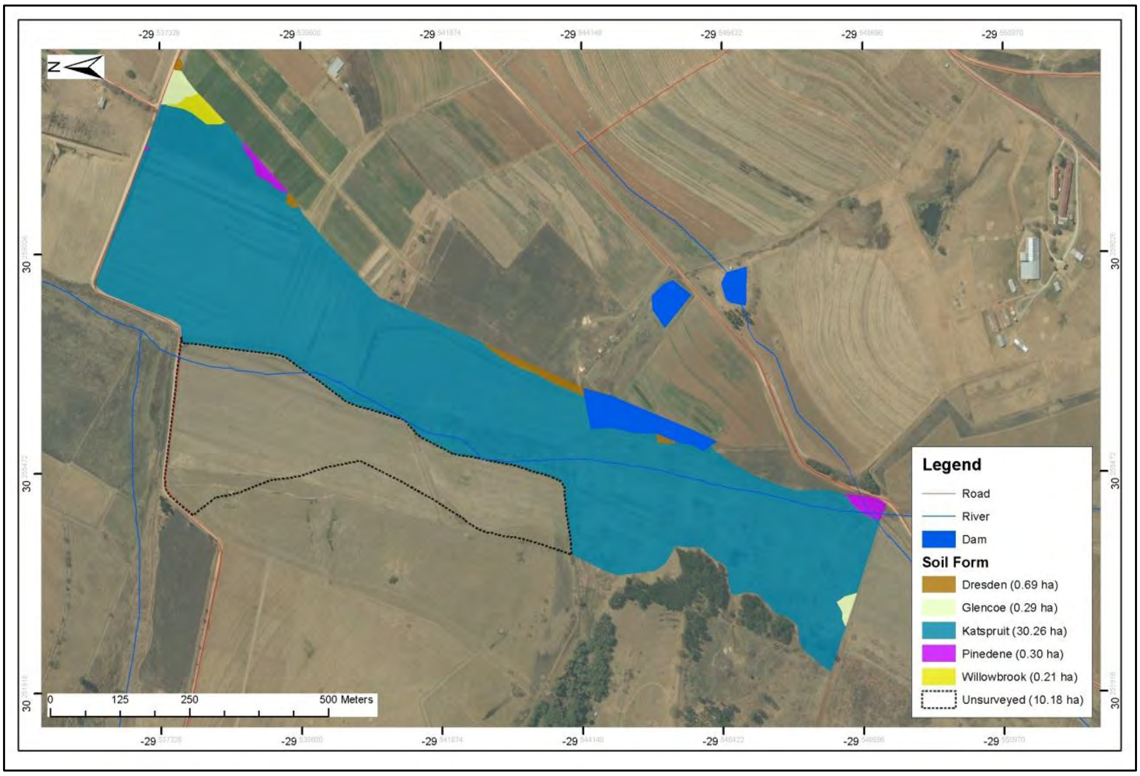

Figure 10: Distribution of soil forms on the wetland drained by ridge and Furrow

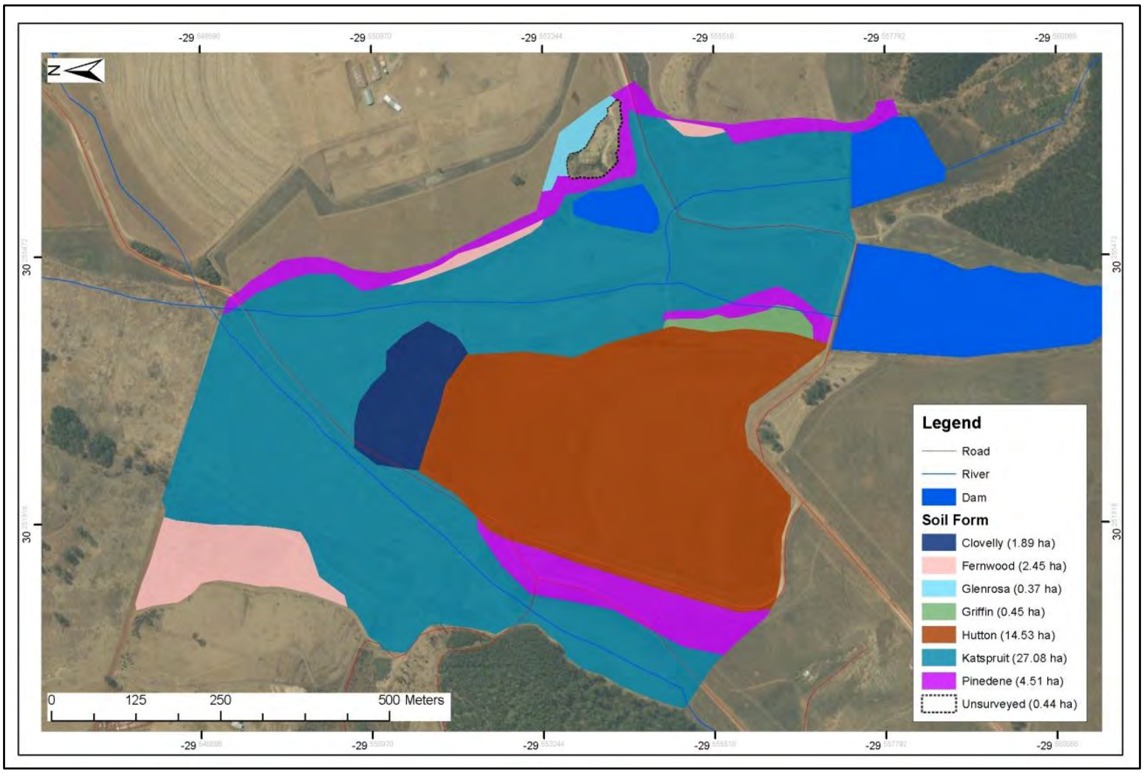

Figure 11: Distribution of soil forms on the "undisturbed" wetland

4.2 Effects of land use change on selected soil properties across all soils

There was no significant interaction effects between land use and soil depth on all the parameters studied. There were significant differences between land uses on all soil parameters, while depth effects were not significant. The ridge/furrow drained wetland had lower clay content (39.9%), total C (1.3%), total N and exchangeable acidity, and higher pH (4.4), Ca and Mg than the other two wetlands (Table 3). The wetland receiving dairy and sewage effluent had higher extractable P, Cu and Zn concentrations than the other two wetlands. The level of Mn was in the order Undisturbed >Dairy / Sewage > Drained. The undisturbed wetland had higher K than the other two wetlands.

Table 3: Selected chemical properties of the wetlands

Soil property	Land-use n=248			
	Dairy/Sewage (n=248)	Drained (n=248)	Undisturbed (n=248)	LSD (0.05)
Clay (%)	47.9	39.9	45.2	2.36
pH	4.1	4.4	4.1	0.17
Total C (%)	1.7	1.3	1.6	0.26
Total N (%)	0.3	0.2	0.3	0.02
K (cmol (+) kg^{-1}	0.23	0.30	1.23	0.11
Ca (cmol (+) kg^{-1}	4.3	6.7	3.4	1.10
Mg (cmol (+) kg^{-1}	2.4	4.7	2.8	0.64
EA (cmol (+) kg^{-1}	1.2	0.6	1.2	0.34
P (mg kg^{-1})	7.3	2.3	2.9	1.76
Mn (mg kg^{-1})	10.8	5.2	25.8	5.33
Zn (mg kg^{-1})	2.3	1.5	1.0	0.48
Cu (mg kg^{-1})	6.6	5.3	5.1	1.12

LSD = least significant difference at $p<0.05$ level.

4.3 Chemical properties of individual soil types across wetlands

4.3.1 Katspruit

Like in overall soils, there was no interaction effect between either land use or soil depth on all the parameters studied in the Katspruit soil. There were significant land use effects on chemical properties, while the effects of depth were not significant (Table 4). The trends of all the parameters in the Katspruit were similar to those obtained for the wetlands across soil types. The ridge/furrow drained wetland had lower clay content and exchangeable acidity and higher pH (4.4), Ca and Mg than the other two wetlands. The wetland treated with dairy slurry and sewage effluent had similar C content to the undisturbed wetland, which was significantly higher than that of the ridge/furrow drained wetland (1.3%) (Table 5). The wetland receiving dairy and sewage waste had two times higher P concentrations and higher Cu and Zn than the undisturbed wetland. The level of available Mn was in the order Undisturbed > Dairy / Sewage Effluent > Ridge/Furrow Drained.

Table 4: Chemical properties of Katspruit soils across wetlands

Soil Property	Land use (n=196)			
	Dairy/Sewage	Drained	Undisturbed	LSD (0.05)
Clay (%)	47.8	39.9	45.2	2.5
pH	4.1	4.4	4.1	0.2
Total C (%)	1.7	1.3	1.6	0.3
Total N (%)	0.3	0.2	0.3	0.1
K (cmol (+) kg^{-1}	0.2	0.3	0.1	0.1
Ca (cmol (+) kg^{-1}	4.3	6.7	3.4	1.1
Mg (cmol (+) kg^{-1}	2.4	4.7	2.8	0.3
EA (cmol (+) kg^{-1}	1.2	0.7	1.2	0.3
P (mg kg^{-1})	2.1	8.2	3.1	1.2
Mn (mg kg^{-1})	10.8	5.6	24.5	5.3
Zn (mg kg^{-1})	2.3	1.6	1.0	0.5
Cu (mg kg^{-1})	6.6	5.7	4.8	1.1

EA = exchangeable acidity

4.3.2 Pinedene

There were significant interaction effects between both land use and soil depth in Pinedene form on soil pH, Ca, Mg and P (Figure 9) but not on clay, total C and N, exchangeable acidity, Mn, Cu and Zn. In the 0-20 cm depth, pH and exchangeable Ca and Mg were higher in the ridge and furrow drained wetland than the other two, while at deeper layers Mg values were similar across wetlands, while pH and Ca were higher in the wetland treated with dairy slurry and sewage effluent. Phosphorus levels were higher in the wetland treated with dairy slurry and sewage effluent than the other wetlands except in the 20-40 cm depth where it was lower. The highest P was in the 40-60 and 60-100 cm depths in the wetland treated with dairy slurry and sewage effluent while the 20-40 and 40-60 cm depths had the highest in the other two wetlands.

There were significant land use effects on Mn, Cu and Zn but not on clay, total C, K and exchangeable acidity (Table 5). The drained wetland had lower Mn than the other two wetlands. The wetland treated with dairy slurry and sewage effluent had higher Cu and Zn than the other two wetlands. There were significant soil depth effects on exchangeable acidity and Zn and not on clay, total C and N, K, Mn and Cu. Exchangeable acidity was higher in depth 20-40 cm than all other depths. On the other hand, Zn was higher at 0-20 cm and 20-40 cm depths than deeper layers (Table 6).

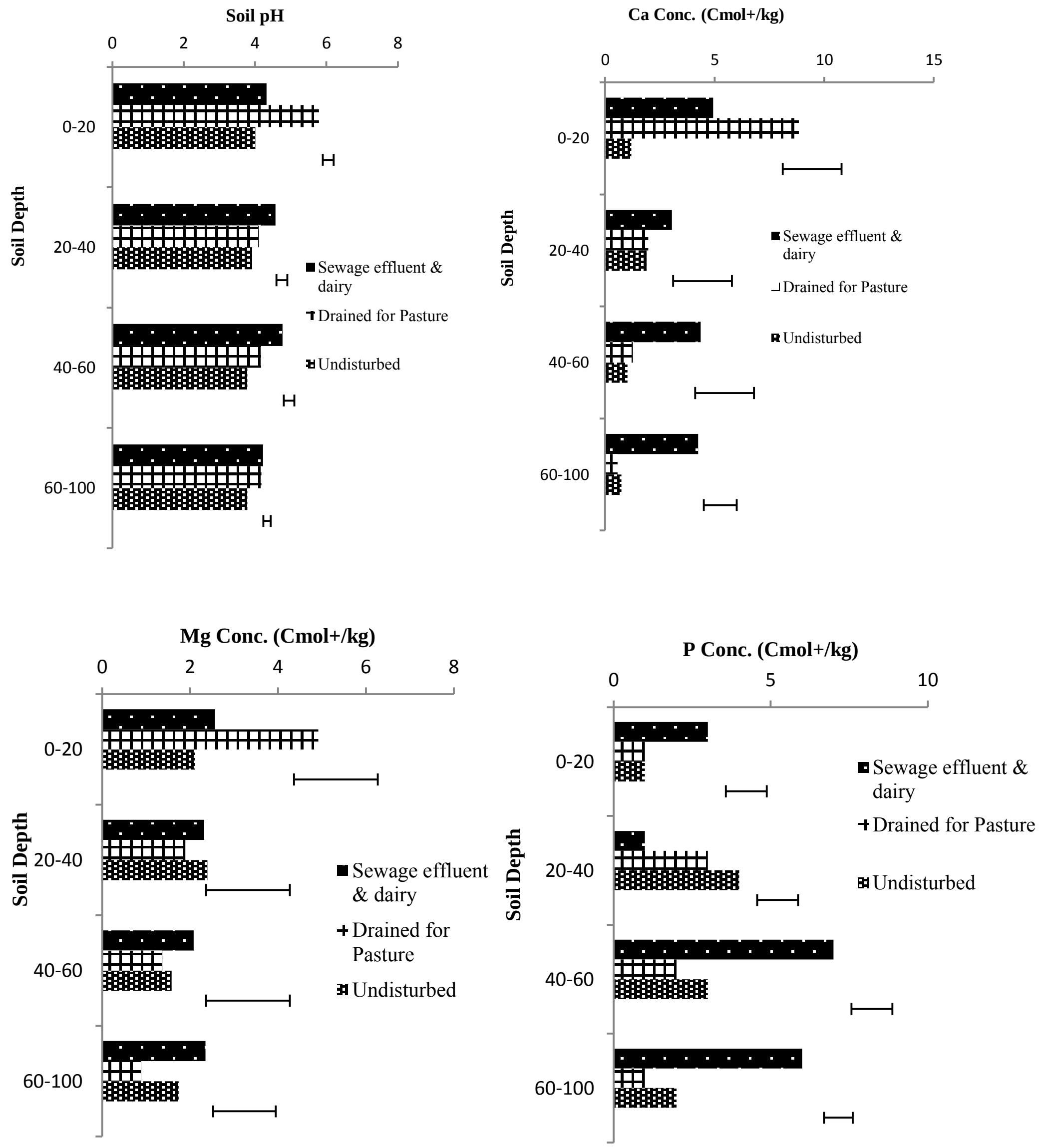

Figure 12**:** Nutrient concentration of Pinedene form on wetlands as affected by soil depth

Table 5: Chemical properties of Pinedene soil form as affected by land use of wetlands

Soil Property	Dairy/Sewage	Drained	Undisturbed	LSD (0.05)
		n=16		
Clay (%)	48.50	48.50	50.19	14.82
Total C (%)	1.92	1.82	1.14	1.69
Total N (%)	0.28	0.21	0.25	0.07
K (cmol (+) kg^{-1}	0.20	0.15	0.28	0.71
EA (cmol (+) kg^{-1}	0.35	1.16	2.39	3.32
Mn (mg kg^{-1})	1.48	0.40	1.47	0.74
Zn (mg kg^{-1})	1.48	0.40	0.47	0.74
Cu (mg kg^{-1})	4.79	2.19	1.38	0.97
CV = 56				

Table 6: Chemical properties of Pinedene soil form as affected by soil depth

Soil Property	Depth (cm)				
	0-20	20-40	40-60	60-100	LSD (0.05)
Clay (%)	50.4	49.2	46.6	51.1	9.24
Total C (%)	1.0	2.1	1.9	1.0	1.26
Total N (%)	0.3	0.3	0.2	0.2	0.10
K (cmol (+) kg^{-1}	3.4	8.2	8.6	5.8	5.9
EA (cmol (+) kg^{-1}	28.3	78.9	45.4	16.3	25.12
Mn (mg kg^{-1})	5.5	4.7	4.0	5.5	6.12
Zn (mg kg^{-1})	0.8	0.8	0.6	0.6	1.03
Cu (mg kg^{-1})	2.5	3.1	2.5	1.8	2.2

4.3.4 Clovelly

There was no Clovelly on the edges of the by ridge/furrow drained wetland. There were no significant differences between the other two wetlands for all measured soil properties except Mn, which was higher in the undisturbed wetland (Table 7). There were also no significant differences among the different depths for all the parameters measured except Mn which was lower at 60-100 cm than all other depths (Table 8).

Table 7: Properties of Clovelly soil form as affected by land use of wetlands

Soil property	Dairy/Sewage n=16	Undisturbed	LSD (0.05)
Clay (%)	47.0	50.6	7.49
pH	4.1	4.2	0.7
Total C (%)	1.7	1.6	0.79
Total N (%)	0.2	0.3	0.05
K (cmol (+) kg^{-1}	2.2	3.3	0.30
Ca (cmol (+) kg^{-1}	3.3	4.3	2.96
Mg (cmol (+) kg^{-1}	2.6	3.2	1.91
EA (cmol (+) kg^{-1}	0.9	0.5	1.10
P (mg kg^{-1})	2.1	1.7	0.90
Mn (mg kg^{-1})	6.3	32.1	8.0
Zn (mg kg^{-1})	1.9	0.8	1.90
Cu (mg kg^{-1})	5.6	4.6	4.20

Table 8: Properties of Clovelly as affected by soil depth of wetlands

Soil Property	Depth (cm)				
	0-20	20-40	40-60	60-100	LSD (0.05)
Clay (%)	45.60	45.60	51.40	52.50	10.59
pH	4.18	4.39	4.01	4.31	0.73
Total C (%)	1.95	1.77	1.84	1.21	1.41
Total N (%)	0.29	0.26	0.27	0.24	0.07
K (cmol (+) kg^{-1}	2.37	2.90	4.00	3.90	0.23
Ca (cmol (+) kg^{-1}	3.58	3.65	5.48	3.40	4.10
Mg (cmol (+) kg^{-1}	5.63	2.50	3.23	3.81	4.18
EA (cmol (+) kg^{-1}	3.63	2.33	2.49	3.14	2.70
P (mg kg^{-1})	0.61	0.50	1.47	0.56	1.56
Mn (mg kg^{-1})	1.25	1.75	3.25	2.0	3.7
Zn (mg kg^{-1})	22.65	22.3	23.02	8.95	8.0
Cu (mg kg^{-1})	0.99	0.81	1.51	2.27	2.68

4.4 Effects of change in land use on water parameters

Monthly temperature and rainfall during the monitoring period are shown on Figure 10. The maximum temperatures were highest in February at 27◦C. Minimum temperatures were lowest in June and July and increased until a maximum was reached between December and February. The highest rainfall was recorded in September, with rainfall in October, February and January being also higher 100 mm, while the least was June. Between September and April, mean monthly rainfall was at least 100 mm, except in March.

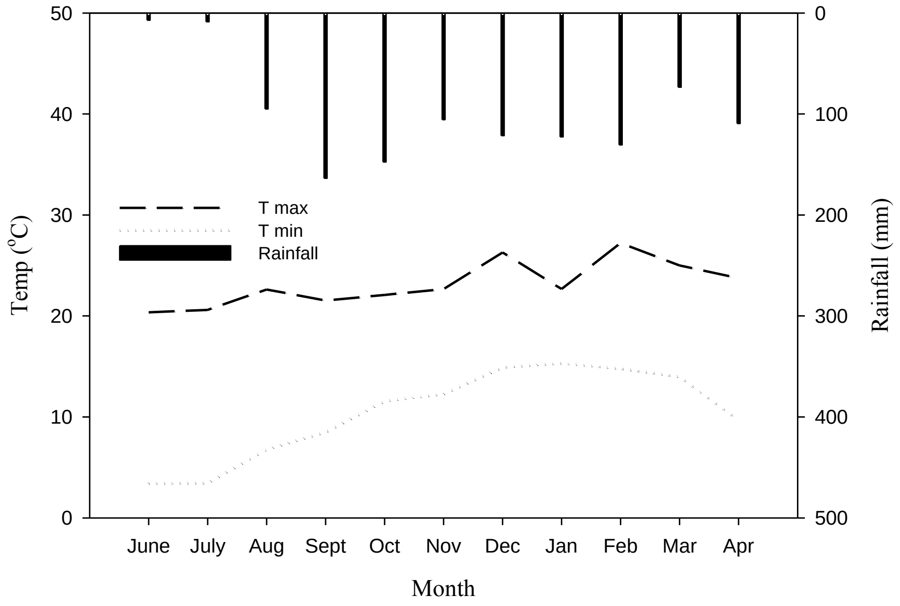

Figure 13: Average monthly temperatures (°C) and total monthly rainfall (mm) during the study period

4.4.1 Water quality parameters as affected by land use and season

There were interaction effects of season and land use betweenwater pH, Cl, Mg, Na SAR and Ca but not on EC, K, NH_4, NO_3, total alkalinity and turbidity. Water pH values for all land uses were similar in spring and lower than the other seasons. In winter, water from the ridge/furrow drained wetland had higher pH than the other two land uses, while in summer the wetland treated with dairy and sewage wastes had higher pH than the other two (Figure 11). The behaviour of Mg were similar to those of pH. While Mg in the wetland treated with dairy and sewage waste did not change with season, the concentrations were higher in winter than the other two seasons for the other two wetlands. The Ca results followed the same trend as those of pH and Mg except that for the undisturbed wetland Ca in winter was similar to the other two seasons. Chloride concentration only changed between seasons for the drained wetland. The highest Cl concentration was in spring while the least was in winter (Figure 11). In winter and summer, Cl concentrations were similar for all land uses, except for the drained wetland which was higher. In spring Cl concentrations in water were in the order: drained > dairy/sewage > undisturbed wetland. In winter Na concentrations were similar for all land uses whereas in summer the drained wetland had higher Na than the other two wetlands (Figure 11). In spring Na concentrations in water were in the order: drained > dairy/sewage > undisturbed wetland. Essentially the trends of Na, SAR and Cl in the water samples were similar (Figure 11). In the drained wetland the Cl^- and Na concentrations and SAR were higher in spring than other seasons and other wetlands.

The NH_4^+ concentration was lower in the winter than other seasons in all wetlands except in the undisturbed wetland where it was similar to the spring. The highest NH_4^+ was in both spring and summer in the wetland treated dairy slurry, which was similar to the drained wetland in spring (Figure 8a). The concentration of Ca and Mg were higher in the drained wetland in winter, than other seasons and other wetlands. Nitrate-N concentration was higher in the undisturbed wetland in winter than other seasons and other wetlands in all seasons (Figure 11). Total alkalinity was higher upstream than downstream in spring. In contrast during winter, it was higher downstream than upstream and in summer midstream had higher values. Samples for Phosphorus were only taken in summer and winter. Water P was higher in summer and lower in winter and was higher in both receiving dairy and sewage effluent and the by ridge/furrow drained wetland.

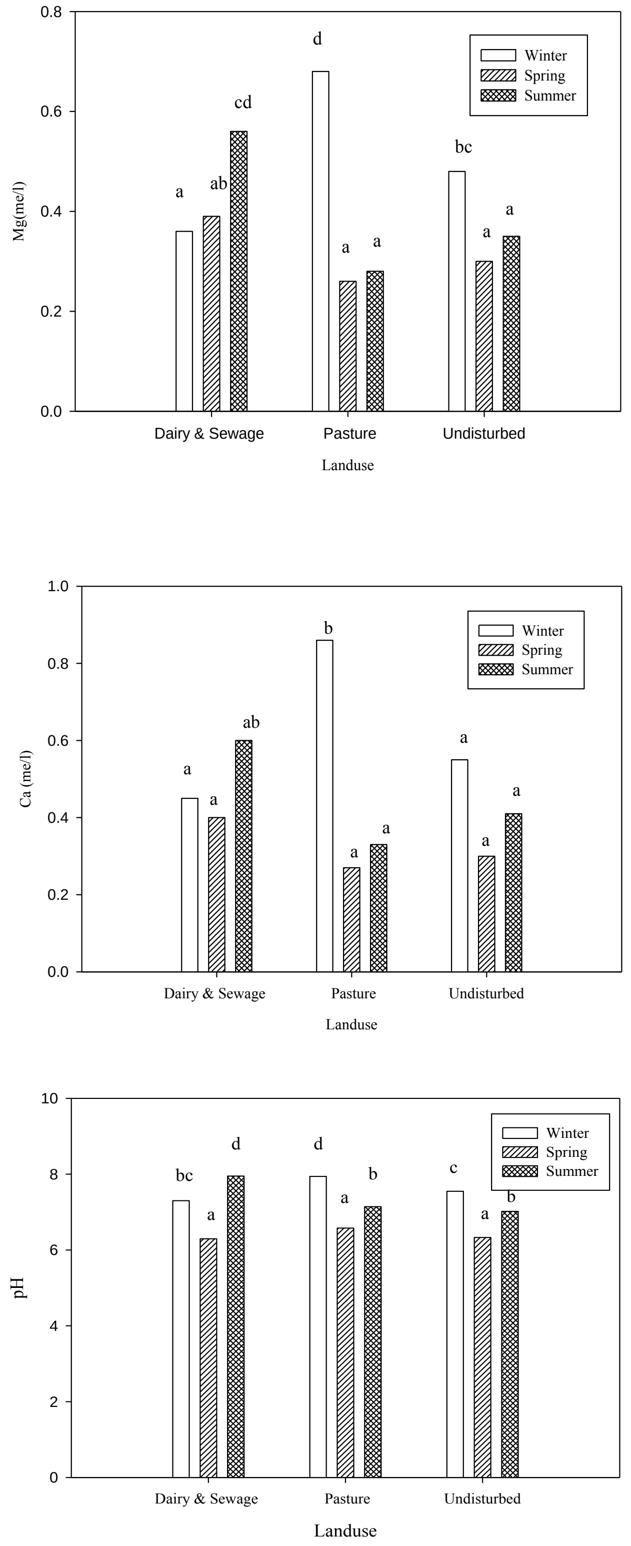

Figure 14**:** Land use effects on selected water quality parameters in different seasons. Bars with same letters indicate non-significant differences.

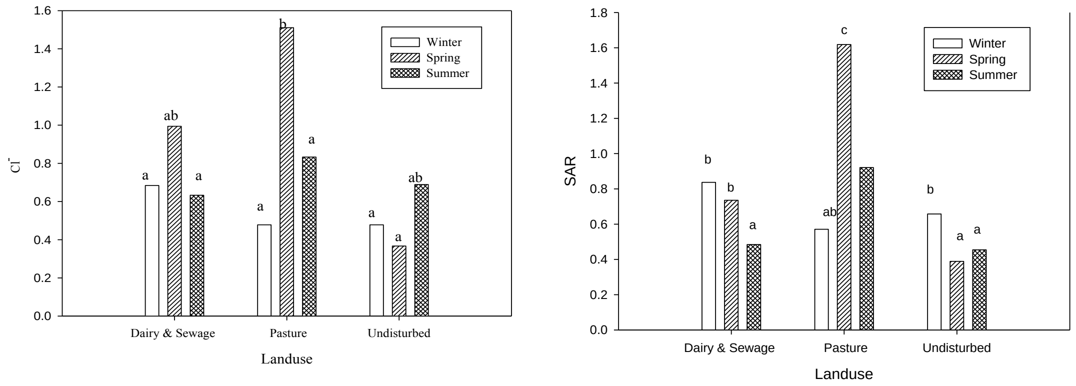

Figure 15: Land use effects on selected water quality parameters in different seasons. Bars with same letters indicate non-significant differences.

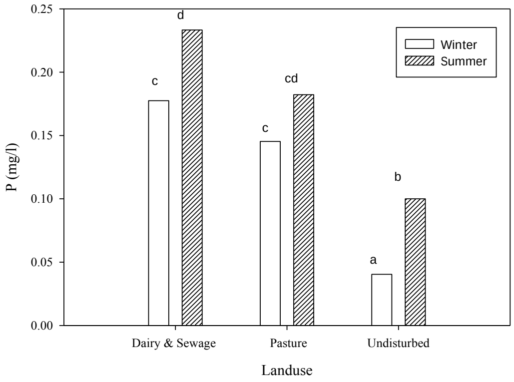

Figure 16**:** Land use effects on Phosphorus in different seasons. Bars with same letters indicate non-significant differences.

4.4.2 Concentrations of Na, Cl and NO3 as affected by land use and sampling position

There were significant interaction effects of land use and sampling position on Na, Cl and NO_3^-. Whilst nitrate levels in the dairy/sludge wetland appeared relatively higher than the other wetlands, there were no significant differences. Water from the midstream of the undisturbed wetland had a higher NO_3^- level than all the other samples, which had similar levels.

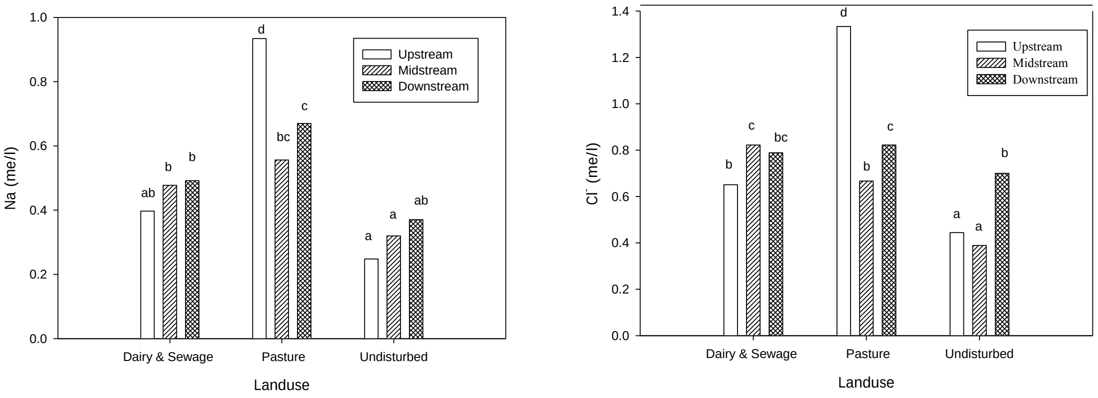

Figure 17**:** Land use effects on concentrations of sodium and chloride in water in different sampling positions. Bars with same letters indicate non-significant differences.

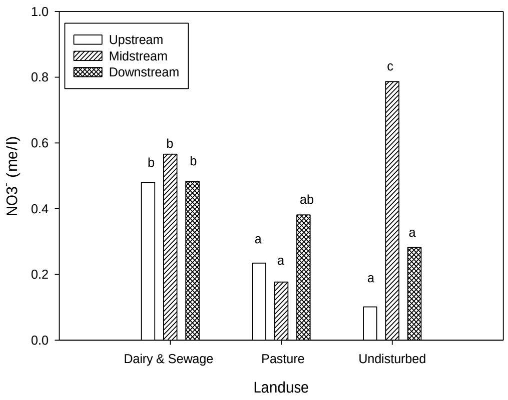

Figure 18**:** Nitrate concentrations in water at different sampling positions. Bars with same letters indicate non-significant differences.

4.4.3 Land use as a main factor on selected water quality parameters

There were no significant differences among land uses for EC, K, mineral N, NH_4^-N, alkalinity and turbidity

Table 9: Effects of land use as a main influence on selected water quality parameters (n=27)

Land use	EC (mS/m)	K^+ (me/l)	Mineral N (mg/l)	NH_4^+ N (mg/l)	Alkalinity (me/l)	Turbidity (NTU)
Dairy / Sewage	13.85	0.12	0.94	1.36a	0.70	1751
Drained/Pasture	14.43	0.07	0.37	1.13a	0.76	955
Undisturbed	11.32	0.05	0.91	0.40b	1.2	56
LSD (0.05)	3.75	0.08	0.87	0.55	0.49	2700.2

4.4.4 Season as a main factor on selected water quality parameters

There were no significant differences in season on EC, K, mineral N, NH_4-N and NO_3-N and turbidity.

Table 10: Effects of season on water quality in the wetlands

Season	EC (mS/m)	K^+(me/l)	Mineral N(mg/l)	NH_4^+ (mg/l)	NO_3^- Nmg/l)	Turbidity (NTU)
Winter	13.51	0.04	0.62	0.17	0.47	2714
Spring	14.31	0.12	0.95	0.49	0.52	21
Summer	11.78	0.07	0.65	0.17	0.48	27
LSD (0.05)	3.77	0.08	0.87	0.50	0.47	2658.7

4.4.5 Sampling position as a main factor on selected water quality parameters

There were no significant differences in the nutrient concentrations along the stream in all wetlands for EC, K, Mg, Mineral N, NH_4-N, SAR, turbidity and P.

Table 11: Effects of sampling position on water quality in the wetlands

Sampling Position	EC (mS/m)	K^+ (me/l)	Mg (me/l)	Mineral N(mg/l)	NH_4^+ (mg/l)	SAR (me/l)	Turbidity (NTU)	P (mg/l)
Upstream	13.19	0.09	0.38	0.65	0.37	0.69	429.8	0.23
Midstream	12.09	0.07	0.43	1.06	0.31	0.64	954.5	0.18
Downstream	14.33	0.07	0.40	0.52	0.14	0.89	1373.5	0.09
LSD(0.05)	3.85	0.08	0.10	0.87	0.50	0.26	2740	0.10

4.5 Plant species at different wetland land uses with their relative distribution

Eight plant families were identified and the Poaceae and Cyperaceae had the highest number of plant species across all wetlands (Tables 13 and 14). Although other species were observed, the tables represent the eight major species present. The wetland influenced by dairy and sewage effluent was dominated by pasture plant species including *Pennisetum clandestinum* (kikuyu), *Lollium perenne* and *Trifolium repens* (white clover) and *Lanceslata lanceolata* (buck horn) as dominant plant species with few wetland plants observed. The wetland drained by ridge and furrow, was dominated by non-wetlant plant species; *Setaria sphacelata, Eragrostis curvulla, Lanceslata lanceolata* and *Trifolium repens* (Table 3), with fewer wetland species. The only non-wetland plants observed in abundance on the undisturbed wetland were *Cyperus esculentus* (>2%) and *Eragrostis curvulla* (<2%).

Table 12: Non-wetland plant species recorded at different wetlands

Family	Species	Wetland		
		Dairy/sewage effluent	Drained by Ridge/Furrow	Undisturbed
Poaceae	*Pennisetum clandestinum* (kikuyu)	++	+	-
Poaceae	*Setaria sphacelata*	+	++	-
Poaceae	*Eragrostis curvulla*	+	++	+
Plantaginacacae	*Lanceslata lanceolata* (buckhorn)	+	++	-
Poaceae	*Lollium perenne* (rye grass)	++	+	-
Malvaceae	*Hibiscus. trionum*	+	+	-
Fabacaeae	*Trifolium repens* (white clover)	++	++	-
Fabacaeae	*Desmodium. Dregeanum*	+	+	-
Cyperaceae	*Cyperus esculentus L.*	-	-	++

+ Represents <2% abundance; ++ represents >2% abundance; (-): absence, (Mulatu, 2014). Obligate wetland (OW) species (> 99% occurrence in wetlands), facultative wetland (FW) species (67-99% occurrence in wetlands), facultative (F) species (grow both in wetlands and non-wetland areas), facultative dryland (FD) species (grow in non-wetland areas).

Wetland plant species were dominantly abundant in the undisturbed wetland, with only a few occurring at lower abundance on the disturbed wetlands. Obligate wetland species such as *Paspalum distichum, P. scrobiculatum, P. urvillei,* which belonged to the Poaceae family and *Cyperus latifolius,* which belongs to Cyperaceae were found in the undisturbed wetland. Facultative wetland species such as *Miscanthus junceus Hemarthria altissima,* and *Paspalum dilatatum* were also more on the undisturbed wetland. Only a few wetland plant species like *Aristida junciformi, Erograstis plana* and *Phragmites australis* were found in all wetlands but were more prevalent in the undisturbed wetland.

Table 13: Wetland plant species recorded at different wetlands

Family	Species	Indicator status	Wetland		
			Dairy/ sewage effluent	Drained by Ridge/Furrow	Undisturbed
Poaceae	*Aristida. junciformis*	FW	+	+	++
Poaceae	*Erograstis. plana*	F	+	+	++
Poaceae	*Miscanthus. junceus*	FW	-	+	+
Poaceae	*Hemarthria altissima*	FW	-	-	++
Poaceae	*Paspalum dilatatum*	FW	-	+	++
Poaceae	*Paspalum distichum*	OW	-	+	++
Poaceae	*Paspalum scrobiculatum*	OW	-	+	++
Poaceae	*Paspalum urvillei*	OW	-	+	++
Poaceae	*Bromus catharticus*	FW	-	+	+
Poaceae	*Phragmites australis*	OW	+	+	++
Iridaceae	*Watsonia pillansii*	FD	-	+	+
Cyperaceae	*Cyperus latifolius*	OW	-	+	++
Cyperaceae	*Cyperus articulates*	FW	-	-	++
Cyperaceae	*Kyllinga erecta*	FW	-	-	++
Typha	*Typha capensis*	OW	-	-	++
Asteraceae	*Helichrysum. moeserianum*	FW	-	-	+

+ Represents <2% abundance; ++ represents >2% abundance; (-): absence, (Mulatu, 2014). Obligate wetland (OW) species (> 99% occurrence in wetlands), facultative wetland (FW) species (67-99% occurrence in wetlands), facultative (F) species (grow both in wetlands and non-wetland areas), facultative dryland (FD) species (grow in non-wetland areas).

CHAPTER FIVE: DISCUSSION AND CONCLUSION

5.1 Discussion

While there were a number of soil forms around the wetlands, the overall soil properties on the wetlands were more influenced by the Katspruit soil form as a result of its dominance in areal extent, with 83, 97 and 53% for Wetlands A, B and C, respectively, whereas the other soils had minimal effect. This was supported by lack of effects of land use and soil depth on the majority of the parameters of the other individual soils. The dominating effects of the Katspruit and Pinedene could be explained by their wetness, which defines a wetland in the first place and land use change including drainage resulted in changes in redox conditions compared to the undisturbed wetland.

The occurrence of the Dresden and Glencoe soil forms, characterized by a hard plinthic layer, in the drained wetland suggested that extreme conditions of fluctuating water table has been experienced in the past resulting in the formation of soft plinthic horizon which over time got cemented by silica and hardened to form the restrictive hard plinthic horizon since drainage (Soil Classification Working Group, 1991). The accumulation of iron and manganese may have progressed from soft mottles to the formation of discrete concentrations and these would form a continuous indurated iron pan (Soil Classification Working Group, 1991) and drainage could facilitate the process.

The larger areal extents of the wetlands based on hydromorphic soils than on the occurrence of wetland plant species suggests that other parts of the wetland, that are not active could have been included. This is because signs of wetness in soils take a long time to form and they could remain visible for long periods of time, irrespective of whether the wetland is active or not. According to recommendations for wetland delineation by DWAF (2005), the occurrence of wetland plants is the first indicator of wetland boundaries. However, in a case where wetland plants are no longer available, such as those in parts of the study area, this may not be entirely practical. The observation that non-wetland plant species occupy most of the disturbed areas on the wetlands, even though the soil forms found were still characteristic of wetland soils, indicates land use change resulted in modification of wetland plant species composition. The use of soil properties in delineating wetlands could be a better approach than to depend on plant species, if the original boundaries of the wetlands are to be established. Moreover, the dominance of wetland species in the undisturbed wetland, which did not have increased pH, Ca, Mg due to liming or P, Zn and Cu due to organic waste, suggests that plant species would be better indicators of a properly functioning wetland in this region.

The lower C and N in the drained wetland could be the result of rapid decomposition of organic matter due to increased availability of oxygen after and breakdown of soil aggregates through drainage, resulting in lower levels. Several works also reported similar results that draining and cultivating wetlands increased soil aeration, which then resulted in for rapid decomposition and mineralization of plant species and thus lower C and N (Burdt, 2003; Zoltan, 2008; Dube and Chitiga, 2011; Mulatu 2014;). Ari et al (2010) found that non-grazed wetlands had greater SOM, TN at 0–10 cm and this was explained by lower decomposition of litter layers. The lower organic matter leaves the soil vulnerable to degradation and erosion.

The lower exchangeable acidity, higher pH and Ca and Mg in the Katspruit and Pinedene of the ridge/furrow drained wetland could be the result of liming of the drained soils for pasture production as well as cultivated fields on the uplands of Hutton soils. The finding on soils results were in agreement with those of water samples on the same parameters. Dolomitic lime could have been used resulting in higher Mg, Ca, pH while lowering exchangeable acidity. These results were in agreement with those by Braekke (1999), Bruland (2003) and Maier *et al.* (2002), who observed high pH, Ca and Mg in wetlands used for agricultural purposes, especially in the upper 0-20 cm due to liming with components such as $CaCO_3$ and $(CaMg(CO_3)_2$. Water draining from these soils could then be affected the same way.

The high ammonia and nitrate downstream than upper streams in the ridge/furrow drained wetland could be due to the runoff of nutrients from agricultural lands as well as furrows depositing water into the main drain. The reduction of NH_4^+ from upstream to downstream, was attributed to plant uptake and its sorption to detritus and inorganic sediment since NH_4^+ bound loosely to the substrate and easily released when water environment conditions change (Kovacic et al., 2006). The high NH_4^+ in both spring and summer in the wetland treated dairy slurry, which was similar to the drained wetland in spring was because of the release of NH_4^+ from breakdown of dairy waste due to increased temperatures. The higher water pH, Ca and Mg in winter than the other two seasons for the drained and undisturbed wetlands could be a concentration effect due to low rainfall, while the dairy/sewage wetland the Mg comes from the organic wastes with a lot of water and therefore not influenced by season.

The higher P and micronutrients in the dairy/sewage wetland, particularly for the Katspruit and Pinedene could have been supplied as components of the organic wastes. Depending on the amount of manure and the nutrient content, dairy manure can supply about 10 g P/kg, 19 mg Zn/kg, 4.5 mg Cu/kg and other nutrients (Mc Bride and Spiers, 2001). The results for P in water were similar to those of soils irrespective of sampling position, suggesting that the sources were external as a result of the land use change. Even though the results for P on sampling position were not significant, P was lower downstream indicating a possibility for the wetlands to be removing nutrients/purifying as they pass through the wetland.
The higher pH and Ca at deeper layers of Pinedene of the dairy/sewage wetland than the other wetlands suggest that the organic waste has a liming effect and that it provides Ca. However, the high concentrations of Ca, Mg, and K in the ridge/furrow drained wetland could have originated from liming and fertilizer application. However, the results were in contrast with Sallantaus (1995), who observed a net loss of Ca, Mg and K from drained catchments compared with undrained catchments. The lower exchangeable acidity and higher Zn concentrations at near surface depths of the Pinedene soil form suggested that they were influenced by surface additions of materials that could include both organic and inorganic materials in the wetland receiving organic wastes.

The lower Mn in the two main wetland soils of the ridge/furrow drained wetland could have been a result of formation of insoluble Mn oxides as a result of aerobic conditions that occurred as a result of drainage. Zhang et al. (2013) and Xue (2011) observed a decrease in manganese after wetlands were used for paddy, maize and forests. The higher Mn in the undisturbed wetland suggested that the conditions were more reducing/ hydromorphic than the other wetland. Under extremely reducing conditions, manganese oxides in the highly weathered soils are reduced to Mn^{2+} which is more soluble (Collins, 2005).

The higher water nitrate level in the midstream of the undisturbed wetland could be a result of nitrogen fertilisation of maize on the Hutton on the western edge of the wetland. Even though the results were not significant, the relatively higher ammonium levels in the wetlands affected by dairy and sewage effluent and the ridge/furrow drained wetland were expected, given the agricultural activities in the areas and dairy. Dairy and agriculture are known to be major contributors to nitrate loadings in freshwaters (Chapman, 1996). The undisturbed wetland does not receive as much nutrient loading as compared to the other wetlands hence the low nutrient and pollution levels observed.

The decline in wetland plant species in both disturbed wetlands could have been because of the changes in water regimes. Unlike pasture species, wetland plants generally adapt to anaerobic conditions because they have structures that enable them to survive in these environments (Mitsch and Gosselink, 2000). These include shallow root systems, aerenchyma, buttressed trunks, pneumatophores, and lenticles on the stem. These allow oxygen to be transported from the shoots of plant to the roots where respiration occurs (Mitsch and Gosselink 2000). Mulatu (2014) and Dixon, (2001) also observed a decline in wetland vegetation due to changes in land use. The results of this study support the idea that undisturbed wetlands supports relatively higher richness, diversity and community productivity of wetland species compared with a degraded wetland communities.

The changes in species composition could also have been a result of soil properties. Some studies have reported an interaction between vegetation characteristics and soil properties (Berendse, 1998; Wassen et al., 2005), especially nitrogen and water (Bai et al., 2010; Li et al., 2011). The patterns found reflect the ability of the species to establish under different water regimes (Fraser and Milleti, 2008). However, some wetland species such as *M. junceus* were still present in the ridge/furrow drained wetland especially along the draines and upper areas which are still very wet. The appearance of these species on these drained wetlands could be related to soil conditions, especially the water regime of the dominant Katspruit soil form in the wetlands, along the drains. Changes in plant community composition can also mean a loss of certain species that provide critical habitat for insects, birds, and other secondary producers.

5.2 Conclusions

Conversion of wetland for pasture, coupled with treatments with dairy slurry and sewage waste increases soil P, Zn and Cu while drainage by ridge and furrow coupled with cultivated pastures increased soil pH, Ca and Mg, and reduced total C and Mn availability in wetland soils. Drainage of wetlands coupled with dairy slurry application and pasture increases Ca, Mg and P in water. Land use change, through Ridge and furrow drainage or Dairy and sewage effluent, results in a decline in wetland plant species diversity and promotes increase in non-wetland species. The findings of this study provide a useful baseline information on the general status of the wetlands on which restoration plans could be based.

5.3 Recommendations

The disturbed wetlands need to be rehabilitated to a state where all wetland characteristics occur, and the proper functioning of the wetlands, including plant and animal biodiversity and water storage and purification, is recovered to the levels of the undisturbed wetland. Effects of such rehabilitation strategies on soil and water quality, and plant species composition and diversity need to be studied.

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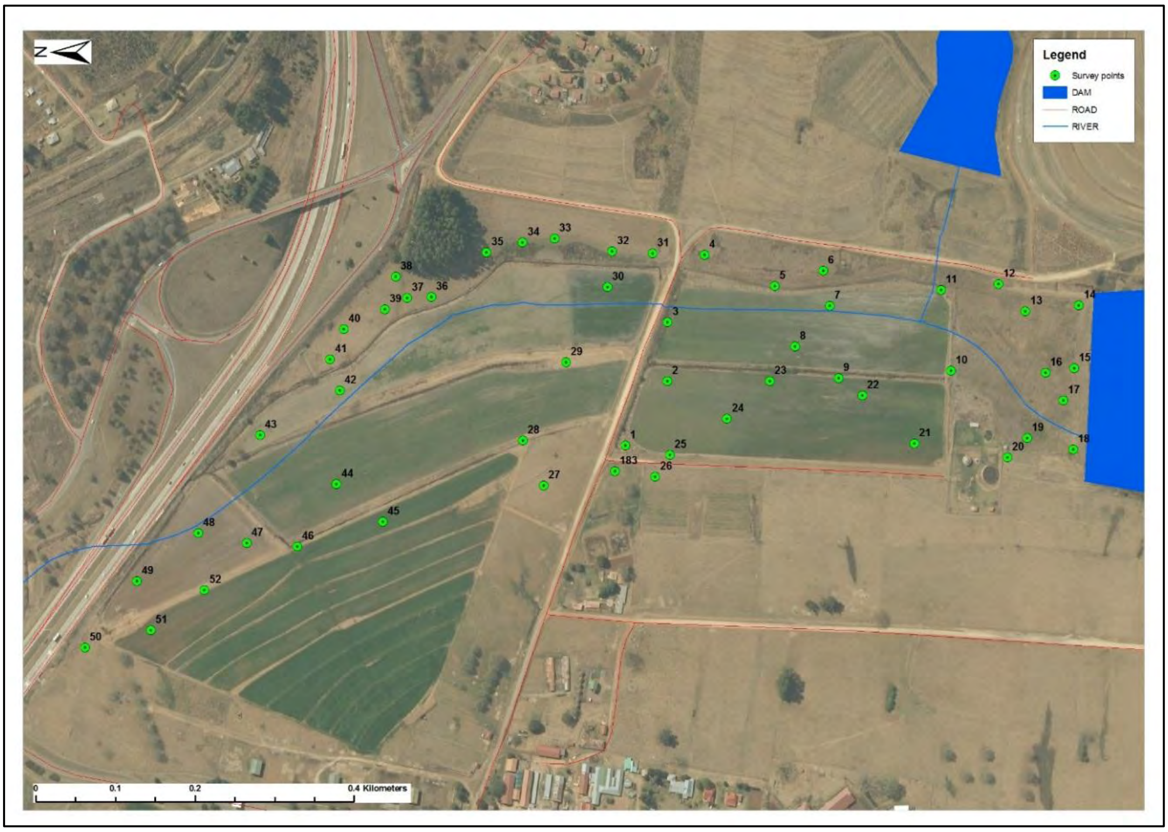
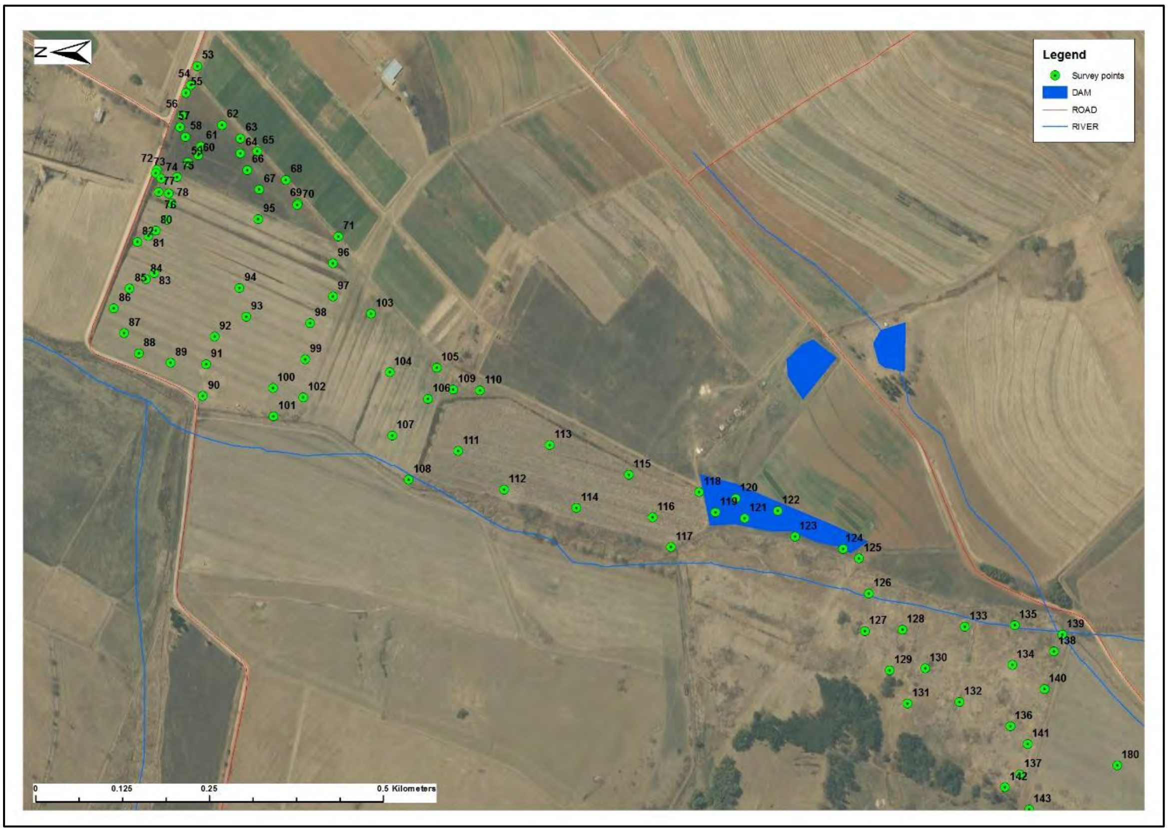
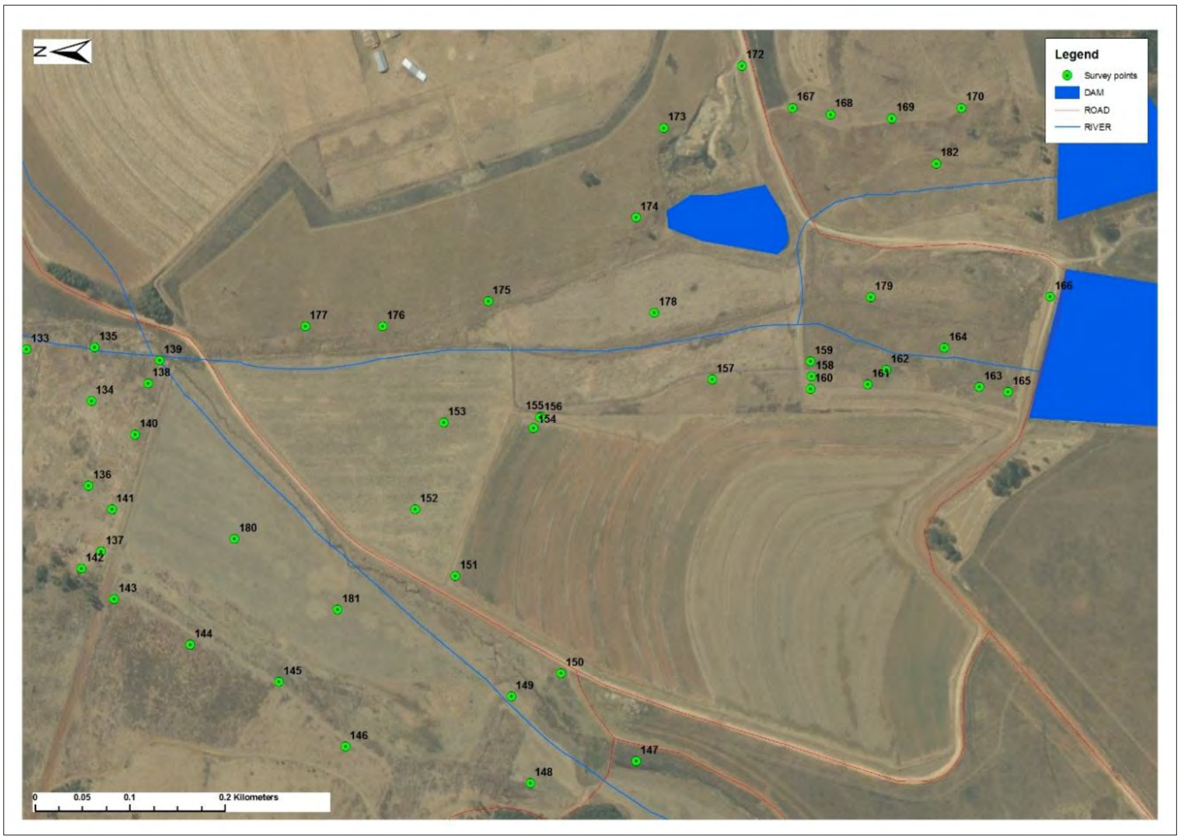
APPENDIX A: LOCATIONS OF SAMPLING POINTS FOR SOIL SURVEY



WETLAND A (Dairy &Sewage)



WETLAND B (Pasture)



WETLAND C (Undisturbed)

APPENDIX B: SOIL FORMS AND SOIL FAMILIES OF SAMPLING POINTS

Wetland	Soil form	Soil family	Map ID
A	Griffin	Gf 1100	183
A	Katspruit	Ka 1000	1
A	Griffin	Gf 1200	2
A	Katspruit	Ka 1000	3
A	Hutton	Hu 1000	4
A	Katspruit	Ka 1000	5
A	Hutton	Hu 1000	6
A	Katspruit	Ka 1000	7
A	Katspruit	Ka 1000	8
A	Katspruit	Ka 1000	9
A	Katspruit	Ka 1000	10
A	Katspruit	Ka 1000	11
A	Mispah	Ms 1000	12
A	Katspruit	Ka 1000	13
A	Hutton	Hu 1000	14
A	Clovelly	Cv 1100	15
A	Katspruit	ka 1000	16
A	Katspruit	Ka 1000	17
A	Clovelly	Cv 1200	18
A	Katspruit	ka 1000	19
A	Hutton	Hu 1000	20
A	Hutton	Hu 1000	21
A	Katspruit	Ka 1000	22
A	Katspruit	Ka 1000	23
A	Katspruit	Ka 1000	24
A	Katspruit	Ka 1000	25
A	Hutton	Hu 1000	26
A	Hutton	Hu 1000	27
A	Clovelly	Cv 1200	28
A	Katspruit	Ka 1000	29
A	Katspruit	Ka 1000	30
A	Clovelly	Cv 1100	31
A	Katspruit	Ka 1000	32
A	Griffin	Gf 1100	33
A	Katspruit	Ka 1000	34
A	Clovelly	Cv 1100	35
A	Katspruit	Ka 1000	36
A	Katspruit	Ka 1000	37
A	Katspruit	Ka 1000	38
A	Katspruit	Ka 1000	39
A	Katspruit	Ka 1000	40
A	Katspruit	Ka 1000	41
A	Katspruit	Ka 1000	42

A	Katspruit	Ka 1000	43
A	Clovelly	Cv 1200	44
A	Clovelly	Cv 1200	45
A	Pinedene	Pn 1200	46
A	Katspruit	Ka 1000	47
A	Katspruit	Ka 1000	48
A	Katspruit	Ka 1000	49
A	Clovelly	Cv 1100	50
A	Hutton	Hu 1000	51
A	Pinedene	Pn 1200	52
B	Dresden	Dr 1000	53
B	Glencoe	Gc 2100	54
B	Glencoe	Gc 2100	55
B	Glencoe	Gc 2100	56
B	Katspruit	Ka 1000	57
B	Katspruit	Ka 1000	58
B	Katspruit	Ka 1000	59
B	Katspruit	Ka 1000	60
B	Katspruit	Ka 1000	61
B	Willowbrook	Wo 1000	62
B	Willowbrook	Wo 1000	63
B	Katspruit	Ka 1000	64
B	Katspruit	Ka 1000	65
B	Katspruit	Ka 1000	66
B	Katspruit	Ka 1000	67
B	Pinedene	Pn 2200	68
B	Pinedene	Pn 2200	69
B	Pinedene	Pn 2200	70
B	Dresden	Dr 1000	71
B	Katspruit	ka 1000	72
B	Pinedene	Pn 2200	73
B	Katspruit	ka 1000	74
B	Katspruit	Ka 1000	75
B	Katspruit	Ka 1000	76
B	Katspruit	Ka 1000	77
B	Katspruit	Ka 1000	78
B	Katspruit	Ka 1000	79
B	Katspruit	Ka 1000	80
B	Katspruit	Ka 1000	81
B	Katspruit	Ka 1000	82
B	Katspruit	Ka 1000	83
B	Katspruit	Ka 1000	84
B	Katspruit	Ka 1000	85
B	Katspruit	Ka 1000	86
B	Katspruit	Ka 1000	87
B	Katspruit	Ka 1000	88

B	Katspruit	Ka 1000	89
B	Katspruit	Ka 1000	90
B	Katspruit	Ka 1000	91
B	Katspruit	Ka 1000	92
B	Katspruit	Ka 1000	93
B	Katspruit	Ka 1000	94
B	Katspruit	Ka 1000	95
B	Katspruit	Ka 1000	96
B	Katspruit	Ka 1000	97
B	Katspruit	Ka 1000	98
B	Katspruit	Ka 1000	99
B	Katspruit	Ka 1000	100
B	Katspruit	Ka 1000	101
B	Katspruit	Ka 1000	102
B	Katspruit	Ka 1000	103
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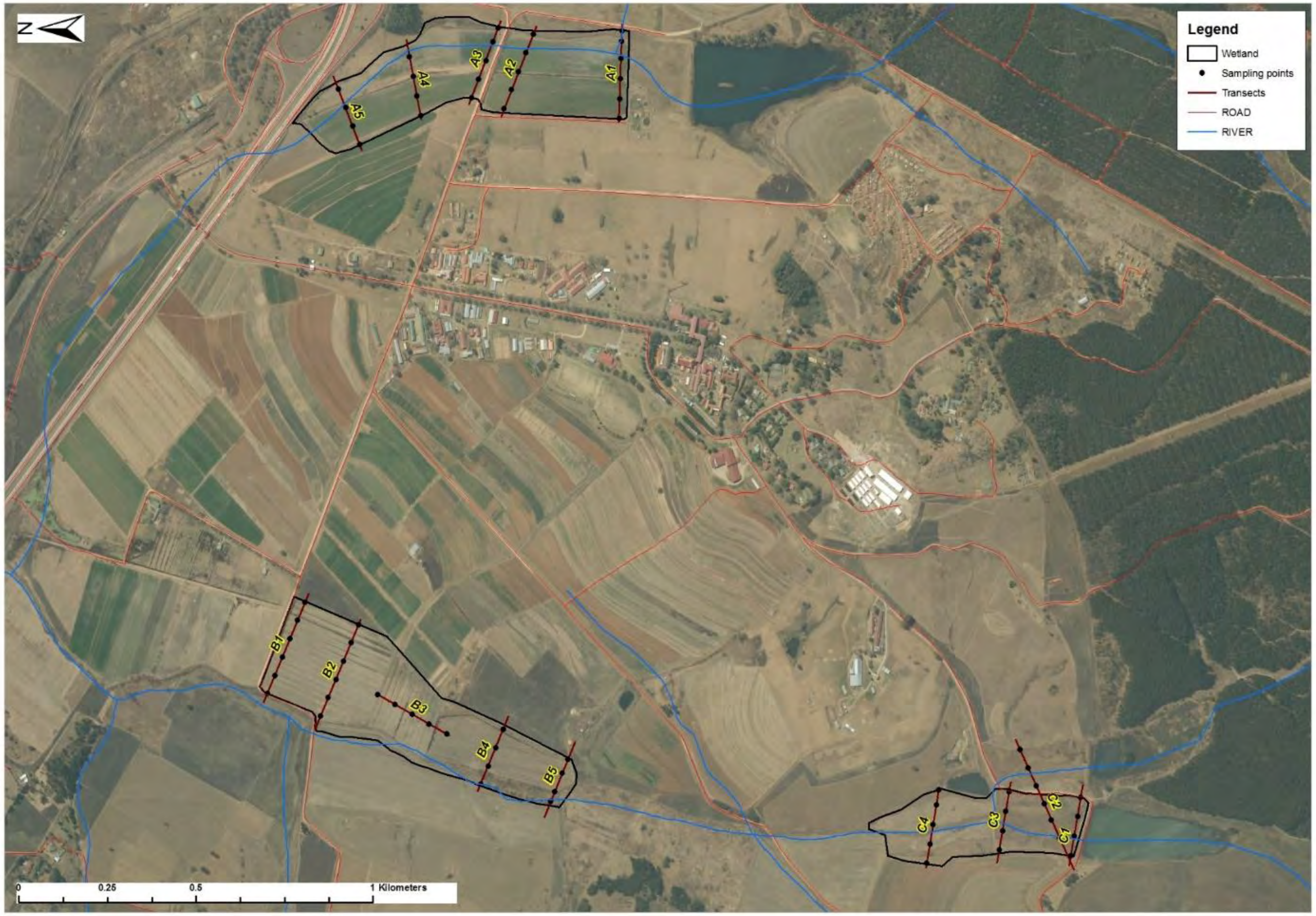
B	Katspruit	Ka 1000	112
B	Katspruit	Ka 1000	113
B	Katspruit	Ka 1000	114
B	Katspruit	Ka 1000	115
B	Katspruit	Ka 1000	116
B	Katspruit	Ka 1000	117
B	Katspruit	Ka 1000	118
B	Katspruit	Ka 1000	119
B	Dresden	Dr 1000	120
B	Katspruit	Ka 1000	121
B	Dresden	Dr 1000	122
B	Dresden	Dr 1000	123
B	Katspruit	Ka 1000	124
B	Katspruit	Ka 1000	125
B	Katspruit	Ka 1000	126
B	Katspruit	Ka 1000	127
B	Katspruit	Ka 1000	128
B	Katspruit	Ka 1000	129
B	Katspruit	Ka 1000	130
B	Katspruit	Ka 1000	131
B	Katspruit	Ka 1000	132
B	Katspruit	Ka 1000	133
B	Katspruit	Ka 1000	134

B	Katspruit	Ka 1000	135
B	Katspruit	Ka 1000	136
C	Pinedene	Pn 2100	139
C	Katspruit	Ka 1000	140
C	Glencoe	Gc 2100	141
C	Katspruit	Ka 1000	142
C	Katspruit	Ka 1000	143
C	Katspruit	Ka 1000	144
C	Fernwood	Fw 1000	145
C	Katspruit	Ka 1000	146
C	Pinedene	Pn 2100	147
C	Katspruit	Ka 1000	148
C	Katspruit	Ka 1000	149
C	Hutton	Hu 2100	150
C	Hutton	Hu 2100	151
C	Clovelly	Cv 2100	152
C	Clovelly	Cv 2100	153
C	Hutton	Hu 2100	154
C	Rensburg	Rg 1000	155
C	Magwa	Ma 1100	156
C	Katspruit	ka 1000	157
C	Pinedene	Pn 2100	158
C	Katspruit	ka 1000	159
C	Hutton	Hu 2100	160
C	Griffin	Gf 2100	161
C	Pinedene	Pn 2100	162
C	Griffin	Gf 2100	163
C	Pinedene	Pn 2100	164
C	Pinedene	Pn 2100	165
C	Katspruit	Ka 1000	166
C	Katspruit	Ka 1000	167
C	Fernwood	Fw 1000	168
C	Pinedene	Pn 2100	169
C	Pinedene	Pn 2100	170
C	Pinedene	Pn 2100	171
C	Pinedene	Pn 2100	172
C	Glenrosa	Gs 2100	173
C	Pinedene	Pn 2100	174
C	Fernwood	Fw 1000	175
C	Pinedene	Pn 2100	176
C	Katspruit	Ka 1000	177
C	Katspruit	Ka 1000	178
C	Katspruit	Ka 1000	179
C	Katspruit	Ka 1000	180
C	Katspruit	Ka 1000	181
C	Katspruit	Ka 1000	182

APPENDIX C: SAMPLING POINTS FOR SOIL CHEMICAL ANALYSIS



APPENDIX D: RESULTS FOR CHEMICAL ANALYSIS

Land Use	Transect No	Sample Depth	density	P (mg/L)	K (mg/L)	Ca(mg/L	Mg(mg/L	Exhangeable Acidity (cmol/L)	Total cations (cmol/L)	PH (KCl)	Zn(mg/L	Mn(mg/L	Cu(mg/L	Clay (%)	Carbon (%)	Nitrogen (%)
Dairy &Sewage	1	0-20 cm	0.98	2	127	299	88	0.52	3.06	4.41	0.4	8	5.4	43.5	2.44	0.185
Dairy &Sewage	1	20-40 cm	1.04	3	61	383	86	0.28	3.06	4.57	0.6	8	2.5	49	0.72	0.185
Dairy &Sewage	1	40-60 cm	0.97	3	43	257	146	0.98	3.57	4.2	0.5	4	0.8	58.5	0.87	0.16
Dairy &Sewage	1	60-100 cm	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Dairy &Sewage	1	0-20 cm	1.12	1	466	504	180	0.08	5.27	4.97	0.9	11	2	47	1.135	0.21
Dairy &Sewage	1	20-40 cm	0.94	12	224	604	114	1.2	5.73	4.15	2.5	15	3.6	39.5	3.33	0.315
Dairy &Sewage	1	40-60 cm	1	8	58	1118	200	0.39	7.76	4.4	2.3	14	3.9	40.5	3.455	0.32
Dairy &Sewage	1	60-100 cm	1.04	3	27	829	191	0.35	6.13	4.43	0.9	4	3.2	42	2.605	0.24
Dairy &Sewage	1	0-20 cm	1	1	30	644	232	0.12	5.32	4.87	1	10	2.6	40.5	1.5	0.19
Dairy &Sewage	1	20-40 cm	0.91	46	69	586	122	2.44	6.54	3.74	4.2	10	7.2	53	2.93	0.365
Dairy &Sewage	1	40-60 cm	0.91	20	69	585	141	2.66	6.92	3.76	4.5	7	7.9	52.5	2.245	0.265
Dairy &Sewage	1	60-100 cm	.	.	.		.	.	.	.	.	.	.	.	.	.
Dairy &Sewage	1	0-20 cm	0.95	21	63	716	187	3.19	8.46	3.64	2.6	9	9.8	50.5	1.485	0.2
Dairy &Sewage	1	20-40 cm	1.02	12	58	909	310	3.31	10.55	3.61	3.9	15	8.8	54	1.55	0.245
Dairy &Sewage	1	40-60 cm	0.92	50	156	730	190	1.89	7.5	3.78	5.5	18	7.1	54	3.045	0.37
Dairy &Sewage	1	60-100 cm	0.96	11	114	879	298	2.12	9.25	3.72	5.3	10	8.7	51	0.675	0.16
Dairy &Sewage	1	0-20 cm	1	5	53	890	339	3.23	10.6	3.59	3.5	9	9.1	54.5	0.66	0.235
Dairy &Sewage	1	20-40 cm	0.99	5	54	1051	395	3.01	11.64	3.61	4.8	12	11.4	55.5	0.9	0.23
Dairy &Sewage	1	40-60 cm	0.89	35	82	1030	303	1.1	8.94	3.94	6.1	17	8.5	51.5	2.555	0.335
Dairy &Sewage	1	60-100 cm	0.91	17	61	956	276	1.08	8.28	4.01	3.3	20	8.2	50	2.565	0.295
Dairy &Sewage	1	0-20 cm	0.97	10	43	976	302	1.68	9.15	3.79	2.2	20	8.1	54	1.65	0.285

Dairy &Sewage	1	20-40 cm	0.95	12	63	880	348	4.83	12.25	3.55	3.2	14	10.1	57	1.65	0.27
Dairy &Sewage	1	40-60 cm	0.96	11	53	928	325	3.26	10.7	3.67	2.7	17	9.1	55	1.65	0.28
Dairy &Sewage	1	60-100 cm	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Dairy &Sewage	2	0-20 cm	0.93	2	88	272	164	1.26	4.19	4.17	1.3	8	3.7	52.5	3.885	0.285
Dairy &Sewage	2	20-40 cm	0.98	1	29	123	110	1.17	2.76	4.18	0.9	9	2.9	55	2.135	0.235
Dairy &Sewage	2	40-60 cm	0.96	1	25	92	97	0.42	1.74	4.48	0.6	17	2.5	54	1.225	0.205
Dairy &Sewage	2	60-100 cm	.	.	.	.	.	.	.	.		.	.	.	.	.
Dairy &Sewage	2	0-20 cm	0.94	5	112	647	207	1.29	6.51	4.18	3	17	4.7	43	3.53	0.275
Dairy &Sewage	2	20-40 cm	0.97	5	52	661	206	1.22	6.35	4.16	3.1	21	4.9	44	3.23	0.27
Dairy &Sewage	2	40-60 cm	1	4	73	447	193	0.9	4.91	4.28	1.4	7	4.1	46	1.775	0.185
Dairy &Sewage	2	60-100 cm	1	1	33	275	215	0.74	3.97	4.29	2.2	10	4.1	48.5	1.535	0.17
Dairy &Sewage	2	0-20 cm	0.94	16	57	897	207	1.46	7.78	3.94	2.6	21	6.5	52.5	1.985	0.26
Dairy &Sewage	2	20-40 cm	0.96	3	42	822	229	2.55	8.64	3.78	1.5	13	6.6	48	0.85	0.145
Dairy &Sewage	2	40-60 cm	0.99	2	30	847	314	3.34	10.23	3.6	2.3	13	8.2	54.5	.	0.22
Dairy &Sewage	2	60-100 cm	1.04	2	52	1029	392	2.48	10.97	3.7	3.5	17	10.7	54.5	0.53	0.215
Dairy &Sewage	3	0-20 cm	0.96	1	37	599	169	0.84	5.31	4.33	1	4	3.8	41	3.935	0.31
Dairy &Sewage	3	20-40 cm	1.03	1	38	388	293	0.31	4.75	4.43	1.3	5	4.2	43.5	1.615	0.23
Dairy &Sewage	3	40-60 cm	1.01	2	53	810	409	4	11.54	3.54	3	8	9.9	53	1.32	0.21
Dairy &Sewage	3	60-100 cm	1.08	3	44	839	334	1.34	8.39	3.74	6.3	15	14.2	45	0.55	0.145
Dairy &Sewage	3	0-20 cm	1.09	3	99	957	405	1.83	10.19	3.72	1.8	6	6.1	51	1.13	0.23
Dairy &Sewage	3	20-40 cm	1.12	1	26	824	331	1.8	8.7	3.7	3.1	9	9.2	45.5	0.975	0.185
Dairy &Sewage	3	40-60 cm	1.06	2	35	947	283	0.87	8.01	3.94	2	7	6.6	46	1.625	0.245
Dairy &Sewage	3	60-100 cm	1.08	3	32	670	214	0.54	5.73	4.1	0.7	6	4.6	36	1.42	0.19
Dairy	3	0-20 cm	0.93	25	93	1354	341	0.37	10.17	4.21	3.3	17	8.1	53	2.595	0.325

&Sewage															
Dairy &Sewage	3	20-40 cm	0.98	21	47	1194	297	0.88	9.4	3.96	2.9	20	8.6	52	1.96	0.305
Dairy &Sewage	3	40-60 cm	1.03	7	40	875	249	2.13	8.65	3.67	2.3	9	8.8	50	0.955	0.21
Dairy &Sewage	3	60-100 cm	1.02	5	32	827	270	2.4	8.83	3.69	3.7	11	10.3	53	0.375	0.235
Dairy &Sewage	3	0-20 cm	0.88	25	165	968	231	1.17	8.31	3.97	2.2	14	6.8	53.5	2.33	0.335
Dairy &Sewage	3	20-40 cm	0.96	12	60	856	245	1.75	8.19	3.85	2.1	14	8.2	51	1.505	0.255
Dairy &Sewage	3	40-60 cm	1	3	28	845	301	1.83	8.59	3.69	2	11	7	49.5	0.6	0.185
Dairy &Sewage	3	60-100 cm	0.98	2	29	1106	400	2.67	11.56	3.65	2.7	15	8.9	55.5	0.54	0.19
Dairy &Sewage	4	0-20 cm	1.01	1	24	510	289	0.08	5.06	4.77	0.5	2	2.4	48	1.65	0.29
Dairy &Sewage	4	20-40 cm	1.01	1	22	487	316	0.07	5.16	4.94	0.6	2	1.9	48.5	1.445	0.295
Dairy &Sewage	4	40-60 cm	1.01	7	106	950	345	0.53	8.38	4.22	1.9	9	3.9	48	2.71	0.29
Dairy &Sewage	4	60-100 cm	1.07	1	26	554	314	0.53	5.95	4.19	0.5	4	2.8	49	1.06	0.21
Dairy &Sewage	4	0-20 cm	1.18	1	37	590	264	0.76	5.97	4.04	0.7	11	4.6	40.5	1.385	0.175
Dairy &Sewage	4	20-40 cm	1.06	3	34	455	298	0.7	5.51	4	1.2	7	4.5	50	1.185	0.26
Dairy &Sewage	4	40-60 cm	1.06	7	530	1205	305	0.08	9.96	4.81	5.8	38	8.8	45.5	3.38	0.405
Dairy &Sewage	4	60-100 cm	0.97	4	125	1651	363	0.08	11.63	4.78	4.3	19	8.4	51	2.12	0.295
Dairy &Sewage	4	0-20 cm	0.83	11	583	956	235	0.71	8.9	4.2	2	3	7.6	53	3.025	0.395
Dairy &Sewage	4	20-40 cm	0.95	6	336	1383	331	0.47	10.94	4.19	2.2	10	10.3	52	1.425	0.215
Dairy &Sewage	4	40-60 cm	1.05	5	171	1021	275	1.53	9.33	3.76	2.2	13	8.3	47.5	1.15	0.215
Dairy &Sewage	4	60-100 cm	1.04	7	42	1388	343	0.7	10.56	3.9	2.3	14	9.9	42.5	1.545	0.255
Dairy &Sewage	4	0-20 cm	0.99	18	83	946	351	1.86	9.68	3.76	4.5	17	8.7	49	1.72	0.24
Dairy &Sewage	4	20-40 cm	0.92	7	52	833	342	1.79	8.88	3.8	1.2	5	7.3	46.5	1.84	0.235
Dairy &Sewage	4	40-60 cm	1.03	8	39	803	366	2.02	9.14	3.71	1.4	8	8.1	46	0.865	0.21
Dairy &Sewage	4	60-100 cm	0.89	24	530	1766	448	0.2	14.06	4.49	4	9	6.8	53.5	2.92	0.375

Dairy &Sewage	5	0-20 cm	1.01	3	81	977	309	0.37	8	4.32	1.5	7	5.4	47.5	1.85	0.26
Dairy &Sewage	5	20-40 cm	0.96	1	76	636	294	0.15	5.94	4.52	1.3	6	5	53.5	1.525	0.305
Dairy &Sewage	5	40-60 cm	0.99	7	125	883	255	0.42	7.24	4.27	1.7	11	4.6	46	2.575	0.295
Dairy &Sewage	5	60-100 cm	1.04	6	39	818	275	0.46	6.9	4.22	1.4	12	4.2	47	1.715	0.26
Dairy &Sewage	5	0-20 cm	1.08	1	18	339	282	0.08	4.14	4.82	0.6	1	1.4	46	1.33	0.27
Dairy &Sewage	5	20-40 cm	1.07	1	33	471	310	0.13	5.12	4.68	0.9	3	2.7	46.5	1.77	0.275
Dairy &Sewage	5	40-60 cm	0.93	3	35	1084	273	0.21	7.96	4.5	1.5	8	4	42.5	3.685	0.34
Dairy &Sewage	5	60-100 cm	0.93	1	18	789	197	0.71	6.31	4.31	1	5	3.7	39.5	4.28	0.35
Dairy &Sewage	5	0-20 cm	1.12	6	177	941	250	0.74	7.95	4	2.7	11	7.2	50	1.52	0.26
Dairy &Sewage	5	20-40 cm	1.07	6	73	973	268	0.87	8.12	3.98	4.1	12	9.4	50	0.87	0.22
Dairy &Sewage	5	40-60 cm	1.12	3	61	654	228	1.96	7.26	3.65	3	10	9.6	45	0	0.12
Dairy &Sewage	5	60-100 cm	1.08	3	117	912	350	0.6	8.33	4.08	1.7	13	6.5	49	1.655	0.27
Dairy &Sewage	5	0-20 cm	1.11	3	58	1418	461	1.21	12.23	3.72	1.4	11	9.5	45.5	0.995	0.24
Dairy &Sewage	5	20-40 cm	1.12	1	27	1800	683	1.42	16.09	3.75	1.5	14	11.5	50	1.43	0.27
Dairy &Sewage	5	40-60 cm	1.11	2	23	1580	619	1.49	14.53	3.68	3.2	20	17.8	50.5	0.775	0.225
Dairy &Sewage	5	60-100 cm	0.99	6	335	1052	262	0.23	8.49	4.26	2.9	11	7.1	46.5	2.215	0.32
Dairy &Sewage	1	0-20 cm	1.19	3	40	1485	298	0.07	10.04	5.69	1.2	2	3.1	26.5	2.1	0.275
Dairy &Sewage	1	20-40 cm	1.22	2	49	1050	418	0.07	8.88	4.79	1	3	6.5	26.5	1.29	0.205
Dairy &Sewage	1	40-60 cm	1.29	1	22	647	335	0.1	6.14	4.88	0.3	1	1.6	25.5	1.035	0.21
Dairy &Sewage	1	60-100 cm	1.31	1	28	742	392	0.1	7.1	4.71	0.4	1	1.4	35.5	1.22	0.235
Pasture	1	0-20 cm	1.07	11	64	1944	544	0.49	14.83	3.95	1.9	7	13.4	40	1.235	0.225
Pasture	1	20-40 cm	1.1	2	34	2275	648	0.23	17	4.1	1.4	9	10.4	43.5	1.3	0.245
Pasture	1	40-60 cm	1.11	1	34	2646	689	0.09	19.05	4.3	4.3	7	11.3	47	0.89	0.26
Pasture	1	60-100 cm	1.03	1	38	2886	1008	0.07	22.86	4.31	8.3	7	12.7	49.5	0.63	0.28

Pasture	1	0-20 cm	1.19	3	178	846	476	0.07	8.66	4.63	1.2	3	2.5	27.5	2.04	0.255
Pasture	1	20-40 cm	1.21	1	122	692	398	0.05	7.09	4.65	0.7	2	2.4	27	1.065	0.185
Pasture	1	40-60 cm	1.19	1	45	1107	643	0.04	10.97	5.29	0.4	1	2.1	35.5	1.385	0.28
Pasture	1	60-100 cm	1.21	1	39	916	945	0.09	12.54	4.62	0.4	2	1.1	38.5	0.435	0.205
Pasture	1	0-20 cm	0.99	1	40	2696	642	0.1	18.94	4.24	2.5	6	9.3	49	2.03	0.37
Pasture	1	20-40 cm	1.03	1	37	2981	1007	0.12	23.38	4.2	2.8	9	12	48	1.295	0.32
Pasture	1	40-60 cm	1.09	1	46	3762	1104	0.25	28.23	4.03	1.8	6	12.6	53	1.15	0.34
Pasture	1	60-100 cm	1.12	1	35	4137	1188	0.07	30.58	4.39	1.5	4	9.3	52	1.22	0.305
Pasture	1	0-20 cm	1.1	5	37	1934	675	0.04	15.34	4.58	1.4	6	7.1	38	1.625	0.31
Pasture	1	20-40 cm	1.11	6	59	1705	673	0.04	14.24	4.61	3.1	5	6.7	31.5	2.05	0.275
Pasture	1	40-60 cm	1.08	4	37	1943	800	0.03	16.4	4.65	1.8	5	8.2	37	1.525	0.265
Pasture	1	60-100 cm	1.15	1	42	3259	1262	0.03	26.79	5.16	0.8	2	6.7	47	0.97	0.265
Pasture	2	0-20 cm	1.08	3	89	1674	551	0.27	13.39	4.09	4.8	6	5.4	41	1.27	0.265
Pasture	2	20-40 cm	1.13	4	46	1599	572	0.08	12.88	4.52	2.2	4	5.2	37	1.45	0.245
Pasture	2	40-60 cm	1.1	1	33	1650	648	0.06	13.71	4.43	1.3	5	5	43.5	0.605	0.27
Pasture	2	60-100 cm	1.11	1	41	1495	651	3.01	15.93	3.59	2.5	5	6.5	44.5	0.285	0.175
Pasture	2	0-20 cm	1.16	1	30	2311	669	0.05	17.16	4.65	1.2	20	6.2	34	2.14	0.275
Pasture	2	20-40 cm	1.23	1	37	2574	1082	0.09	21.93	4.28	1.9	10	7.3	46	2.18	0.315
Pasture	2	40-60 cm	1.23	1	34	2499	862	0.07	19.71	4.37	0.9	8	8.1	35	1.135	0.225
Pasture	2	60-100 cm	1.28	1	26	1730	683	0.03	14.35	4.7	0.5	1	13.1	27	0.37	0.155
Pasture	2	0-20 cm	1.06	1	44	1936	892	0.05	17.16	4.42	1.6	5	9	47.5	1.535	0.29
Pasture	2	20-40 cm	1.12	1	44	1904	920	0.25	17.44	0.7	11.5	4	9.1	43.5	0.745	0.215
Pasture	2	40-60 cm	1.13	1	36	1835	857	0.42	16.72	3.92	1.2	5	9.3	42	1.035	0.265
Pasture	2	60-100 cm	1.1	3	65	401	121	0.31	3.47	4	2.5	10	11.7	48	1.105	0.22
Pasture	2	0-20 cm	1.11	1	66	740	466	0.4	8.1	4.05	1.1	7	5.2	42	1.045	0.23

Pasture	2	20-40 cm	1.13	1	81	829	152	0.25	5.83	4.13	0.4	3	3.2	48.5	0.74	0.225
Pasture	2	40-60 cm	1.14	3	58	720	159	0.04	5.09	5.02	0.5	3	3.1	42	1.445	0.3
Pasture	2	60-100 cm	1.15	1	40	380	117	0.05	3.01	5.4	0.4	2	1.9	39.5	1.315	0.295
Pasture	3	0-20 cm	1.17	14	61	302	130	1.35	4.08	3.87	4.9	8	5.8	37	2.245	0.265
Pasture	3	20-40 cm	1.1	8	43	452	138	1.33	4.83	3.86	3.2	5	6.9	41	1.23	0.23
Pasture	3	40-60 cm	1.14	1	33	237	102	1.4	3.51	3.79	7.3	2	1.3	29.5	1.48	0.225
Pasture	3	60-100 cm	1.07	1	30	2224	1046	1.87	21.65	3.91	0.8	2	1.5	57.5	0.755	0.285
Pasture	3	0-20 cm	1	2	24	1254	482	0.33	10.61	4.38	0.3	5	4.1	38	2.9	0.3
Pasture	3	20-40 cm	1.04	2	20	1260	690	1.8	13.82	3.93	0.2	6	3.8	34.5	1.855	0.25
Pasture	3	40-60 cm	1.19	1	14	1055	661	0.76	11.5	4.07	0.1	2	1.6	24	1.535	0.215
Pasture	3	60-100 cm	1.2	1	13	914	702	0.19	10.55	4.42	0.5	2	0.8	26	2.865	0.3
Pasture	3	0-20 cm	0.96	3	61	671	114	1.6	6.04	4.07	1.9	6	4.4	44.5	3.87	0.285
Pasture	3	20-40 cm	1.17	3	42	254	74	1.74	3.72	3.84	1.9	10	4.9	27	1.63	0.165
Pasture	3	40-60 cm	1.22	2	20	954	338	1.74	9.33	3.95	0.9	3	3	24.5	0.97	0.125
Pasture	3	60-100 cm	1.33	2	26	224	114	0.51	2.63	4.37	1.5	3	2.2	23	1.07	0.21
Pasture	3	0-20 cm	1.09	5	97	760	183	0.43	5.98	4.35	1.2	6	3.5	32.5	1.99	0.25
Pasture	3	20-40 cm	1.18	3	77	589	225	0.59	5.58	4.15	0.4	2	1.4	25.5	0.955	0.185
Pasture	3	40-60 cm	1.16	1	82	891	420	0.17	8.28	4.4	0.6	1	2.1	33	1.07	0.22
Pasture	3	60-100 cm	1.19	1	45	1353	955	0.1	14.83	4.92	0.4	2	2.5	38.5	0.155	0.2
Pasture	3	0-20 cm	0.98	3	146	954	353	1.02	9.06	3.96	1.2	7	10	39.5	2.145	0.27
Pasture	3	20-40 cm	0.99	2	64	785	306	1.94	8.54	3.84	1.2	11	8.9	45.5	1.86	0.265
Pasture	3	40-60 cm	0.98	2	37	900	318	1.7	8.9	3.85	1.9	8	9.8	50.5	1.485	0.27
Pasture	3	60-100 cm	1.02	1	104	1132	469	0.05	9.82	4.54	1.2	7	7.1	45	1.95	0.285
Pasture	4	0-20 cm	1.01	2	1047	913	357	0.13	10.3	4.45	1.1	5	4.5	48.5	2.165	0.3
Pasture	4	20-40	1.06	1	657	1267	547	0.11	12.61	4.29	1	13	5.6	44.5	1.245	0.28

		cm														
Pasture	4	40-60 cm	1.11	1	519	1453	634	0.12	13.92	4.18	1	9	4.4	46	0.085	0.25
Pasture	4	60-100 cm	1.1	1	226	1550	901	0.09	15.82	4.56	0.7	6	5.2	48	0.31	0.275
Pasture	4	0-20 cm	1.14	1	532	575	346	0.1	7.18	4.61	0.4	4	3.4	42	2.14	0.23
Pasture	4	20-40 cm	1.06	1	237	526	350	0.05	6.16	5.16	0.2	2	2.6	37.5	1.87	0.19
Pasture	4	40-60 cm	1.14	1	282	817	556	0.06	9.43	4.76	0.7	6	4.7	34	1.235	0.21
Pasture	4	60-100 cm	1.21	1	167	365	275	0.07	4.58	4.49	1	7	2.3	29	1.39	0.22
Pasture	4	0-20 cm	1.18	11	747	580	264	0.1	7.08	5.17	0.4	2	1.7	26	2.94	0.27
Pasture	4	20-40 cm	1.25	1	479	224	117	0.38	3.69	4.42	0.5	1	1.1	26.5	1.53	0.2
Pasture	4	40-60 cm	1.31	1	468	270	211	0.05	4.33	4.85	1.6	1	1.1	28	0.745	0.195
Pasture	4	60-100 cm	.		.	.	.	.	.		.	.	.	.	.	.
Pasture	4	0-20 cm	1.02	3	148	299	190	2.7	6.13	3.77	1.6	5	4.5	39	1.9	0.27
Pasture	4	20-40 cm	1.03	2	49	256	167	2.71	5.49	3.79	1.6	3	5.5	44.5	1.705	0.27
Pasture	4	40-60 cm	1.09	1	47	213	230	1.46	4.54	3.97	0.7	5	1.7	39	1.535	0.26
Pasture	4	60-100 cm	.	.	.	.	.	.	.		.	.	.	.	.	.
Pasture	4	0-20 cm	1.01	1	36	574	485	1.41	8.36	3.87	0.9	3	2.2	42	0.46	0.25
Pasture	4	20-40 cm	0.96	3	42	1132	346	2.32	10.92	3.68	2.1	14	10	53	1.87	0.28
Pasture	4	40-60 cm	0.98	6	40	1134	392	3.54	12.53	3.61	2.7	14	17.2	55	1.42	0.265
Pasture	4	60-100 cm	1	3	116	1444	505	2.5	14.16	3.57	2.7	17	13.1	45.5	0.45	0.24
Pasture	5	0-20 cm	1.07	7	77	1319	594	3.22	14.89	3.44	1.6	17	10	45	0.2	0.185
Pasture	5	20-40 cm	0.81	3	65	1171	333	0.05	8.8	5.31	1.7	8	3.6	34	3.755	0.34
Pasture	5	40-60 cm	1.04	1	35	818	489	0.05	8.25	5.03	0.2	9	3.4	43	1.255	0.3
Pasture	5	60-100 cm	1.04	1	34	1018	729	0.05	11.22	5.56	0.3	3	1.6	43.5	0.585	0.23
Pasture	5	0-20 cm	1.04	1	32	1173	911	0.05	13.48	5.54	0.2	3	3.8	38	0.565	0.3
Pasture	5	20-40 cm	1.04	2	49	1035	338	0.05	8.12	5.39	0.3	2	3.2	28	1.31	0.23

Pasture	5	40-60 cm	1.04	1	29	716	444	0.06	7.36	4.85	0.2	1	1	34.5	0.5	0.22
Pasture	5	60-100 cm	1.05	1	37	875	667	0.14	10.09	4.87	0.4	1	0.8	41	0.37	0.23
Pasture	5	0-20 cm	0.96	1	33	1036	737	0.1	11.42	5.05	0.5	1	1.1	44.5	0.73	0.245
Pasture	5	20-40 cm	0.84	7	102	1524	512	0.08	12.16	5.32	1.7	4	2.8	31	3.075	0.345
Pasture	5	40-60 cm	1	1	26	882	346	0.73	8.05	3.93	0.6	1	4.6	34.5	0.695	0.195
Pasture	5	60-100 cm	1.01	1	36	1210	644	0.35	11.78	4.16	0.6	1	3.4	40	0.35	0.185
Pasture	5	0-20 cm	1.07	1	42	1398	691	0.24	13.01	4.32	0.9	1	6.1	37.5	0.135	0.165
Pasture	5	20-40 cm	0.89	4	134	1302	416	0.24	10.5	4.24	1.1	2	3.7	42	2.355	0.305
Pasture	5	40-60 cm	0.95	2	94	1849	644	0.06	14.83	5.68	0.8	5	5.1	43	1.42	0.255
Pasture	5	60-100 cm	0.97	1	57	1927	727	0.08	15.83	6.18	1	2	2.9	47.5	0.49	0.26
Pasture	1	0-20 cm	1	1	57	1772	598	0.07	13.98	5.79	0.8	2	2.2	49	0.415	0.265
Pasture	1	20-40 cm	0.98	3	110	402	234	1.49	5.7	4.11	0.4	7	3.1	48	2.76	0.22
Pasture	1	40-60 cm	0.97	2	48	261	172	1.69	4.53	4.17	0.1	3	2.3	45	2.4	0.205
Pasture	1	60-100 cm	0.98	1	23	116	110	1.49	3.03	4.18	0.3	3	1.3	52	1.69	0.13
Undisturbed	1	0-20 cm	1.01	4	37	66	90	0.99	2.15	4.23	0.5	2	0.6	48	0.78	0.14
Undisturbed	1	20-40 cm	0.9	2	138	681	359	0.59	7.3	4.26	1.7	11	3	40	3.115	0.285
Undisturbed	1	40-60 cm	1.02	3	31	510	335	0.49	5.87	4.29	0.7	9	2.4	49	2.165	0.22
Undisturbed	1	60-100 cm	0.98	2	26	274	206	1.5	4.63	4.13	0.6	6	2.2	47.5	1.98	0.215
Undisturbed	1	0-20 cm	1	2	70	323	324	0.17	4.63	4.81	0.6	9	1.5	51	0.925	0.17
Undisturbed	1	20-40 cm	1.02	2	20	599	251	0.26	5.37	4.49	0.8	35	5.5	46	1.575	0.245
Undisturbed	1	40-60 cm	0.94	4	36	486	221	1.69	6.03	3.89	1.5	80	9.9	43.5	1.85	0.265
Undisturbed	1	60-100 cm	0.97	1	24	593	225	0.8	5.67	3.92	1	140	7	45.5	1.32	0.25
Undisturbed	1	0-20 cm	1	2	29	851	505	0.07	8.55	4.56	1	38	4.8	43.5	1.09	0.24
Undisturbed	1	20-40 cm	0.93	4	38	802	416	0.23	7.75	4.5	1.9	73	6.5	41.5	2.5	0.29
Undisturbed	1	40-60	0.97	3	34	826	460	0.15	8.15	4.53	1.45	55	5.6	42.5	1.79	0.27

		cm														
Undisturbed	1	60-100 cm	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Undisturbed	1	0-20 cm	1.01	2	17	453	246	0.93	5.26	4.18	0.5	67	7	44.5	1.155	0.165
Undisturbed	1	20-40 cm	0.95	3	29	635	344	1.1	7.17	4.01	1.2	76	11.4	48	1.705	0.27
Undisturbed	1	40-60 cm	0.97	2	32	555	314	1.85	7.29	3.83	1.3	41	9.4	49.5	2.04	0.315
Undisturbed	1	60-100 cm	0.89	5	80	263	244	3.3	6.83	3.86	0.7	2	3.1	42	2.975	0.445
Undisturbed	2	0-20 cm	0.9	2	25	38	39	2.57	3.14	4.07	0	1	1	55.5	2.395	0.27
Undisturbed	2	20-40 cm	0.97	4	35	81	33	2.79	3.56	3.86	0.3	3	1	55.5	1.87	0.25
Undisturbed	2	40-60 cm	1.02	4	36	110	35	3.1	4.03	3.77	0.3	3	0.9	53.5	1.165	0.225
Undisturbed	2	60-100 cm	1.03	5	61	907	373	0.21	7.96	4.06	2.9	8	3.5	41	1.98	0.25
Undisturbed	2	0-20 cm	1.04	4	51	987	371	0.14	8.25	4.15	2.2	8	4.1	41.5	1.715	0.235
Undisturbed	2	20-40 cm	0.99	3	63	993	500	0.06	9.29	4.57	1.7	6	6.6	44	1.7	0.28
Undisturbed	2	40-60 cm	0.93	3	32	1311	543	0.06	11.15	4.44	1.1	14	7.2	45.5	1.91	0.31
Undisturbed	2	60-100 cm	0.96	2	30	1226	566	0.11	10.96	4.23	1.2	23	6.8	46.5	1.185	0.29
Undisturbed	2	0-20 cm	0.96	5	37	997	531	0.47	9.91	3.85	1.8	51	8.6	45	0.91	0.265
Undisturbed	2	20-40 cm	1.04	4	21	338	123	2.14	4.89	3.65	0.7	18	5.7	34	0.61	0.125
Undisturbed	2	40-60 cm	1.1	2	13	236	117	1.77	3.94	3.64	0.3	12	2.4	30.5	0.2	0.12
Undisturbed	2	60-100 cm	0.95	2	18	281	182	0.98	3.93	3.95	0.4	11	2.8	42	1.235	0.245
Undisturbed	2	0-20 cm	0.93	2	28	387	328	0.34	5.04	4.19	0.9	10	1.9	48	1.46	0.345
Undisturbed	2	20-40 cm	0.94	4	492	434	301	0.84	6.74	4.05	1.1	4	2.1	48.5	3.01	0.28
Undisturbed	2	40-60 cm	0.99	2	161	191	198	1.74	4.73	3.91	0.2	1	1.4	53.5	1.53	0.18
Undisturbed	2	60-100 cm	0.93	2	37	124	201	2.16	4.53	3.87	0.1	3	0.6	60.5	0.675	0.185
Undisturbed	3	0-20 cm	0.99	1	35	119	210	3.06	5.47	3.83	0.1	3	0.5	57	0.15	0.21
Undisturbed	3	20-40 cm	0.98	5	83	357	305	2.61	7.11	3.79	0.5	2	2.2	47	1.1	0.255
Undisturbed	3	40-60 cm	0.96	4	38	224	197	4.13	6.97	3.64	0.4	1	1.8	42	1.195	0.225

Undisturbed	3	60-100 cm	1.01	2	34	178	235	4.69	7.6	3.68	0.6	4	1	45	0.015	0.15
Undisturbed	3	0-20 cm	1.09	2	39	275	368	5.04	9.54	3.52	0.9	8	0.9	41.5	0	0.125
Undisturbed	3	20-40 cm	0.94	16	116	1155	354	0.76	9.73	3.82	2.8	9	7.9	43	2.165	0.285
Undisturbed	3	40-60 cm	0.9	8	33	1618	505	0.45	12.76	3.88	2.4	12	9.3	46.5	1.85	0.295
Undisturbed	3	60-100 cm	0.94	2	45	2352	897	0.68	19.91	3.72	1.4	13	9.5	49	0.42	0.265
Undisturbed	3	0-20 cm	0.96	1	54	2693	1055	1.07	23.33	3.63	1.4	19	8.7	50	0.175	0.265
Undisturbed	3	20-40 cm	1	4	49	719	366	0.44	7.17	4.13	0.6	4	3.6	45	2.395	0.25
Undisturbed	3	40-60 cm	0.96	3	22	436	316	0.45	5.28	4.18	0.4	4	2.6	58.5	1.36	0.24
Undisturbed	3	60-100 cm	0.88	1	16	333	358	0.17	4.82	4.66	0.2	5	2.6	67.5	1.71	0.275
Undisturbed	4	0-20 cm	0.83	2	51	121	56	3.14	4.34	3.7	1.2	28	7.3	41	2.765	0.27
Undisturbed	4	20-40 cm	0.96	2	33	138	66	3.39	4.71	3.73	0.9	26	6.4	34.5	2.93	0.22
Undisturbed	4	40-60 cm	1.04	3	29	190	91	2.98	4.75	3.72	1.6	19	6.1	32.5	2.005	0.15
Undisturbed	4	60-100 cm	1.07	1	27	96	48	2.04	2.98	3.74	0.3	9	4.1	30	1.075	0.185
Undisturbed	4	0-20 cm	0.85	3	100	927	500	0.11	9.11	4.82	1.2	28	7.1	49	2.475	0.295
Undisturbed	4	20-40 cm	0.87	3	36	454	150	2.16	5.75	3.71	1.4	130	9.5	46.5	1.825	0.29
Undisturbed	4	40-60 cm	0.91	3	36	482	186	2.06	6.09	3.68	0.8	100	6.1	47.5	1.215	0.275
Undisturbed	4	60-100 cm	0.84	3	39	611	278	0.78	6.22	4.02	1	90	7.8	49.5	1.1	0.31
Undisturbed	4	0-20 cm	0.85	4	47	504	226	1.74	6.24	3.81	1	20	10.4	42	2.535	0.39
Undisturbed	4	20-40 cm	0.91	2	33	506	327	0.97	6.27	3.95	0.5	18	8.5	42	2.15	0.345
Undisturbed	4	40-60 cm	0.88	1	44	617	472	0.23	7.31	4.4	0.6	8	4.2	50.5	1.83	0.395
Undisturbed	4	60-100 cm	0.91	7	46	953	429	0.12	8.52	4.53	2.9	18	5.3	45.5	2.675	0.345
Undisturbed	4	0-20 cm	0.95	2	28	885	312	0.55	7.61	3.99	1.2	70	7.1	43.5	2.055	0.285
Undisturbed	4	20-40 cm	0.98	1	37	405	150	1.21	4.56	4.04	0.7	80	4.1	45.5	1.62	0.25
Undisturbed	4	40-60 cm	1.03	1	38	383	139	0.84	3.99	4.08	0.7	69	3.9	46	1.96	0.335
Undisturbed	4	60-100	0.91	3	50	1393	563	0.08	11.79	4.64	1.7	12	6.1	48.5	1.5	0.32

		cm														
Undisturbed	4	0-20 cm	0.96	2	48	1678	856	0.11	15.65	5.63	1.2	10	6.5	45	1.75	0.255
Undisturbed	4	20-40 cm	0.96	1	71	1920	923	0.1	17.46	4.82	1.1	11	7.4	42.5	1.275	0.235
Undisturbed	4	40-60 cm	0.98	1	91	1863	1029	0.08	18.08	5.5	1.3	5	8.2	45	1.125	0.26
Undisturbed	4	60-100 cm	0.97	5	47	989	409	0.62	9.04	3.96	1	11	6	37	1.69	0.19
Undisturbed	4	0-20 cm	0.98	2	60	893	406	0.22	8.17	4.28	1.2	6	3.8	31	1.6	0.17
Undisturbed	4	20-40 cm	1.01	1	58	1682	569	0.92	14.14	3.74	1.5	21	6.5	37	1.51	0.185
Undisturbed	4	40-60 cm	1.07	1	83	1929	786	0.07	16.38	4.55	0.5	11	4.8	34	0.58	0.205