THE INTERACTION BETWEEN VEGETATION AND NEAR-SURFACE WATER IN A WETLAND SYSTEM, STELLENBOSCH, SOUTH AFRICA

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Signature …………………… Date: 4 November 2004

Summary

Understanding the responses of individual plant communities to variations in near-surface water levels and to water quality is a step towards determining the critical or important factors applicable to a Rapid Wetland Assessment System.

This thesis describes and discusses factors associated with wetland plant communities, with an attempt to predict changes in a wetland system. This study was initiated with a primary aim of establishing the relationship between plant communities and the variation in near-surface water levels in areas occupied by various plant communities in the Middelvlei wetland system at Stellenbosch. A second aim was to assess whether water quality had an influence on the plant communities.

Seven plant communities are identified and described from this particular wetland system using standard Braun-Blanquet techniques (*Typha capensis* Reedswamp; *Cyperus textilis* Sedgeland; *Pennisetum macrourum* Grassland; *Juncus effusus* Sedgeland; *Cyperus longus* Sedgeland; *Cliffortia strobilifera* Shrubland and *Populus canescens* Forest). The *Typha capensis* Reedswamp community is found in the wettest parts of the wetlands, with a fluctuation in water table from 0.10 m above surface during the wet season to 0.43 m below surface during the dry season. The *Populus canescens* Forest is actively invading the wetland replacing the wetland species by modifying the wetland hydrological condition. Water samples from 35 wells, collected on a monthly basis over 11 months, are used to assess sodium, magnesium, potassium, calcium, nitrate and phosphate, pH, redoxs potencial and dissolved oxygen levels in each community, over four seasons.

Both multivariate analysis (ANOVA) and regression tree analysis (CART) are applied to evaluate differences between communities or groups of plant communities on a seasonal basis. Direct gradient analysis (CCA) is used to determine the relationship between plant communities and environmental variable gradients.

A wide variation in water quality condition between plant communities is present. The *Typha capensis* Reedswamp community is associated with low nutrient levels (phosphates and nitrates) in all seasons. The *Cyperus textilis* Sedgeland is associated with

low levels of nitrates and high phosphate levels. The *Juncus effusus* Sedgeland displays the highest phosphate concentration, occurring in summer, while low nitrate levels occur in this community during all the seasons.

Dissolved oxygen in the near-surface water in this wetland is at very low concentrations, and has no significant difference between communities. It plays no major role in determining the occurrence and distribution of the plant communities.

Most of the water chemical constituents measured in this study are the result of multiple complex relationships, with constituent variations occurring differently between communities. A remarkable seasonal distinction in the chemical constituents in different communities is present.

Despite the complex nature of the relationships between plant communities and environmental factors, the low species diversity levels through the tendency for single species dominance and the strong association of these communities with particular environmental variables, the combination of these factors all add value to the use of wetland vegetation as a good tool to indicate wetland condition. An effort to understand wetland plant communities in relation to determining environmental factors would promote the use of plant communities as user-friendly tools for wetland monitoring and assessment.

Opsomming

Om die reaksies van plantgemeenskappe teenoor variasies in naby-oppervlakte watervlakke te verstaan, is die eerste krities-belangrike faktor die ontwikkeling van ‘n sisteem om vleilande vinnig te assesseer. Hierdie studie se basiese mikpunt is om verwantskappe te soek tussen plantgemeenskappe in die Middelvlei Vleilandsisteem en wisseling in naby-oppervlak watervlakke. ‘n Sekondêre doel is om te bepaal of daar enige korrelasie is tussen waterkwaliteit en die plantgemeenskappe teenwoordig in die vleiland.

Sewe plantgemeenskappe is in hierdie vleilandsisteem geïdentifiseer en beskryf deur gebruik te maak van standaard Braun-Blanquet tegnieke, naamlik die *Typha capensis* Rietmoeras; *Cyperus textilis* Biesieveld; *Pennisetum macrourum* Grasveld; *Juncus effusus* Biesieveld; *Cyperus longus* Biesieveld; *Cliffortia strobilifera* Struikveld en ‘n *Populus canescens* Woud. Die *Typha capensis* Rietmoeras kom in die natste dele van die vleilande voor, met vrywater wisselling vanaf 0.10 m bo grondoppervlakte, tydens die nat-seisoen, tot 0.43 m onder grondoppervlakte tydens die droë seisoen. Die *Populus canescens* Woud het die grootste wisseling in watervlak vanaf die grondoppervlakte tot ten minste ‘n diepte van 1.0 m gehad. Dit blyk dat die *Populus canescens* Woud besig is om die vleigemeenskappe aktief binne te dring deur die vleiland uit te droog.

Water is maandeliks, oor 11 maande, uit 35 geperforeerde plastiek pype, sogenaamde ‘putte’ onttrek, om natrium, magnesium, kalium, kalsium, nitrate en fosfate, pH, redokspotensiaal en opgeloste suurstof vlakke se seisoenale wisseling te bepaal. Beide veelvuldige analise (ANOVA) en regressie-analises (CART) is bereken om enige betekenisvolle verskille tussen plantgemeenskappe te bepaal. Direkte Gradiëntanalise (CCA) is gebruik om die verwantskap tussen plantgemeenskappe en gradiënte van omgewingsveranderlikes te bepaal.

Groot variasies in waterkwaliteit tussen plantgemeenskappe is waargeneem. Die *Typha capensis* Rietmoeras-gemeenskap is geassosieer met lae voedingstofvlakke (veral van fosfate en nitrate) in alle seisoene. Die *Cyperus textilis* Biesieveld-gemeenskap is

geassosieer met lae nitraat- en hoë fosfaatvlakke. Die *Juncus effusus* Biesieveld-gemeenskap vertoon die hoogste fosfaatvlakke, tydens die die somermaande, terwyl die nitraatvlakke deur al die seisoene ook laag bly.

Opgeloste suurstof in die naby-oppervlakte water in die vleilandsisteem het deurgaans ‘n lae konsentrasie vertoon met geen betekenisvolle verskille tussen gemeenskappe nie. Dit speel dus geen belangrike rol in die voorkoms of verspreiding van die plantgemeenskappe nie

Die meeste van hierdie faktore, gemeet om die waterkwaliteit te bepaal, het veelvoudige, komplekse verhoudingsverskille, gebaseer veral op konsentrasieverskille, tussen die gemeenskappe.

Ten spyte van die komplekse verwantskap tussen die plantgemeenskappe en omgewingsfaktore, is die spesierykheid laag en kom die neiging tot eensoortige-dominansie algemeen in die vleiland-plantgemeenskappe voor. Die sterk assosiasie tussen die plantgemeenskappe en bepaalde omgewingsveranderlikes voeg aansienlike waarde daaraan toe om vleilandplantegroei te gebruik as indikator van vleilandtoestand. ‘n Poging om die verwantskappe tussen vleiland-plantgemeenskappe en omgewingsveranderlikes algemeen te bepaal, sal die gebruikersvriendelike nut van vleiland-plantgemeenskappe vir vleilandmonitering en assessering duidelik uitwys.

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DEDICATION

I dedicate this work to my late father, Samuel Njeru Kareko, who passed away in the course of this study and to my dedicated brother Nimrod N. Kareko who went a mile further to make my stay in South Africa possible. To the entire family, thank you for all your support and encouragement.

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1.1 Introduction

It is the intention of this study to give an insight into the relationship between wetland plant communities and environmental variables. This thesis focuses on the relationship between wetland plant communities, wetland hydrology and wetland water quality.

Wetlands are defined by the Convention on Wetlands of International Importance also known as Ramsar Convention, Iran, 1971 as: ‘areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water, the depth of which does not exceed six meters’ (Ramsar Convention Bureau (RCB) 1990). The Convention also states that wetlands: ‘may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six meters at low tide lying within the wetlands’ (RCB 1991). This definition is very broad, aimed to define all wetlands of the world, and may not be adequately applicable at local and national levels.

Many wetland definitions exist in a wide variety of texts. A number of countries have developed national wetland definitions to suit each country’s needs in respect of their variations in wetlands. South Africa, being a party to the Ramsar Convention, has adopted the above Ramsar Convention definition (Cowan 1995), although other definitions are still widely used. Coetzee *et al.* (1994) define wetlands as areas dominated by soils that are either periodically or permanently saturated with water and support a characteristic flora and fauna, however, further guidelines need to be formulated to highlight the circumstances under which a particular definition is applicable. Some of the shortcomings regarding the definition of wetlands are addressed in Chapter 2.

A wetland delineation procedure and criteria for definition is necessary, if different research findings in the country are to be harmonised for comparative purposes. A literature review on South Africa wetlands reveals that a number of attempts have been made to classify wetlands (Jones 2002), but unfortunately, the lack of a common wetland definition has made it difficult to compare the findings of the different studies.

South Africa is an arid country, with an average rainfall of 497 mm, making the presence of wetland areas in the country very significant, especially where they act as water reservoirs and rechargers for water systems (Kotze *et al*. 1995). The highly seasonal rainfall has stimulated the creation of numerous artificial water impoundments to cater for the increased water demand for domestic, industrial and agricultural use during the dry periods (Kotze *et al*. 1995).

Wetlands are regarded as one of South Africa's most endangered ecosystems (Walmsley, 1988). Despite their known importance as water reservoirs, stream flow regulators, flood regulators, water purifiers and as specialized habitats for plants and animals, only few natural wetlands remain. Draining in the course of agricultural, industrial and urban development (Kotze *et al.* 1995) has destroyed many wetlands. According to Van Wyk *et al*. (2000), degradation of wetlands in South Africa is still continuing, as little is known about their management, their desired condition or of their conservation status.

To facilitate successful implementation of wetland area management, adequate knowledge about individual biotopes, ecological characteristics, distribution and composition of flora and fauna is necessary. The presence or absence of some key species can serve as an indication of the condition of the wetland, if the environmental requirements of these species, or the communities in which they occur, is known. It is therefore necessary to undertake an in-depth vegetation analysis of selected wetlands, to explain the distribution of plant communities in relation to variations in environmental factors.

A brief literature review on wetland hydrology and of wetland plant communities in relation to water quality has indicated that few conclusive studies have been conducted in South Africa. Some wetlands in the KwaZulu-Natal Region have been studied in detail (Donkin 1994; Chapman, 1990), but very few have been investigated in detail in the Western Cape. Lack of intensive long term wetland monitoring has made it difficult to understand and quantify the specific nature of each wetland system.

Organization of the thesis

The thesis has six chapters, while chapter one introduces the general contents of the study and the study area other chapters relate various aspects of wetland hydrology and water quality constituents to plant communities. Although conventionally it would be in order and logical to discuss the soils first followed by hydrology, water chemistry, vegetation and finally multivariate analysis, we start with the plant community description to give a insight of the plant communities that are discussed in the preceding chapters in terms of hydrology, water quality. We would also like to clarify from this point, that plants communities are used to signify the area they occupy, in relation to the factors under investigation. Further on the near-surface water will be used in reference to the soil pole water.

A brief description of the chapters contained in this thesis is as follows:

Chapter 1 gives a brief introduction to the study, presenting a review of background information pertinent to the study and a general description of the Middelvlei study area. The objective and justification for the study are also presented.

Chapter 2 presents an in-depth description of the Middelvlei Wetland System; the analytical procedures applied and include the identification and description of the wetland plant communities. A vegetation map is included to indicate the distribution of the communities through the system.

Chapter 3 investigates the relationship between the near-surface water levels and the wetland plant communities identified in Chapter 2. It further investigates the response of the water levels in each community to the rainfall. The method applied in monitoring the water levels is described in detail.

Chapter 4 assesses the relationship between the wetland plant communities (Chapter 2) and water chemistry. The water chemistry parameters monitored included the nutrients, physical and chemical parameters. These are discussed in detail in this chapter in relation to each individual community. Seasonal variation in water quality between communities is also investigated.

Chapter 5 serves to integrate the wetland vegetation and abiotic factors using an ordination technique. The factors determining the distribution of the constituent plants and their groupings are investigated.

Chapter 6 presents a synthesis of the results obtained in the preceding chapters. It also cites management recommendations and some wetland research needs.

The Chapters in this thesis are written in the format of the African Journal of Aquatic Science.

1.1.1 Location of the study area

The study area is situated in the Western Cape within the Stellenbosch Region, which is located about 40 km east of Cape Town. It is centered between the latitude S 33^{o} 57' and longitude E 18^{o} 51'. The Stellenbosch Basin is mainly drained by the Eerste River, which has its headwaters to the south east in the Dwarsberg Mountains. The two major tributaries of the Eerste River in Stellenbosch are the Plankenbrug and Veldwachters Rivers. A number of other tributaries join the river lower down its course (Söhnge 1991). The Veldwachters River drains the Devon Valley, with the Middelvlei Stream draining the Middelvlei Farm Basin including Onderpapegaaiberg Suburb, to the west of Papegaaiberg (Figure 1.1).

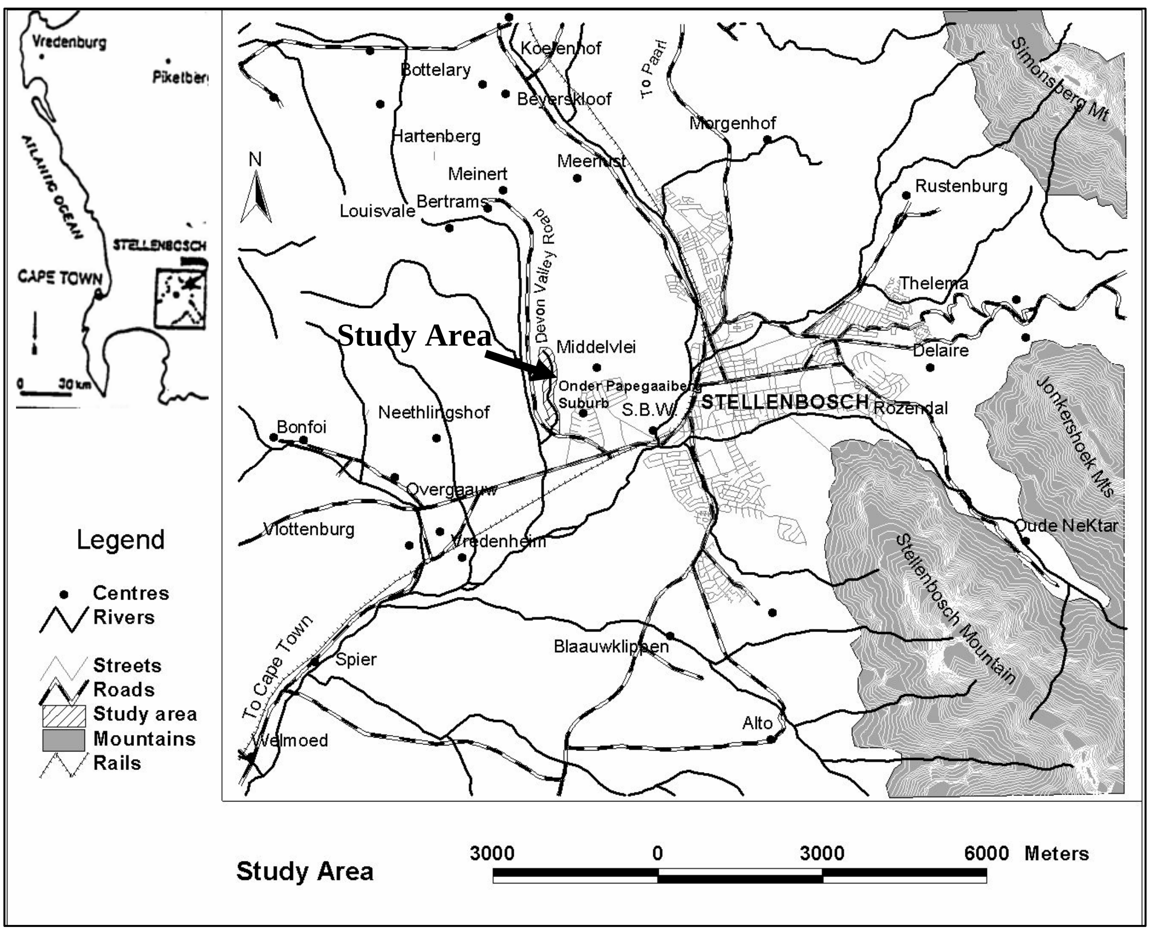

Figure 1.1 Stellenbosch map showing the location of the study site, Middelvlei.

The Middelvlei Wetland System (the study area) is a located on the Middelvlei Stream, a tributary of the Veldwachters River. Petitjean (1987) described the Veldwachters River as being non-perennial, only flowing after heavy winter rains. The natural flow of the river has been altered by the construction of impoundments.

The Middelvlei Wetland System consists of four marshes and three dams, which will be referred to here as the upper, middle and the lower dams, with the wetland marshes above and below the dams (Chapter 2). Land use adjacent to the wetlands includes vineyards, citrus and olive orchards, with urban settlement along the eastern fringes. The Middelvlei Stream flows through the Stellenbosch Sewage Treatment Works at its confluence with the Veldwachters River below the study area.

1.1.2 Geology and Soils of Stellenbosch area

The mountain ranges south and east of the Stellenbosch town are composed of heavily folded sandstone of the Table Mountain Group. The foothills and valleys are underlain by phyllites belonging to the Tygerberg Formation of the Malmesbury Group and by intrusive Cape Granites. Stellenbosch Town itself is largely located on coarse alluvial soils (Figure. 1.2). These soils formed during the Oligocene and Miocene under a humid climate (Söhnge & Greeff 1985).

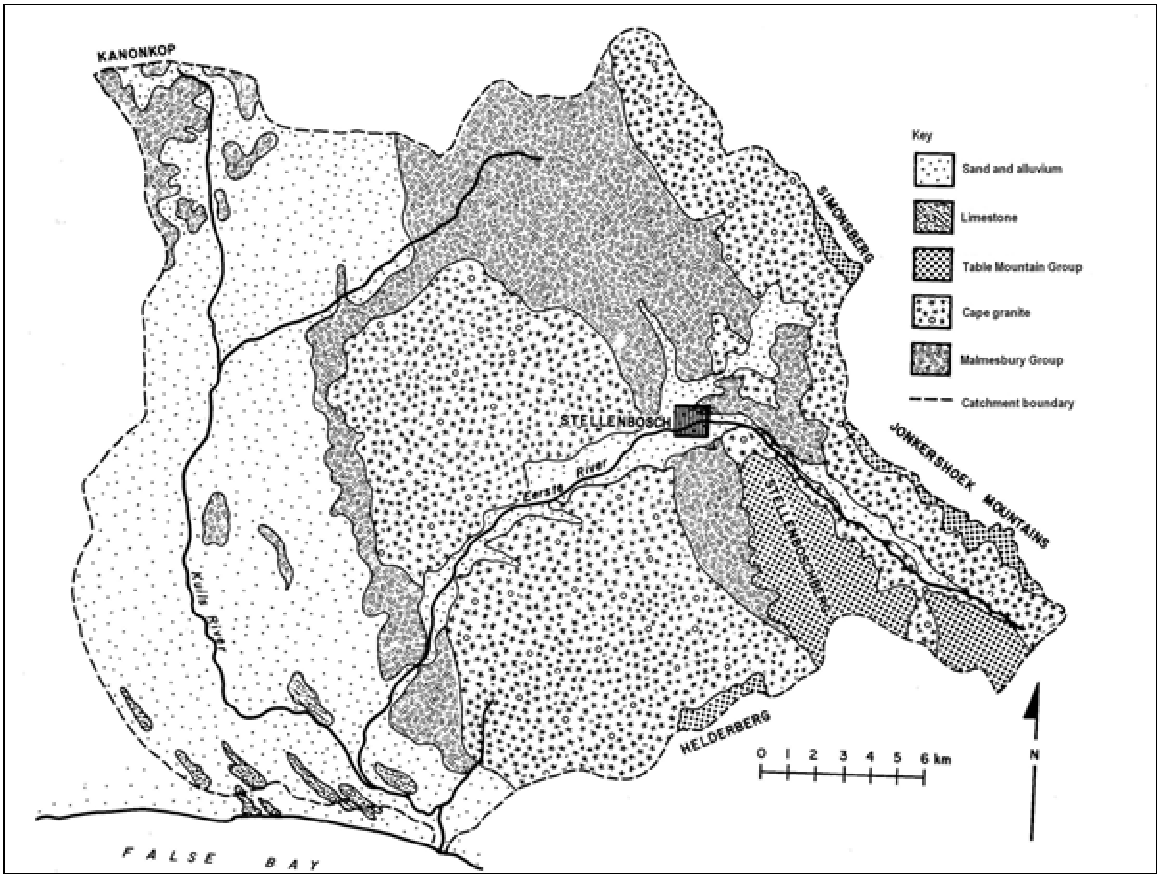

Figure 1.2 Geological map of Eerste River (Modified from Wessels & Greeff 1980).

1.1.3 Topography and Hydrology of Stellenbosch Area

Stellenbosch lies between fold mountain ranges namely the Jonkershoek, Simonsberg and the Stellenbosch Mountains (Figure 1.2). Many perennial rivers originate in these mountains, the most notable being the Eerste River that rises in the Jonkershoek Mountains and flows through the town of Stellenbosch to mouth into False Bay. The Plankenbrug River drains the Simonsberg and its foothills to the north and joins the Eerste River. There are other seasonal tributaries of the Eerste River; that mainly flowing in wet winters including the Blaauwklippen, Bonte, Veldwachters and Sanddrif Rivers (Figure 1.3).

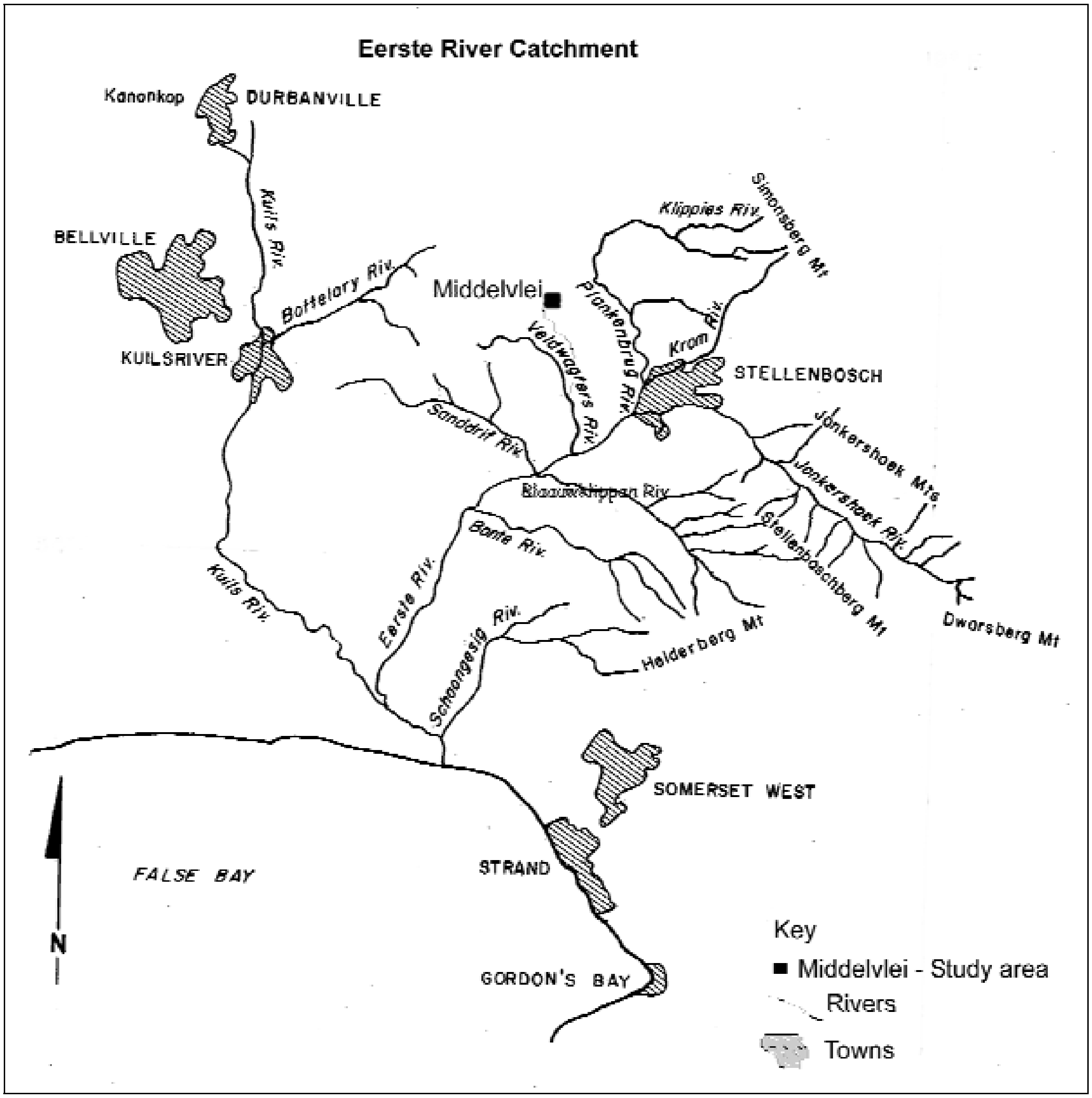

Figure 1.3 Eerste River Catchment (Modified from Söhnge 1991), indicating the location of Middelvlei Farm in the study area.

1.1. 4 Climate

The Western Cape Province experiences a Mediterranean climate with arid summers that are accompanied by strong south-easterly winds and cold rainy winters associated with cold fronts that are accompanied by strong north-westerly winds. The south-easterly winds cool as they pass over the mountains causing the condensation of moisture and montane precipitation feeding the Eerste River. More than 60% of the 250-3000 mm annual rainfall in this region falls during winter.

The average maximum and minimum daily temperatures in summer are 15 ^{o}C and 28 ^{o}C with some extremes that can reach up to 43 ^{o}C. The winter average maximum and minimum daily temperatures are 4 ^{o}C and 15 ^{o}C with an extreme minimum of -5 ^{o}C and a maximum of 30 ^{o}C (Weather Bureau 1984).

1.1.5 Archaeological and recent historical background

Pre-European Occupation

Artifacts found in the fynbos landscape belonging to the earlier Stone Age associated with the Acheulian culture; act as evidence for early occupation. The oldest sets of the artefacts found in excavation sites along the Eerste River were typologically similar to the oldest known artefacts from Europe (Seddon, 1966). The abundant hearths in human occupation sites of the time showed the ability to make fire (Deacon 1992). This is an implication that fire was used as a tool to farm the fynbos from the beginning of the late Pleistocene (125 000 years ago).

European (Colonial) settlement

With the exception of the Cape Peninsula, Stellenbosch ranks as the oldest area settled by Europeans in South Africa. Occupation of this area took place in the late 17th century.

The first farmers settled in the Stellenbosch Valley between 1679 and 1682. The District had a pronounced European population by 1682 (Duthie 1922). Most of the impacts on the vegetation around Stellenbosch were experienced with the arrival of the colonialists at the Cape. The impacts resulted from their dependence on indigenous wood for fuel, furniture and construction; this led to the virtual disappearance of natural forests in and around Stellenbosch (Saunders 1988).

The earliest reference in relation to the European settlement along the Veldwachters River dates to the late 1600's. The first farms in Stellenbosch were allocated to Free Burghers who were mainly farmers, as from 1679 during the rule of the Dutch East India Company (Smuts 1979). They first selected farms close to the Eerste River, and when no more land was available, they spread into the Eerste River Catchment and the adjacent areas in which the study area is located. Vineyards, with wine grapes, are the dominant agricultural crops in the Stellenbosch District.

1.2 Rationale for thesis

There is little quantitative information about the water requirements of individual communities and species in South Africa or for that matter in the rest of Africa (Le Maitre *et al.* 1999).

An in-depth understanding of the groundwater requirements of plants is a necessity to determine the ecological reserve before water-use licenses are granted or renewed (Le Maitre *et al.* 1999). In a project to identify the research priorities for South Africa, Scott and Le Maitre (1998) highlighted the interaction between vegetation and groundwater as a water research priority for South Africa.

A marked shortage of quantitative information about the interaction between vegetation and near-surface water, useful to the water engineers and wetland managers, exists in the country. This deficiency has hindered the rigorous use of indigenous and wild plant communities in the design of artificial wetlands (constructed wetlands), and in wetland rehabilitation and restoration programmes.

The results from this study should also be useful in the rapid assessment of wetlands, as the understanding of the factors determining the presence and distribution of wetland plant communities, is also relevant in determining the condition of a wetland. Information obtained from a study such as this one should also be useful in the classification of wetlands.

The high demand for irrigation water, especially in the dry summers in the Western Cape, has led to dams being constructed along most of the water channels, which in turn changes the natural water regime in the wetland. The effects of change of water regime on the biota can be predicted if information about the hydrological requirements of the constituent plants is available.

There is a need to understand the hydrological importance and functions of the wetlands within the Middelvlei Valley in the South Western Cape region. This will serve to inform managers and farm owners on the negative impacts upon their management and value by farmers on whose land these wetlands are primarily located. Virtually no wetland management measures have been put into consideration, in farm management decision-making in the region, except to consider them either as wastelands useful for dumping or to be drained.

1.3 Research objectives

This study was initiated with the primary aim of establishing the relationship between plant communities and the variation in near-surface water levels in a natural wetland system in Stellenbosch. A secondary aim of this study was to assess whether water quality has an influence on the wetland plant communities.

1.3.1 Specific objectives

1. Characterise and analyse the vegetation communities within the Middelvlei Wetland System (Chapter 2).
2. Determine and describe the near-surface groundwater level ranges for individual plant communities, over a one-year period, as a predictor of their composition and potential shifts resulting from changes in the groundwater (Chapter 3).
3. Rank the plant communities in their potential as wetland condition indicators (Chapter 3)
4. Evaluate the relationship between plant communities and water chemistry (Chapter 4).
5. Determine the relationship between the vegetation communities and the environmental variable gradients (Chapter 5).
6. Provide recommendations about management options (Chapter 6).
7. Suggest future research needs for wetlands, particularly in the Stellenbosch region (Chapter 6).

1.4 Key questions

1. Is there a significant relationship between the wetland plant communities, near-surface water levels (soil pole water – up to a 1 m depth) and water quality?
2. Can wetland vegetation serve as a rapid method for the assessment of wetland condition (hydrology and water chemistry) in this temperate area?

1.5 Literature review

1.5.1 Vegetation of the Western Cape

The Cape Floristic Region (CFR), found in the south-western tip of Africa, is regarded as one of the most biologically diverse regions on earth. It is ranked as one of the six floral kingdoms in the world. Two main plant communities occur in the immediate vicinity of the study area: (1) The fynbos communities consisting of evergreen shrubs on the hills and mountain slopes and (2) Indigenous forest found along the riverbanks and in mountain ravines (Smuts 1979).

1.5.1.1 Fynbos Biome

The Fynbos Biome communities cover 6.1% of South Africa (Scott & Le Maitre 1998). This is a fire-prone sclerophyllous shrubland characterized by the presence of Restionaceae (Cowling & Hilton-Taylor 1997), other species and individuals that are found predominantly in the Fynbos Biome include the families Proteaceae, Ericaceae and Rutaceae (Bond & Goldblat 1984). These growth forms are associated with predominantly winter rainfall from 250 to 2000 mm annually. Fynbos is found on the low fertile soils derived from the Cape sandstones and quartzites and on more fertile soils derived from Cape granites, and shales of the Malmesbury and Bokkeveld Groups (Midgley *et al*. 1997).

1.5.1.2 Riparian vegetation

Bands of indigenous riparian forest are found in the region along rivers and in the protected mountain ravines. Over the period of European occupation the indigenous forest has been largely eradicated by fires, and human exploitation for timber and firewood fuel. At present some remnants of indigenous riparian forests are found along some rivers e.g. Eerste River and its tributaries in Jonkershoek (Smuts 1979). A high density of indigenous riparian vegetation along the Eerste River is found in the Jonkershoek Nature Reserve, and decreases towards the disturbed urban areas (Salie 1995). Alien vegetation is actively replacing the indigenous forest, but the Working for Water Programme Group (Calder & Dye 2000) is pursuing its eradication with encouraging results.

1.5.2 Wetlands of Western Cape

The Western Cape falls under the limnological region of southern Africa containing temperate acid waters (Allanson *et al.* 1990). The region is characterized by porous soils that allow most of the rainwater to percolate into rivers and aquifers. A few permanent lakes, temporary wetlands and ponds exist in the region. The rivers in the Fynbos Biome are usually short, while wetlands such as the lakes and ponds, locally known as “vleis”, are mainly confined to the sandy coastal plains (King & Day 1979).

The water bodies found in the Fynbos Biome are generally found to be oligotrophic in their natural state; this can be associated to the low nutrient levels of the soils. The waters of the mountain streams and wetlands have low levels of total dissolved solids (TDS) and the pH varies, although it is commonly found to approach neutrality, low pH levels, in the range of 4-6 have been reported in some rivers and wetlands. King and Day (1979) associated the low pH of water in the wetlands to the decaying vegetation and the prevailing soil types in the region. The wetlands in the region have received little botanical attention and published literature is extremely sparse.

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Chapter 2: Middelvlei Catchment Wetland plant communities, Stellenbosch, South Africa

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Abstract

Wetland plant species and communities have been described before in South Africa, but little investigation has been done on factors determining single species dominated plant communities in wetlands. The objective of this study was to identify and describe plant communities in a natural wetland system in Stellenbosch. Forty-six sample plots were used to collect vegetation data that were analysed using standard Braun-Blanquet techniques. Seven plant communities are identified and described from this particular wetland system. Different communities were found to be single species dominated, and had specific environmental variables within which they occur.

The difference in water table levels was found to play a key role in determining the distribution of the plant communities. Understanding and monitoring the relationships between plant communities and various environmental variables is a useful tool for a rapid wetland assessment especially in anthropogenic-disturbed environments.

Keywords: Braun-Blanquet, plant communities, redox potential, water level, wetlands

2.1 Introduction

Wetland plants are commonly defined as those plants that grow in water or in a substrate that is at least periodically deficient in oxygen as a result of excessive water content (US EPA 2002), restricting their growth under wet conditions. Vegetation has successfully been applied as an indicator of the presence of wetland areas, determining their boundaries, and as a basis for wetland classification schemes in Europe and North America (Costa *et al*. 1996). Fresh water wetlands are classified on the basis of the vegetation they contain, for example, marshes are wetlands that are dominated by herbaceous emergent vegetation; swamp forests are dominated by woody vegetation while those dominated by peatmosses and other acid tolerance plants are known as bogs (Craft 2001).

A key factor in understanding why plants are considered to be one of the best indicators of the factors shaping wetlands within the landscape is the understanding of the contributions the plants themselves make to wetland ecosystems. These contributions include, primary production, provision of habitats for other taxonomic groups like phytoplankton, birds, aquatic invertebrates etc. Wetland plants also remove nutrients from wetlands through uptake and accumulation in tissues hence improving the water quality (U.S. EPA, 2002), a role that is important for wetland fauna. Wetland plants are regarded as good indicators of wetland condition due to their rapid growth rates and response to environmental changes. A quantifiable shift in plant community composition occurs in wetland ecosystems due to degradation of the environment caused by human-related activities. These include clearance, filling and draining for agriculture, road construction and urban developments (Kotze *et al*. 1995). Individual species show differential tolerance to a wide array of stressors, with variation in environmental conditions causing reactionary shifts in community composition. A change to the hydrology of an area is a particularly important factor causing changes in the vegetation (Van der Valk 1981, Spence 1982, Squires & Van der Valk 1992). The vegetation zones along water gradients in wetlands serve as ideal biological monitoring criteria to demonstrate changes in water regimes. The vegetation zones are usually well defined and are relatively simple because each zone is usually only dominated by a single species. Plant community patterns can therefore be used to diagnose wetland impacts. However, a clear understanding of the relationship and response of individual plants to the relevant environmental factors is crucial.

Studies linking hydrology and plant community dynamics have shown that the important facets of the hydrological regime that affects wetland plants are primarily water depth, inundation period and water chemistry (Spence 1982, Mitsch and Gosselink 2000).

2.1.1 Dominant plants as a measure of wetland condition and function

Wetland function can be considered to encompass the rates and processes of change in a wetland. The measure of function is complex and expensive; hence it has not been a feasible objective to many ecologists when assessing wetlands. The biophysical structure of wetland plants is assumed to correlate closely with function. It is therefore necessary to determine the characteristics and requirements of the plants when attempting to assign them to various categories of functional groups. In most wetlands a few species tend to dominate in terms of numbers of individuals and in the percentage of aerial cover. The existence and survival of these groups in wetlands indicates that the wetlands meet certain conditions that are requirements for these plants. Some of the functions have a direct link to the plant functional groups outlined below (Cole 2002).

2.1.1.1 Short- and long-term surface water storage

Short- and long-term surface water storage is improved through the vegetation reducing the rate of water flow. Depending on the inundation period, characteristic plant groups will develop that indicate the wetness and inundation condition of the wetland.

2.1.1.2 Water table level

This is a parameter that has often been used to determine wetland delineation. It is expected that certain plant groups thrive in areas with a particular water level range depending on their level of tolerance to inundation and ability to withstand desiccation.

2.1.1.3 Nutrients

There has been a strong correlation shown between soil nutrient density and plant biomass, however, the high percentage cover of plants may not translate directly to high biomass (Cole 1992). Some plant groups may prefer soils with or without certain nutrients. These plants groups, in turn, can act as indicators of nutrient condition of the wetland. Nutrient cycling by plants plays a temporary role of nutrient removal from the wetland substrate with their accumulation in the vegetative tissue. This takes place during the plants active growing period, however, the nutrients are deposited back into the sediment when the plants die or shed their vegetative parts (Vymazal *et al*. 1999).

2.1.1.4 Accumulation of organic matter and inorganic sediments

Wetlands are generally found in the lower parts of catchments with most of the sediments eroded from the high-lying areas accumulating in the wetlands. This commonly occurs when the wetland is a basin type, without any outlet, or when the wetland is densely vegetated. Mediterranean wetland types, that experience wet winters and dry summers, have their vegetative matter withering and drying in summer. This dead material is deposited on the wetland soils and due to their anoxic nature, high organic content matter is evident in the soil due to the slow rate of decay.

2.1.2 Vegetated wetlands in the Western Cape

The wetlands of this floristically rich region have not received much attention in respect to the characteristics and description of the vegetation (Rogers 1997). Allanson *et al.* (1990) described the aquatic vegetation of the mountainous area as relatively uncharacteristic, but this contradicts the dominance by species of Restionaceae. Jones (2002), while classifying the wetlands of the Western Cape, found that 69% of the 62 wetlands considered in her study were vegetated; however species belonging to the Restionaceae, Juncaceae and Cyperaceae were not considered as wetland plants in her study.

2.1.3 Wetland Soils

These are soils that are saturated, flooded, or ponded long enough during the growing season to develop anoxic conditions under which hydrophytic vegetation are able to grow. The characteristics of the hygric soils are a product of vegetation; animal activity and micro organisms in these water saturated soils (Craft 2001). Vegetation is critical to the development of the hygric soil characteristics, as it is responsible for the accumulation of net primary production from emergent and woody plants. The micro organisms are responsible for the decomposition of organic matter while the animals help in organic matter break down. This leads to the formation of characteristic organic rich subsurface soil horizons.

Based on unpublished literature on studies carried out on the wetlands found in the Western Cape, Wanless (1992), studying the wetland floral community of a Betty's Bay Wetland or "vlei", found that the soil characteristics did not determine the community structure. This could be true for the Betty's Bay wetland, but Boix (1992) (unpublished), in contrast, while studying the Noordhoek and Kommetjie Basin on the Cape Peninsula, found that the plant communities were strongly related to the soil type and moisture status. This is an indication that individual wetlands could differ in their vegetation characteristics.

This Chapter is primarily aimed at identifying, classifying, describing and mapping the wetland plant communities in the Middelvlei Wetland System, and later to; investigate the relationship of these plant communities to wetland hydrology and water quality (Chapters 3 to 5).

2.2 Methods

The Braun-Blanquet method of investigating, analysing and describing vegetation (Muller-Dombois & Ellenberg 1974, Kent & Coker 1996) is used in this study. This method has been developed and successfully used to classify Fynbos Biome vegetation (Campbell 1986). A phytosociological study is able to explain more detail about the specific areas under study and the data can be used in a variety of analyses depending on the objective of the study in question.

According to the Braun-Blanquet approach, vegetation samples should be taken from homogeneous stands of vegetation (Muller-Dombois & Ellenberg 1974). A vegetation sample, also known as a relevé, has to be homogeneous or uniform, hence it should consist of one vegetation type with no obvious floristic or structural boundaries. It is important for the researcher to stratify the vegetation according to physiognomic and physiographic features before sampling takes place. This forms the basis for the description and definition of the vegetation.

In most studies orthophoto maps, aerial photographs or satellite imagery are used to delineate physiognomic-physiographic units. However, the delineation of these units in this study was not possible using the 1: 10 000 orthophoto maps and 1: 50 000 scale aerial photographs available as they are at a scale that is too small to identify the vegetation patterns. Pixel size in the available satellite imagery was too coarse to provide sufficient details for the study. The area was stratified on the basis of clearly discernible homogeneous floristic and growth form differences observed during physical reconnaissance of the area. These units were then used to determine the distribution of samples.

2.2.1 Sample unit size

The size of the sample is largely dependent on the vegetation structure. Small vegetation stands may be sampled sufficiently using one plot for each stand. Ideally for larger stands, the size of the sample should be large enough to contain all the species occurring in that stand.

Plot sizes used in wetland and riverbank vegetation surveys vary from study to study, in various parts of the world (Table 2.1). The size of the plot used in a particular study is determined by the nature of the study, the question under investigation and the type and nature of the vegetation under investigation.

Table 2.1 Sample unit size used in South Africa and other parts of the world to sample wetland plants.

Author	*Study Area*	*Riparian vegetation type*	*Plot Size*
Lopez & Fennessy (2002)	Colorado Canada	Herbs	0.45 m^2
		Shrubs	25 m^2
		Trees	100 m^2
Dingaan (2000)	Bloemfontein, wetland	Herbs	16 m2
		Woody plants	100 m2
Stromberg *et al*. (1996)	San Pedro Arizona river U.S.A	Herbs	1 x 1 m^2
		Woody plants	5 x 20 m^2
Nel (1995)	Veldwachters River, Stellenbosch, R.S.A.	Herbs	50 m^2
		Trees	100 m^2
Coetzee *et al*. (1994)	Ba and Ib Witbank – Heidelberg near Pretoria, R.S.A.	All plants	100 m^2
Bleem *et al*. (1993),	Verlorenvlei Nature reserve	All plants	16 m^2
Cooper (1986)	Cross Creek Colorado, U.S.A.	Herbs	25 m^2

An ideal size for a plot can be determined by use of species area curves. The minimum area curves are determined by successively doubling the area of a sample quadrat, and counting the number of species in all the successive plots (Kent & Coker 1992). Though the concept of the minimum area curve is widely used in many vegetation studies, it has not gone without challenges. Buys (1991), challenges the idea of minimum area curves, concluding that no convincing minimum–area definition has been formulated; hence the concept is unsuitable for ascertaining suitable plot sizes for sampling vegetation. In a later study, Buys *et al.* (1994) modelled the species-area relationships of terrestrial plant communities around Stellenbosch and recommended a maximum area of 500 m^2 that could meet the species area criterion, the model was found to break down in areas greater than 500 m^2.

For this study 1 m^2 plots were used, based on Braun-Blanquet School of vegetation and phytosociology recommendation (Mueller-Dombois & Ellenberg 1974, Kent & Coker 1996), on the appropriate quadrat sizes for grassland surveys.

Forty-six randomly placed 1 m^2 sample plots were located in the study area, as representatives of homogenous vegetation stands. Thirty-nine out of these 46 sample plots (Figure 2.2 a, b, c & d) were selected for monthly monitoring to determine the physiochemical changes (Chapter 2 & 3) over a one-year period.

2.2.2 Environmental Data

The habitat environmental parameters recorded included aspect, slope, soil type, and presence of surface water, near-service water level, water pH, redox potential, dissolved oxygen and temperature. Soil types and texture are also recorded.

2.2.3 Floristic data

In each sample plot the species are recorded together with their projected abundance cover. A cover-abundance score was assigned to each species following the Braun-Blanquet scale (Kent & Coker 1996). Vegetation height was estimated and recorded. A herbarium specimen of each species encountered was collected for identification and verification in the Stellenbosch University Herbarium. The data were used to classify the vegetation using the Braun-Blanquet vegetation analysis technique.

Edward's classification procedure is based primarily on structural growth form, cover and height of plants. The primary attributes considered in the classification are namely:

A set of four growth form types (trees, shrubs, grasses and herbs)

A set of four cover classes and

A set of four height classes for each growth form type.

- Trees are classified as rooted, woody, self-supporting plants over 2 m high and with one or a few defined trunks branching above the ground.
- Shrubs are defined as rooted, woody, self-supporting plants up to 5 m high, multi-stemmed and branching at or near ground level when 2-5 m high, or either multi-stemmed or single stemmed when less than 2 m high.
- Grasses are rooted, non-woody, herbaceous plants belonging to the family Poaceae, or graminoid plants, for example, Cyperaceae and Restionaceae that resemble grasses. At a lower classification Cyperaceae and Restionaceae are referred to as sedges and restioids.
- Herbs are rooted, non-woody, self-supporting, non-grass-like plants, if woody, the wood is restricted to the lower portion near the ground.

2.2.4 Soils

Soil samples were collected at the 39 of the 46 sampling plots identified (Figure 2.2 a, b, c & d), using a soil auger to a depth of 1.0 m. The soil samples were analysed to determine their characteristics and were then classified on the basis of the horizon characteristics, mainly Horizon A, B and C.

The physical and chemical properties of the soil were determined by the properties and contents of the near-surface water sampled from the 36 wells, hence no direct measurements of these parameters were considered when soil analysis was undertaken. This is based on the assumption that the near-surface chemical water properties reflect those of the respective soils.

2.2.4.1 Soil texture

Soil texture was determined by use of soil particle size distribution (Black 1965). The soils were dried at room temperature, after which they were ground to break up any coagulation. The soils were then mechanically shaken through a set of nested sieves. The sieves used had the following raster sizes; 2000, 500, 250 and 53 µm separating the soils into categories as displayed in Table 2.2 below.

Table 2.2 Soil texture categories and the particle size.

Soil Texture	*Particle Size*
Stones	>2000 µm
Course Sand	500 – 2000 µm
Medium Sand	250 – 500 µm
Fine Sand	53 – 250 µm
Clay and silt	< 53 µm

2.2.4.2 Determination of the Soil Organic Carbon (OC)

Organic carbon was determined using the Walkley-Black method based on carbon loss on ignition (dry combustion) using a muffle furnace (Walkley 1934). (Note that these soils are non-calcareous and weight loss from this source is therefore excluded). The percentage of organic matter lost on ignition is used to determine the organic carbon content of soils with a high content of soil organic matter. Dry soils were put in an oven at 100 ^{o}C for 2 hours to ensure that any moisture therein was eliminated. Thereafter 30 grams of the dried soils were put in the muffle furnace at 900 ^{o}C for 1 hr. The difference in mass before and after ignition is the organic content of the sample because the organic matter is oxidised and carbon dioxide is lost to the atmosphere.

2.2.4.3 Soil Types

Soil types were identified and classified using the soil classification taxonomic system for South Africa (Soil Classification Working Group 1991). Mr BHA Schloms of the Geography Department, University of Stellenbosch, who is well acquainted with the soil types in the study area, verified the identification of the soil types.

2.2.5 Vegetation and soil mapping

Actual distances along the edge of each plant community (point to point) were measured and recorded for all the communities on the ground and all their Global Positioning System (GPS) readings were recorded.

The vegetation and the soil type boundaries were mapped from the digitised aerial photograph image (electronic format) of the Stellenbosch District. The image was projected using the Transverse Mercator and WGS84 projection and the Meridian 19 as the reference. The areal image was prepared by Global Imaging Inclusion Consultants (Technopark, Stellenbosch).

The plant community boundaries were digitised on the image after which a ground-truthing exercise through the area was undertaken. The distribution of soil types in each site was identified and they were also digitised onto the same image. The entire mapping in this study was undertaken using the Global Information System (GIS) Arc-view 3.3 software computer programme.

2.3 Results and Discussion

Seven major plant communities are recognized in the classification of the vegetation of the Middelvlei Wetland System, based on the results of the analysis of the data collected during this study, as presented in the phytosociological table (Table 2.3). The location of these communities is illustrated in Figure 2.1.

Table 2.3 Phytosociological table of Middelvlei Wetland System																																													
Releve' number	45	12	14	44	29	30	22	3	34	16	15	7	36	37	19	35	2	38	39	42	43	31	32	21	23	25	26	6	10	28	20	17	1	18	24	9	27	13	33	4	5	46	8	40	41
Date (year/month/day	21107	20806	20806	21107	20807	20808	20808	20812	20808	20807	20806	20805	20809	20809	20807	20808	20812	21107	21107	21107	21107	20808	20808	20807	20808	20807	20808	20806	20805	20807	20807	20807	20812	20807	20808	20805	20808	20806	20808	20809	20809	21107	20805	21107	21107
Altitude (m)	128	149	129	138	130	140	127	122	134	129	125	121	117	121	127	130	112	131	102	108	120	137	140	132	124	133	124	120	117	128	128	128	111	125	124	121	125	104	134	110	111	119	119	114	115
Aspect (degrees)	SE			SE	SSW						SSE	N	SE	SE										SSW		SSW	NW		SE	SSW			W												
Slope	G	L	L	G	G	L	L	L	L	L	G	G	G	G	L	L	L	L	L	L	L	L	L	G	L	G	G	L	G	G	L	L	G	L	L	L	L	L	L	L	L	L	L	L	L
Latitude (S)	3355956	3355977	3355961	3355952	3355851	3355751	3355908	3356317	3355746	3355929	3355953	3356015	3356977	3355975	3355918	3355747	3356314	3356444	3356391	3356320	3356331	3355749	3355750	3355913	3355906	3355892	3355884	3356017	3356011	3355858	3355917	3355927	3356313	3355926	3355906	3356010	3355879	3355972	3355749	3356081	335607	3356008	3356011	3356315	3356315
Longitude(E)	1849696	1849720	1849700	1849697	1849741	1849891	1849763	1849633	1849862	1849758	1849687	1849699	1849676	1849683	1849735	1849852	1849643	1849431	1849636	1849642	1849650	1849889	1849881	1849714	1849758	1849730	1849782	1849707	1849674	1849745	1849722	1849752	1849657	1849748	1849755	1849681	1849774	1849704	1849873	1849667	1849651	1849689	1849689	1849635	1849636

Table 2.3 Phytosociological table of Middelvlei Wetland System (continuation)

Community No.	1					2						3						4					5												5		6			7						
Releve' number	45	11	12	14	44	29	30	22	3	34	16	15	7	36	37	19	35	2	38	39	42	43	31	32	21	23	25	26	6	10	28	20	17	1	18	24	9	27	13	33	4	5	46	8	40	41
Number of species	3	3	2	2	5	5	2	3	5	2	2	3	2	3	4	2	6	2	3	3	3	3	3	2	4	2	2	2	2	3	2		3	2	3	3	3	3	3	2	2	3	2	2	2	3
Differential species for the *Populus canescens* Forest																																														
Populus canescens	5	2	5	4	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Differential species for the *Juncus effusus* Sedgeland																																														
Juncus effusus	.	.	.	.	1	5	5	5	1	5	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species common to *Cyperus longus* Sedgeland & *Cyperus longus* Sedgeland																																														
Cyperus longus	.	.	.	.	.	.	.	.	.	.	+	4	5	5	5	5	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Differential species of the *Cliffortia strobilifera* Shrubland																																														
Cliffortia strobilifera	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	5	5	5	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Species common to *Cliffortia strobilifera* Shrubland & *P. macrourum* Grassland																																														
Pennisetum macrourum	.		.	.	.	.	.	.	.	.	.	.	.	.	.	2	5			1	+	3	5	5	5	5	5	5	5	5	5	1	1	3	2	2	.	.	.	.	.	.	.	.	.	.
Species common to *Typha capensis* Reedswamp																																														
Typha capensis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	1		4	5	2	5	5	.	.	.	.
Persicaria serrulata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	4	2	.	.	.	.	.	.	.
Differential species for the *Cyperus textilis* Sedgeland																																														
Cyperus textilis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	3	5	5
Phytolacca octandra	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Senecio pterophorus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Solanum mauritanum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pittosporum undulatum	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Halleria elliptica	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Oenothera sp	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Oxalis sp	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Olea europaea subsp. africana	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
Species common to all communities																																														

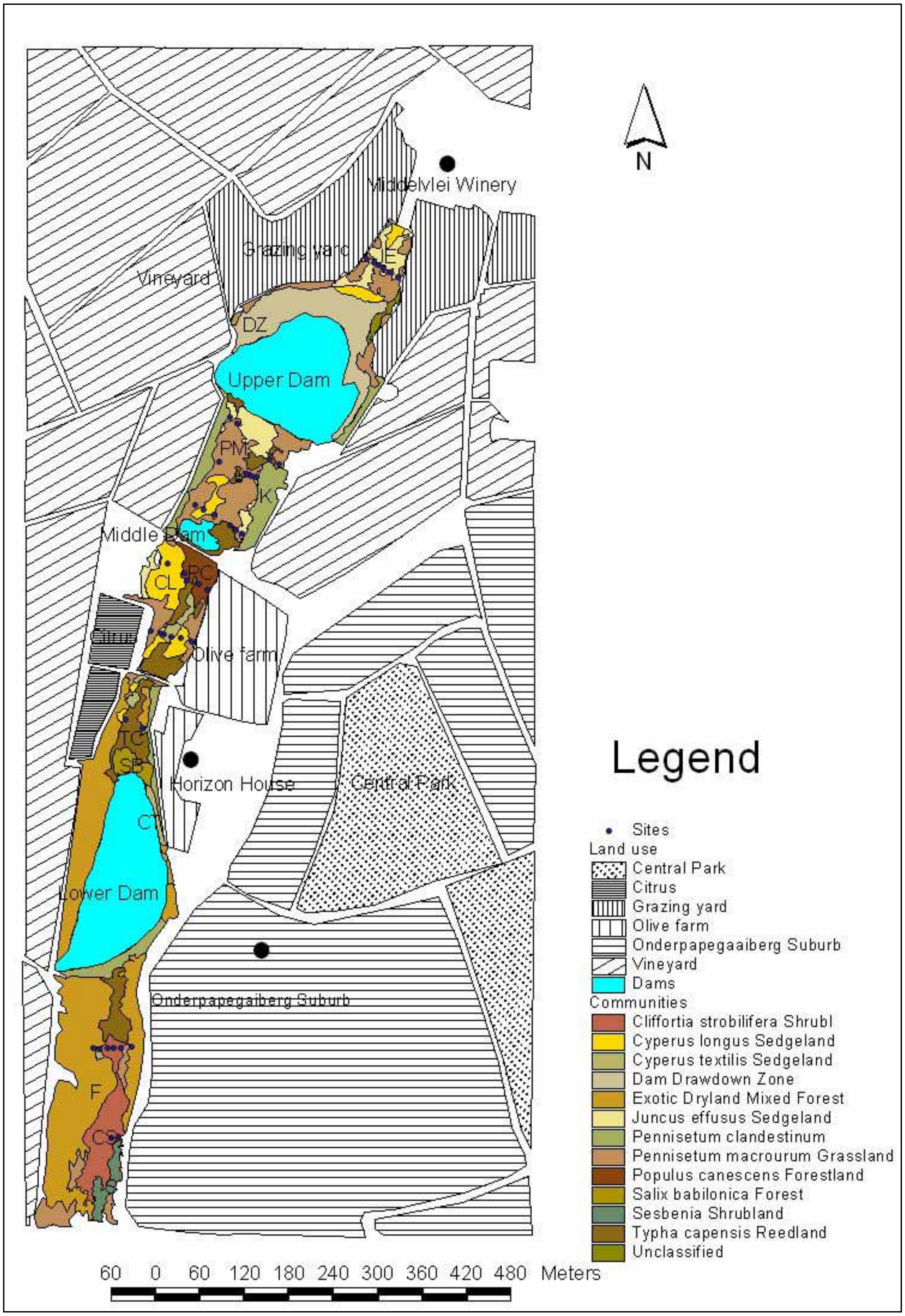

Figure 2.1 Vegetation map of Middelvlei Wetland System, showing the location and distribution of the communities. Plant community codes are: PC = *Populus canescens* Forest; JE = *Juncus effusus* Sedgeland; CL = *Cyperus longus* Sedgeland; CS = *Cliffortia strobilifera* Shrubland; PM = *Pennisetum macrourum* Grassland; TC = *Typha capensis* Reedswamp and CT = *Cyperus textilis* Sedgeland, K = *Pennisetum cladestinum,* F = Forest. DZ = Drawdown Zone. The vegetation map is displayed at a larger scale in Figure 2.2 a, b, c & d.

The following communities were identified in this study. Edwards structural classification criteria (Edwards 1983) was applied to categorize the communities:

- *Typha capensis* Reedswamp
- *Cyperus textilis* Sedgeland
- *Pennisetum macrourum* Grassland
- *Juncus effusus* Sedgeland
- *Cyperus longus* Sedgeland
- *Cliffortia strobilifera* Shrubland
- *Populus canescens* Forest

The total area covered by each plant community in the study area at the time of this study is given in figure 2.4.

As indicated in Figure 2.1, other distinctive non-wetland communities that occur in or adjacent to the wetlands are specifically excluded from this study. This includes anthropogenically-disturbed parts of the wetlands that have been filled in and are to a higher extent dominated by exotic species. This follows Hurt & Carlisle (2001) who found that wetlands in areas where the vegetation cover no longer consisted of native plant species; or which were artificially denuded of vegetation; or ecotonal areas dredged or filled areas could not be used to identify wetlands.

The anthropogenic vegetation types that were observed in the study area and were included in the vegetation map (Figure 2.1), but were not investigated, include: *Sesbania punicea* Shrubland, Exotic Dryland Mixed Forest and *Pennisetum clandestinum* Grassland. Nel (1995) gives a brief description of these communities in his account of the vegetation and flora of the Veldwachters River and its tributaries.

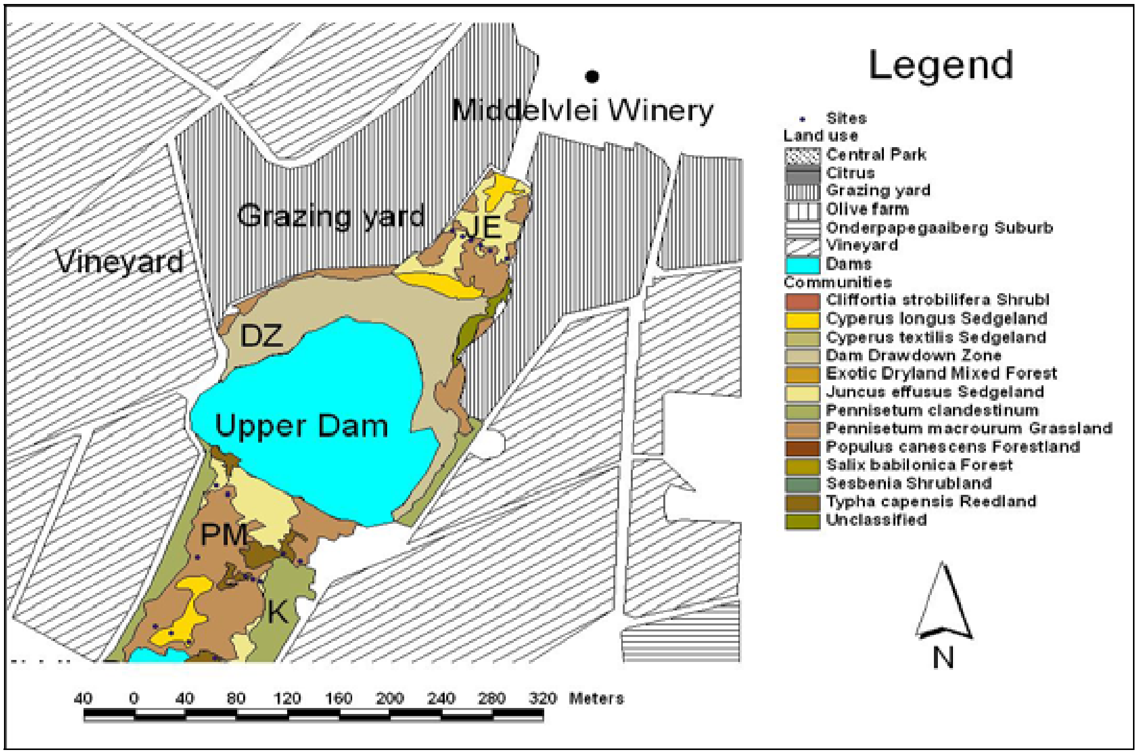

Figure 2.2a) Vegetation map of Middelvlei Wetland System's Upper wetland showing the distribution of vegetation and the sampling plots.

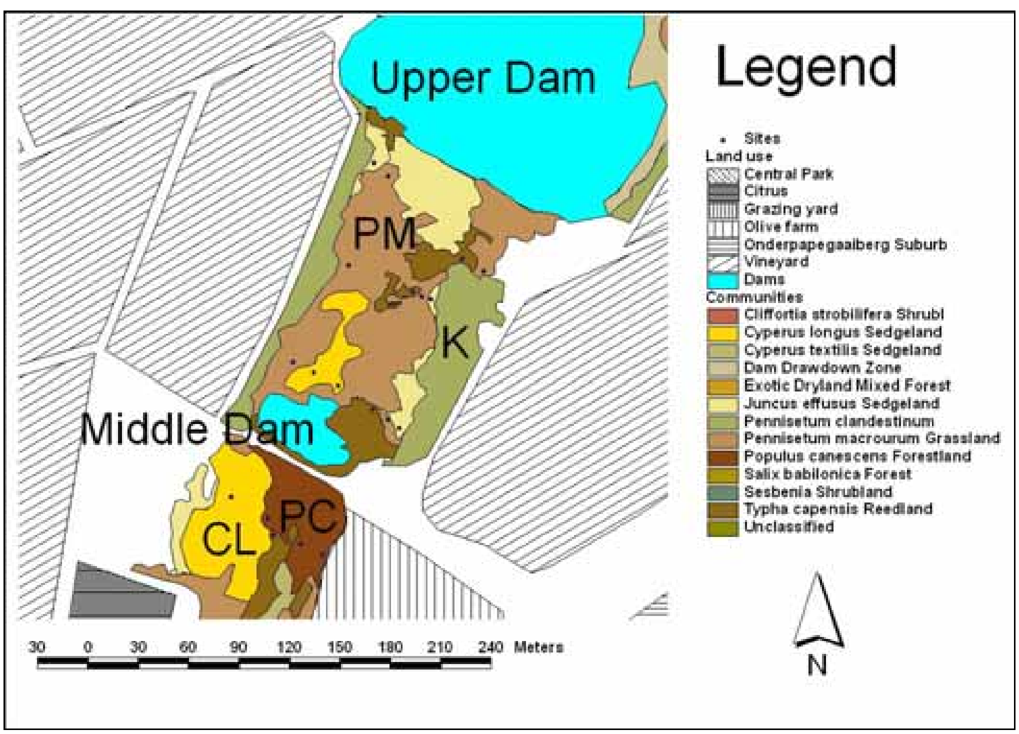

Figure 2.2b) Vegetation map of Middelvlei Wetland System's Middle wetland (Upper) showing the distribution of vegetation and the sampling plots.

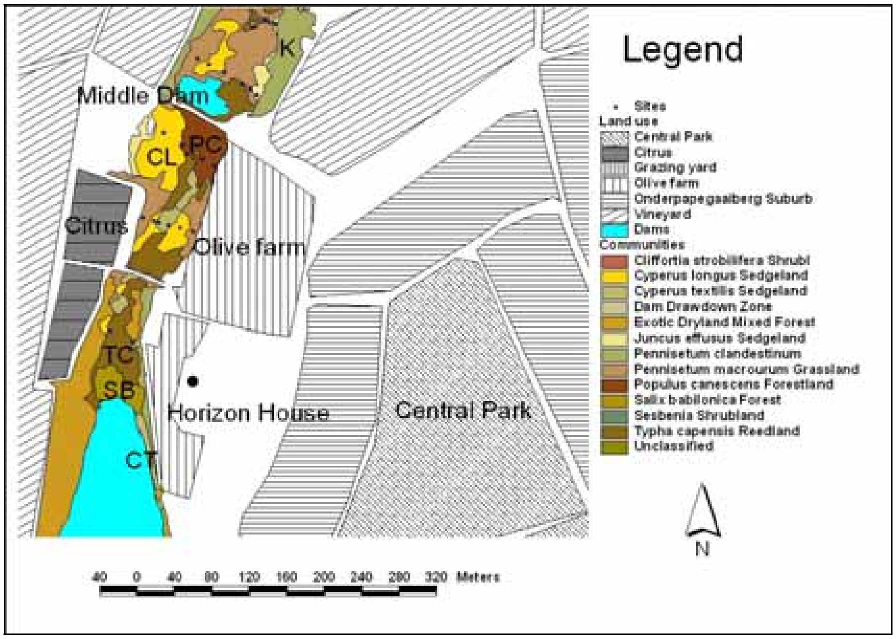

Figure 2.2c) Vegetation map of Middelvlei Wetland System's Middle wetland (Lower) showing the distribution of vegetation and the sampling plots.

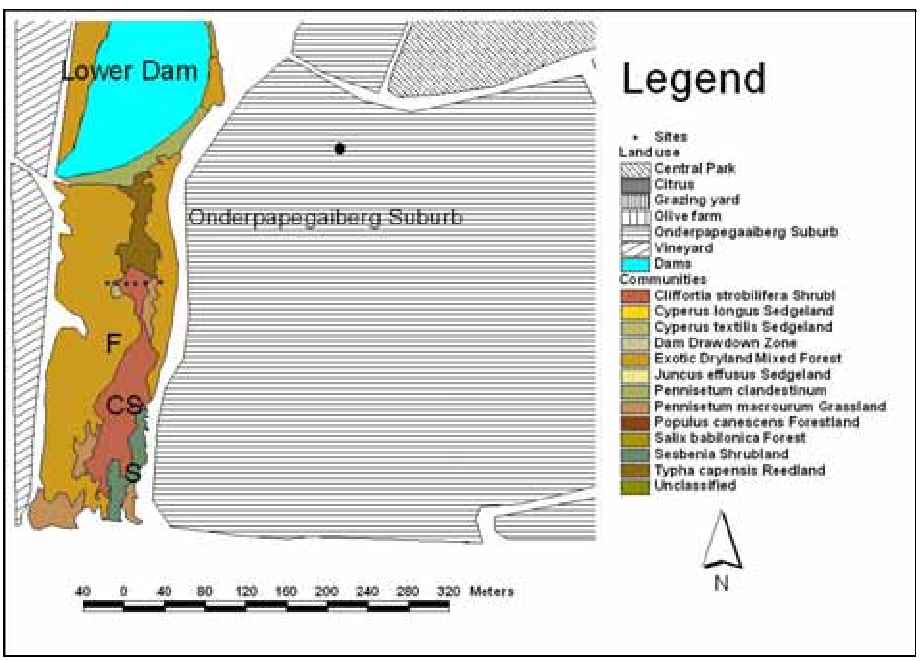

Figure 2.2d) Vegetation map of Middelvlei Wetland System's Lower wetland showing the distribution of vegetation and the sampling plots. Plant community codes are: PC = *Populus canescens* Forest; JE = *Juncus effusus* Sedgeland; CL = *Cyperus longus* Sedgeland; CS = *Cliffortia strobilifera* Shrubland; PM = *Pennisetum macrourum* Grassland; TC = *Typha capensis* Reedswamp and CT = *Cyperus textilis* Sedgeland, K = *Pennisetum cladestinum,* F = Forest. DZ = Drawdown Zone.

Table 2.4 Middelvlei Wetland System community areas in hectares (ha)

Community	*Area (ha)*
Populus canescens Forest	0.2398
Cyperus textilis Sedgeland	0.1984
Pennisetum macrourum Grassland	2.0548
Cyperus longus Sedgeland	0.7031
Juncus effusus Sedgeland	0.6469
Typha capensis Reedswamp	1.0015
Cliffortia strobilifera Shrubland	0.5974

2.3.1 Description of the plant communities

Vegetation can be viewed in two general ways namely, either as species arranged continuously along environmental gradients, or as a limited number of rather distinct and repeated communities, each community with a distinct composition or structure (Cooper 1986). In most wetland communities variation in community composition occurs distinctly, in such a way that it is relatively easy to recognise the communities in their characteristic stands. The differences between communities are a result of micro topographic changes that may result in the addition or loss of species due to various environmental changes, like differences in the depth to water table. The environmental changes might follow a gradient, yet a single species may persist as a dominant over a specific range and can therefore be regarded as the characteristic or identifying species of that particular community.

The seven communities recognised in the Middelvlei Wetland System are described below in progressive order from wet to mesic (from wettest to moist soils).

I. *Typha capensis* Reedswamp

Figure 2.3 *Typha capensis* Reedswamp.

This community generally occurs in areas that have permanent free water or are frequently flooded. It is found in the lowest parts of the wetland close to the water channel and around permanently inundated dams and ponds (Figure 2.1), where it forms pure stands. The *Typha capensis* Reedswamp community consists of dense stands of erect herbaceous plants, mainly *Typha capensis* individuals (Figure 2.3), with an average height of 2.0 m.

Soil types in this community are dominated by Katspruit Form (Soil Classification Working Group (SCWG) 1991), although Dundee Form was found to be present in some areas. The soils supporting this community had a high sand content, with 4.2% Organic Carbon (OC). These soils had a mean pH of 6.6 ± 0.07 and 13.6 mV redox potential. The community occurs in areas with a relatively neutral pH. The community is also found in areas dominated by sandy soils with a high water table that ranges between surface and 0.075 m depth. The only plant species found associated with *Typha capensis* in this community is *Zantedeschia aethiopica,* which frequently occurred in the disturbed areas.

A similar community has been described from the Potchefstroom (Cilliers *et al.* 1998) and Klerksdorp (Van Wyk *et al*. 2000) Municipal areas. This community has also been found to occur along rivers and wetlands (Nel 1995, Withers 2002).

II. *Cyperus textilis* Sedgeland

Figure 2.4 *Cyperus textilis* Sedgeland.

This community is found in two small stands located in the middle channel of the wetlands where they are flooded regularly, although a clump of *Cyperus textilis* Sedgeland in the lower wetland (Figure 2.2d) was found thriving in relatively well-drained soils. This is an indication that high water table could be a requirement for the initial establishment of the community. It can tolerate relatively low water table, if the decline in water level take place after the community's establishment. The water table for this community ranged from ground surface level to levels well below 1.0 m. *Cyperus textilis* (Figure 2.4) is the dominant species in the community, with a projected canopy cover of 100%. A few individuals of *Zantedeschia aethiopica* occur where the community is disturbed. The *Cyperus textilis* Sedgeland consists of dense clumps of erect herbaceous stems with an average height of 1.4 m.

This community is found on Dundee and Katspruit Form soils, rich in organic matter, with an average pH range of 6.02 ± 0.90; the slightly acidic condition is associated with the relatively high organic content of the soils containing 5.1% organic carbon. The soil had a low redox potential of 12.7 mV. Nel (1995) described a similar community along the main stem of the Veldwachters River.

III. *Pennisetum macrourum* Grassland

Figure 2.5 *Pennisetum macrourum* flowering spike.

The *Pennisetum macrourum* Grassland is widely distributed within the Middelvlei Wetland System (Figure 2.1). This community occurs in both relatively dry and wet zones of the wetland. This community is dominated by *Pennisetum macrourum* (Figure 2.5), with an average height of 1.5 m and a 100% projected canopy cover. The community is associated with *Cliffortia strobilifera, Cyperus longus, Olea europaea* subsp. *africana, Persicaria serrulata* and *Zantedeschia aethiopica.*

This community is found in the following soil types: Tukulu, Westleigh, Longlands and Dundee Forms, although Westleigh Form occurred more regularly than the other soil forms. These soils varied from clay to sandy, with a 2.8% organic carbon, these soils ranged from being slightly acidic to neutral with a mean pH of 6.12 ± 0.32 and a redox potential of 20.7 mV. The community has a wide water table range, ranging from surface level to 1 m below the surface. The community's ability to thrive in a wide range of soil types and water table depths, to a larger extent explains its wide distribution within the Middelvlei Wetland System.

IV. *Juncus effusus* Sedgeland

Figure 2.6 *Juncus effusus* Sedgeland.

The *Juncus effusus* Sedgeland community dominates the upper wetland, where the community forms pure dense monotypic stands of *Juncus effusus* (Figure 2.6), with a 100% canopy cover. A few patches of the community also occur in the middle wetland (Figure 2.2c). This community has an average height of 1.2 m. This community is found in areas dominated by Tukulu Form soils (SCWG 1991). These soils have high clay content, and a 2.8% organic carbon. The community is distributed in areas with shallow free surface water during winter, but successfully tolerates drier conditions during summer. The soils are slightly acidic, with a mean pH of 6.0 ± 0.44 and a redox potential of 54 mV. *Juncus effusus* is also found to occur along the Lourens River in the Western Cape (Tharme *et al.* 1997). This is an indication that its distribution is highly determined by moisture conditions, hence the reason for its wide distribution in wetlands, rivers and around dams.

V. *Cyperus longus* Sedgeland

Figure 2.7 *Cyperus longus* Sedgeland.

The *Cyperus longus* Sedgeland community occurs in the upper drier zone of the middle wetland. A few patches are found in wetter zones of the upper wetland where surface water flows frequently occur. The community is widely distributed within the wetland. It is found in areas of varying moisture content, ranging from dry, seasonally wet or waterlogged. This distribution is in agreement with similar descriptions of the community by Cilliers *et al.* (1998) and Dingaan *et al.* (2001), describing the wetland vegetation of Potchefstroom Municipal area wetland and Bloemfontein respectively.

The community is dominated by *Cyperus longus* (Figure 2.7), reaching an average height of 0.46 m with a 100% canopy cover. The community is found in close association with *Pennisetum macrourum* Grassland.

Cyperus longus Sedgeland is found in areas dominated by the Katspruit Form soils (SCWG 1991) with 2.4% organic carbon content. This community had the lowest organic carbon content, of all the communities investigated in this study. The mean soil pH for this community was 6.3 ± 0.56 with a 56 mV redox potential.

VI. *Cliffortia strobilifera* Shrubland

Figure 2.8 *Cliffortia strobilifera* Shrubland, *Kniphofia*, a garden escape, is prominently in flower in the centre foreground.

The *Cliffortia strobilifera* Shrubland is widely distributed through the lower wetland (Figure 2.2d). The community is located in the middle of the wetland, where the soils are wetter and surface water is usually present during wet winters. The water levels within this community can drop to below 1 m below surface in the dry summer period. This is an indication that the community occurs over a wide water table range. This community consists of erect shrubs of *Cliffortia strobilifera* (Figure 2.8) with an average height of 1.3 m and a 95-100% canopy cover. The shrubs are evergreen maintaining their small narrow leaves in winter and summer. It was found in close association with the *Pennisetum macrourum* Grassland, this can be explained by the fact that the two communities are both found over a wide water level range.

This community is found in areas that are dominated by Westleigh Form soils (SCWG 1991). These soils have high clay and a 3.1% organic carbon content. The soil pH for this community was relatively neutral ranging between 6.27 ± 0.23; the neutral pH in this community can be associated with the low soil organic matter content in the soil. The soil had a low redox potential of 18 mV. A similar community is described by Nel (1995) to form distinct stands on the drier riverbank vegetation along the Veldwachters River.

VII. *Populus canescens* Forest

The *Populus canescens* Forest occurs in the middle wetland below the middle dam (Figure. 2.2b). The community consists of a dense stand of *Populus x canescens* trees (Figure 2.9), which usually shed their leaves in autumn-winter. New growth involving active development of young leaves takes place in spring. The largest trees reach an average height of 6.5 m with a 100% projected canopy cover. Distinct stands consisting of cohorts with varying heights were observed (Figure 2.9). This is an indication that their recruitment (by root suckering) is seasonal. Active recruitment was observed in spring and summer with little or no recruitment occurring in autumn and winter.

This community is found in areas with loamy soils, with coarse sand extending down from 0.4 m to at least 1.0 m. The area in which this community occurs was dominated by Katspruit Form (SCWG 1991) soils. These soils had 2.5% organic carbon content. Unexpectedly, low pH values (up to 4.3) were recorded in this community despite the low organic carbon content. The mean pH in this community was 6.01 ± 0.48 with a redox potential of 49 mV. The *Populus canescens* Forest is found in areas with soils that have a high water table during winter but drop to a depth greater than 1 m in summer. Scattered *Zantedeschia aethiopica* and *Oxalis* sp. were the only species recorded under the dense canopy of this community.

Figure 2.9 *Populus canescens* Forest, showing different colonization ages as the forest progressively invades the wetland. A^0 oldest plants, A^1 second age group, A^2 the third stratum with the youngest plants. B indicates the *Typha capensis* Reedswamp and C indicates the *Cyperus longus* Sedgeland.

2.3.2 Soil texture

Table 2.5 Percentage soil texture content for the wetland plant communities

Community	% Stone	% Course Sand	% Medium Sand	% Fine Sand	% Clay & Silt
Populus canescens Forest	8.5	37.1	20.2	32.0	2.2
Cyperus textilis Sedgeland	5.9	40.7	23.7	28.4	1.3
Pennisetum macrourum Grassland	5.2	44.1	20.8	27.5	2.4
Cyperus longus Sedgeland	5.2	44.1	22.6	26.8	1.3
Juncus effusus Sedgeland	4.1	40.0	19.6	32.2	4.2
Typha capensis Reedswamp	2.6	37.9	21.7	34.9	2.9
Cliffortia strobilifera Shrubland	1.7	36.0	25.2	34.2	2.9

All the communities had soils that had a relatively high course and fine sand content. It can be deduced from the above results (Table 2.5) that the *Cyperus longus* Sedgeland and *Pennisetum macrourum* Grassland have soils of similar uniform texture, all the other communities had soils that varied in texture. The clay and silt content was relatively low compared to that of the other communities. The *Juncus effusus* Sedgeland had the highest clay and silt content of the communities examined, followed by the *Typha capensis* Reedswamp and *Cliffortia strobilifera* Shrubland (Table 2.5). The relationship between soil texture and the water table is highlighted further in Chapter 3.

2.3.3 Soil Organic Carbon

Table 2.6 Soil percentage organic carbon (OC) content for wetland plant communities

Plant community	*% Organic carbon*
Populus canescens Forest	2.45
Juncus effusus Sedgeland	2.83
Cyperus longus Sedgeland	2.71
Cliffortia strobilifera Shrubland	3.07
Pennisetum macrourum Grassland	2.79
Typha capensis Reedswamp	4.16
Cyperus textilis Sedgeland	5.10

The soil percentage carbon differed between the Middelvlei Wetland System plant communities. *Populus canescens* Forest has the lowest soil percentage carbon while *Cyperus textilis* Sedgeland has the highest percentage soil organic carbon (Figure 2.10). Although differences in soil organic carbon content exists between communities, little variation is evident between the *Juncus effusus* Sedgeland, *Populus canescens Cyperus longus* Sedgeland, *Cliffortia strobilifera* Shrubland and *Pennisetum macrourum* Grassland, a remarkable difference in percentage soil organic carbon content is found to exist between the previously mentioned communities compared to both the *Typha capensis* Reedswamp and the *Cyperus textilis* Sedgeland, which have a relatively high organic carbon content. Details regarding the soil carbon content and plant communities are highlighted in Chapter 4 & 5.

2.3.4 Soil types

Five soil types are found within the Middelvlei Wetland System (Figure 2.11). The soils are mainly, the Dundee Form, Katspruit Form, Longlands Form, Tukulu Form and Westleigh Form. The soils are described in the terms defined by the Soil Classification Working Group (SCWG 1991).

These soils are longitudinally placed down stream the Middelvlei Wetland System. This is a good indication that the soils are likely as result of surface flow deposition. This further indicates that communication exists between the upper and the lower wetland of the Middelvlei Wetland System.

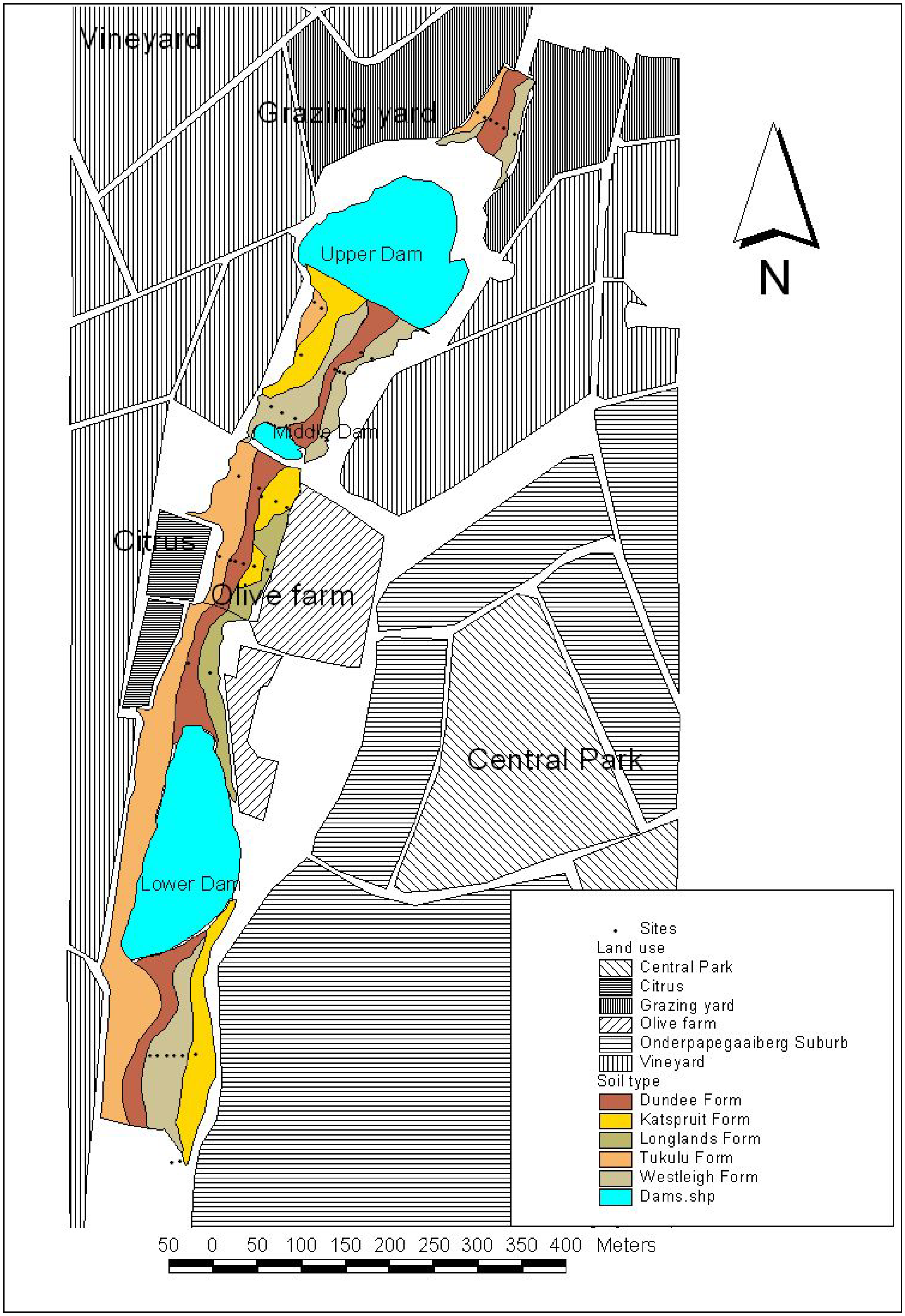

Figure 2.10 Soil types distribution and land use activities at Middelvlei Wetland System.

2.4 Conclusions

The wetland plant communities identified in the Middelvlei Wetland System seem to occur in relatively similar conditions. The plant community distribution can be attributed to a product of various environmental factors that are shared by all the communities within the localised area. The variation in response to these factors by different communities is mainly responsible for the existing community distribution pattern in the wetland, although it is difficult to determine the role played by each factor in relation to other factors at this stage. This is discussed further in Chapter 5 in this thesis.

The results of this study confirm that the water level gradient and status (degree of wetness, surface water, depth to water table) were the most important of the environmental variables measured accounting for the vegetation pattern present in this wetland system. A high level of species turnover is witnessed along the water level gradient.

A tendency for single species dominance in the wetland communities is clearly displayed. This is in agreement with the general findings in the South African literature (Nel 1995, Runhaar *et al*. 1997, Withers 2002). This attribute is important for wetlands managers, as the communities are well delineated, hence easily identifiable in the field. One does not need to be a vegetation expert to recognize the wetland communities, hence paving way for voluntary and non-expertise personnel to assist in wetland monitoring with minimal training and supervision. Understanding the community dynamism in response to environmental changes and stressors would well build into use of wetland vegetation for rapid wetland condition assessment. Some of these factors, regarding environmental variable relationships with the plant communities are discussed further in Chapters 3, 4 5 and 6.

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Chapter 3: Near-surface water level relationship of wetland plant communities in the Middelvlei Wetland System, Stellenbosch

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Abstract

Understanding the responses of individual plant communities to variations in near-surface water levels is a step towards determining the critical factors applicable to a Rapid Wetland Assessment System.

This study was initiated with the primary aim of establishing the relationship between plant communities and the important role played by near-surface water to their spatial distribution and composition in a natural wetland system in Stellenbosch.

Thirty-nine sample plots were used to collect vegetation data that were analysed using standard Braun-Blanquet techniques. Replicated perforated plastic tubes, so called ‘wells’, were installed in the 39 sites located in each of the communities to a depth of 1.0 m. The free water level in each well was monitored in each community, on a monthly basis over an eleven-month period during 2002/03, covering a winter-wet season and a summer-dry season to determine the range of variation over this period. June was used to represent the wettest month while December represented the driest month of the year. The variation in free water levels in relation to the surface of the ground was assessed.

Seven plant communities are identified and described from this particular wetland system. Different communities were found to have specific ranges within which they occur. The *Juncus effusus* Sedgeland community has the narrowest total range in free water depth (+0.03 to -0.40 m) and is considered to occur in areas with the least fluctuation in free water levels. In contrast, the area occupied by the *Populus canescens* Forest has the greatest fluctuation in free water (0.00 to -1.00 m). This exotic species currently appears to be invading the natural wetland and replacing the wetland species by modifying the wetland hydrological

condition. Temporal changes due to the encroachment of more drought tolerant species during the dry season appear to be happening. Monitoring the relationship between plant communities and temporal water level changes appear to be useful, and a cost effective management tool to provide early warnings about changing wetland conditions especially in areas where active groundwater abstraction, farm irrigation and interference with the natural water regime is prevalent.

Key words: Hydrology; Near-surface water; Plant communities; Water level; Water table.

3.1 Introduction

The importance of hydrology in maintaining the condition of wetland systems is emphasized by various researchers (Hammer 1989; Kent 1994; Mitsch & Gosselink 2000). Management of wetland systems requires a clear definition and understanding of wetland functions and processes. Wheeler and Proctor (2000) concluded that the main variables defining freshwater wetland habitats are water regime, nutrient richness, management and succession status.

The relationship between wetland vegetation and hydrology is widely used as classification and identification criteria for wetlands. These criteria regard vegetation, hydrology and hygric soils as the three key components commonly used in wetlands identification (Costa *et al.* 1996).

Vegetation zones dominated by single species, particularly in the emergent zones in freshwater wetlands have been defined along water depth gradients (Spence 1982). This is a strong indication that each vegetation zone has a particular water depth requirement. Each vegetation zone is inhabited by plant species having a particular water depth preference, dependant on their level of inundation tolerance.

3.1.1 Wetland hydrology

Natural wetlands are usually located in areas where the water table is close to the ground surface for much of the year during most years. The occurrence of relatively stable water levels, a characteristic of wetlands, can result from (1) a permanent surface or subsurface stream or seep flowing into a shallow depression or, (2) areas of moist cool climate where the rate of evapotranspiration is low and the water holding capacity of the substrate is high. Thus among other factors, precipitation, evapotranspiration gradient and the soil water holding capacity play an important role in occurrence and existence of wetlands (Duever 1990).

It is recognised that different wetland types have different hydrological requirements and regimes. Some wetlands, like bogs, receive all their water inputs from precipitation (Bay 1969), while others, for example, fens and swamps, and receive considerable ground water inputs (Siegal & Glasser 1987; Roulet 1990).

Hydrology and the dynamic nature of water affect wetland vegetation (composition, structure and diversity), by influencing and controlling its organic accumulation, transport and nutrient cycling (Gosselink & Turner 1978). Hydrology is further recognised as having an influence on the homogeneity or heterogeneity of wetlands. It is closely associated to the broad monotypic vegetated flats (Bedlinger 1979), which is a common occurrence in most wetlands.

Wetlands are transitional areas between terrestrial and open water aquatic systems. Small changes in hydrology in wetlands can therefore be expected to alter vegetation composition, densities and distribution, shifting the system either to terrestrial or aquatic vegetation in case of water decline or increase, respectively.

Mitsch and Gosselink (1986) describe hydrology as the single most important factor determining the establishment and maintenance of specific types of wetland species. Water depth, seasonality and nutrient status play a great role in controlling the distribution of wetland vegetation. It can therefore be argued that most significant wetland functions can be described completely or in part by hydrologic factors (Nestler & Long 1994). Hydrological factors play a major role in determining the wetlands floral and faunal development and composition (Nalubega 1999).

Despite hydrology being one of the most important aspects in the wetland ecosystem function, very little attention has been paid to hydrologic measurements in wetland studies (Mitsch & Gosselink 2000).

3.1.2. Effect of wetland hydrology on plant communities

Wetland vegetation succession can be influenced by wetland hydrology. Following the Gleasonian successional approach (Van der Valk 1981), succession is considered to occur if the relative abundance of species, plant cover and/or floristic composition changes with time. These changes are triggered by continuous changes in environmental conditions (natural, induced or disturbances). Succession is easily noticed in wetlands by a characteristic monotypic community zonation. On developing a freshwater wetlands succession model, Van der Valk (1981) considered succession to occur whenever one or more new species becomes established, when one or more species already present is extirpated or when the two occur simultaneously in a wetland. Wetland hydrology is considered to play an important role in influencing succession.

Studying the restructuring of the plant communities by shallow ground water at the San Pedro River (USA), Stromberg *et al.* (1996) found that the cover of wetland vegetation varied significantly with depth of ground water. With small changes in water level depth (0.25 m to 4 m), five wetland indicator groups were made apparent. In a related study, Cooper (1986), found that small differences in water relations in the Cross Creek Valley wetland in Colorado (USA) made a significant difference to vegetation composition. He recognised key indicator plant communities that could be used to determine hydrological conditions of the wetland. In this study he concluded that any permanent changes in water levels, especially during summer, would initiate a secondary succession process that would affect all stands and communities within the wetlands, where some species would be eliminated first if the water table were lowered. The communities dominated by these species in turn would be eliminated. Hierarchical placement of species or community water level ranges would give a predictable pathway for possible secondary succession and the floristic changes expected within a wetland system.

3.1.3 Hydrological regimes for Western Cape wetlands

Information on hydrological regimes and inundation conditions of wetlands in the Western Cape is scant. Jones (2002), on classifying the wetlands in the Western Cape, grouped them into five categories in accordance with their hydrological regimes. Those that are permanently inundated; winter inundated and summer saturated (seasonally inundated); winter inundated and summer dry (seasonally inundated); winter saturated and summer dry (seasonally saturated) and ephemerally saturated (ephemerally wet).

Due to the significant problems associated with alien woody plant invasions in the Western Cape, there has been a strong research focus on the relative hydrological requirements of natural versus invaded communities. This is relevant to the study of wetlands, as many of these species are a particular problem in this habitat type. In a study of the comparative water use of riparian wattle thickets (invader community) and riparian fynbos (natural communities) in the Wellington and Jonkershoek Valleys of the Western Cape, Dye & Moses (1999), found that daily evaporation in the high canopy was closely correlated to total daily solar radiation. The annual water use by the wattle trees was higher than in fynbos, although the difference was small. The absence of large differences was attributed to non-limiting soil water at the study sites and the evergreen nature of the fynbos plant communities. It is well recognised that invasive alien species (especially trees) have increased water usage compared to native (indigenous) vegetation (Calder & Dye 2000).

The existing information on plant water use in the Western Cape and in South Africa in general, deals with individual plant species, mainly focusing on evapotranspiration rates (Chapman 1990; Donkin 1994; Dye & Moses 1999; Calder & Dye 2000). Very little emphasis has been placed on wetland plant communities in relation to near-surface water levels.

This chapter is aimed at investigating the effects of the near-surface water level changes on wetland plant communities. The aims were firstly to determine the influence of the near-surface water on the distribution of wetland plant communities Secondly, to describe near-surface water ranges for individual wetland plant communities. Thirdly, to quantify the relationship between near-surface water levels and wetland plant communities and finally, to rank the wetland plant communities in a possible predictable succession sequence or shifts in response to changes in near-surface water levels.

3.2 Methods

3.2.1 Near-surface water levels

Subsurface water levels were monitored for one year, on a monthly basis from June 2002 to June 2003. Thirty-nine wells were installed in the plots used for vegetation analysis (Chapter 1). A ground well system (Kent 1994) was used to monitor water levels in the 39 sites. The position and distribution of the wetland plant communities (Chapter 2) within the wetland determined the positioning of the wells. Transects were positioned across the wetland and the wells were installed in the community types encountered along each transect.

Eight transects were positioned across the wetland. The number of wells in each transect depended on the number of major communities intercepted by the transect. Thirty-nine wells (0.04 m in diameter x 1.0 m deep) were sunk, into which 0.04 m diameter x 1.5 m long; polyvinyl chloride (PVC) pipes were inserted to prevent the wells from collapsing. The 1 m section of the pipe that was sunk into the ground was perforated with 40 holes of 2 mm diameter to allow free groundwater flow through the well. The remaining 0.5 m un-perforated portion was above ground, designed to prevent the surface water from directly interfering with the subsurface water during floods and times of rainfall (Figure 3.1). The top of each well was closed to prevent any contamination of the subsurface water.

A two-week settling period was allowed before the first water level reading was taken. The water depth was determined by inserting a calibrated profiler rod with a floater into the standing water level in the well using the equation:

$$WL\ (m) = L\ (m) - 0.5\ m$$

Where WL = depth to water level; L = distance from top of well to standing water

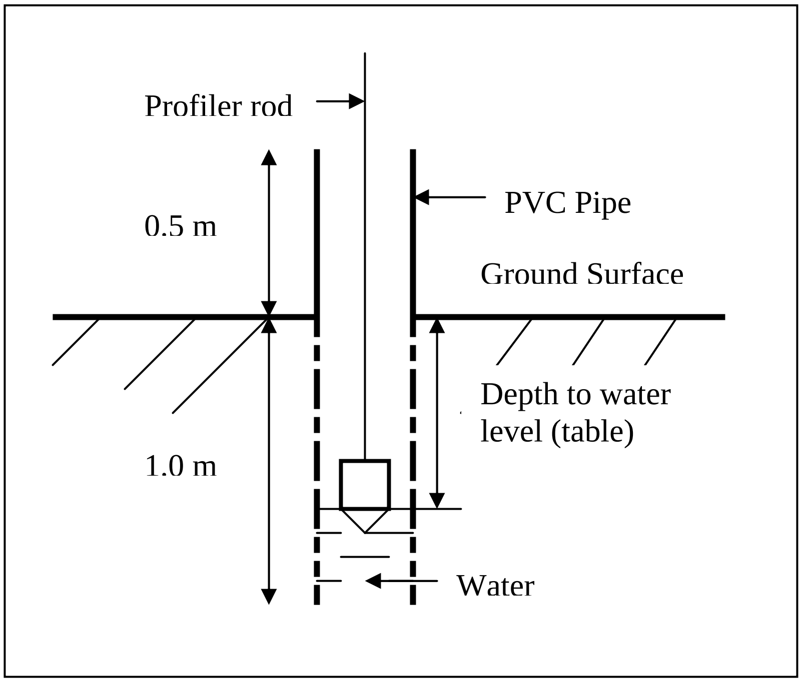

Figure 3.1 Diagram showing the design of a well used for the study.

3.2.2 Hydro-meteorological data

In this study only rainfall data were considered in the analysis, although other meteorological and biotic factors such as evapotranspiration could significantly affect the wetland hydrology. Monthly rainfall data were obtained from the Middelvlei weather station, located within latitude 33°56’ S and longitude 18°50’ E at an altitude of 147 m.

3.2.3 Estimation of the inundation period

Determination of the period that plant communities are able to withstand flooding (inundation period) is difficult to measure directly in the field. Climatic conditions vary seasonally and annually; hence to obtain accurate inundation periods would require a long monitoring period allowing seasonal replication.

In this study we considered the plant species growing around the dam (reservoir) useful to determine the level of inundation that plant species are able to tolerate with their roots under water. The species rooting depth (the distance from the water level to the surface where the plant is rooted) and emergent levels were measured relative to the dam overflow level. The dam fills and overflows in winter and remains full through spring effectively giving a 6-month inundation period. This gave reasonable reliability to the assumption that the plants growing along the dam edge, at and below the overflow level have their roots covered by water for an extended period.

To estimate inundation levels for each species encountered at the dam edge, the species rooting distances relative to the dams' overflow level were measured. This was useful in determining the species rooting range above and below the water surface.

3.2.4 Mapping

Geographical Information System (GIS), Arcview 3.2. Computer software was used to develop the maps in this Chapter.

The height above sea level were measured using a dumpy level, using a reference point, with a known contour calibration above the sea level as starting point. The dumpy level uses a telescope to level the position of its placement and a distance target. The height is then calculated by subtracting or adding the differences in height depending on level of the target in reference to the level of the dumpy.

3.2.5 Data analysis

A numerical comparison of the water level data was done using multivariate analysis (ANOVA), to determine any statistical differences between plant community water levels. To group the plant communities into relatively homogeneous (low standard deviation) groups in relation to water levels, the Classification and Regression Tree Analysis (CART) was used. CART is a nonparametric statistical method that partitions data stepwise into low standard deviation terminal nodes using a regression tree procedure to split the data (Stanford 1994, Steinberg & Colla 1995).

3.3 Results

3.3.1 Wetland geometry

Transect cross sections through the wetlands showing variations in water level are illustrated in Figure 3.2a. The wetland surface slope across the wetland is generally moderate although the profiles (Figure 3.2b) show that the slopes vary along different transects. Water level isolines shown in Figure 3.2a indicate the possible water flow patterns in the wetland. The water around the wetland flows to the lower wetland levels where it converges and flows along the longitudinal gradient. Surface flows in the wetland are present during winters resulting from winter rainfalls or dam overflows.

3.3.2 Wetland Hydroperiod

A wet winter and dry summer characterized the hydrological year from June 2002 to July 2003. Winter during 2003 was relatively dry with an average monthly rainfall of 84.27 mm. July 2002 recorded the highest total monthly rainfall (114.8 mm) while February 2003 had the lowest (10.4 mm) in the hydrological year.

The hydrograph profiles in Figures 3.2b and 3.3 show that the wetland water table was close to the surface in most wells in the wettest month irrespective of the plant community. The differences in water table depth between communities in this period were very small.

Transect (T1) in the lower wetland had an unexpectedly lower water table compared to all the other communities in the wettest month. In this period the other transects had a relatively high water table. The low water level is attributed to the exotic dry *Populus canescens* Forest community. This community is mainly composed of alien trees and shrubs (Figure 2.1). Large differences were noted in the depth of the water table in the sections of the wetlands associated with the different plant communities, between the months of June and March (Figure 3.3). Transects T2; T7 and T8 maintained high water tables despite low rainfall. Transect T3 is located above the lower dam (Figure 3.2); hence a back water retention or a back fill from the dam could explain the consistently high water table in this zone.

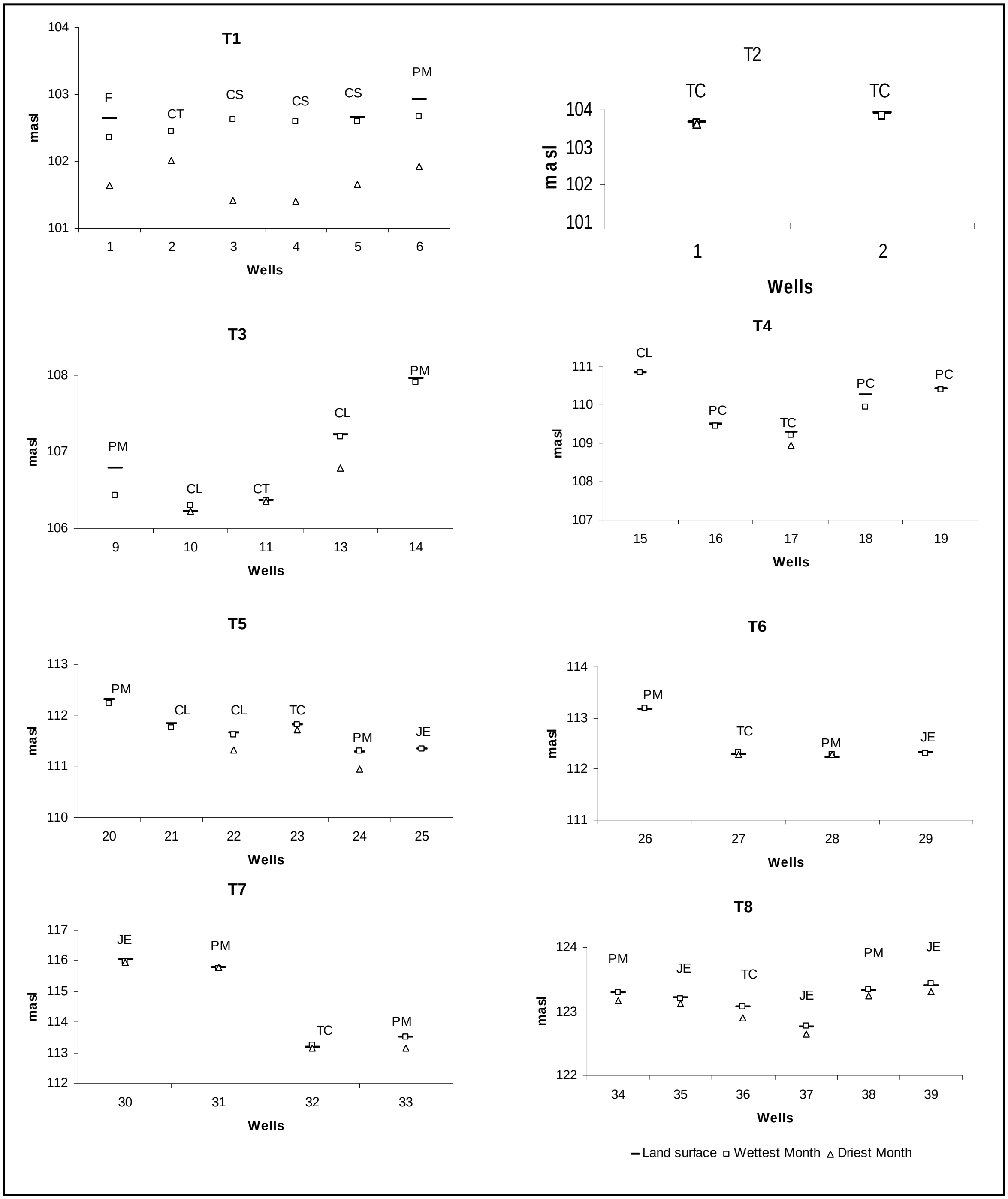

Figure 3.2b Transects (T1- T8) profile (hydrographs) displaying the water depth level in relation to the land surface in the wettest (July 2002) and driest (January 2003) months in the hydrological period.

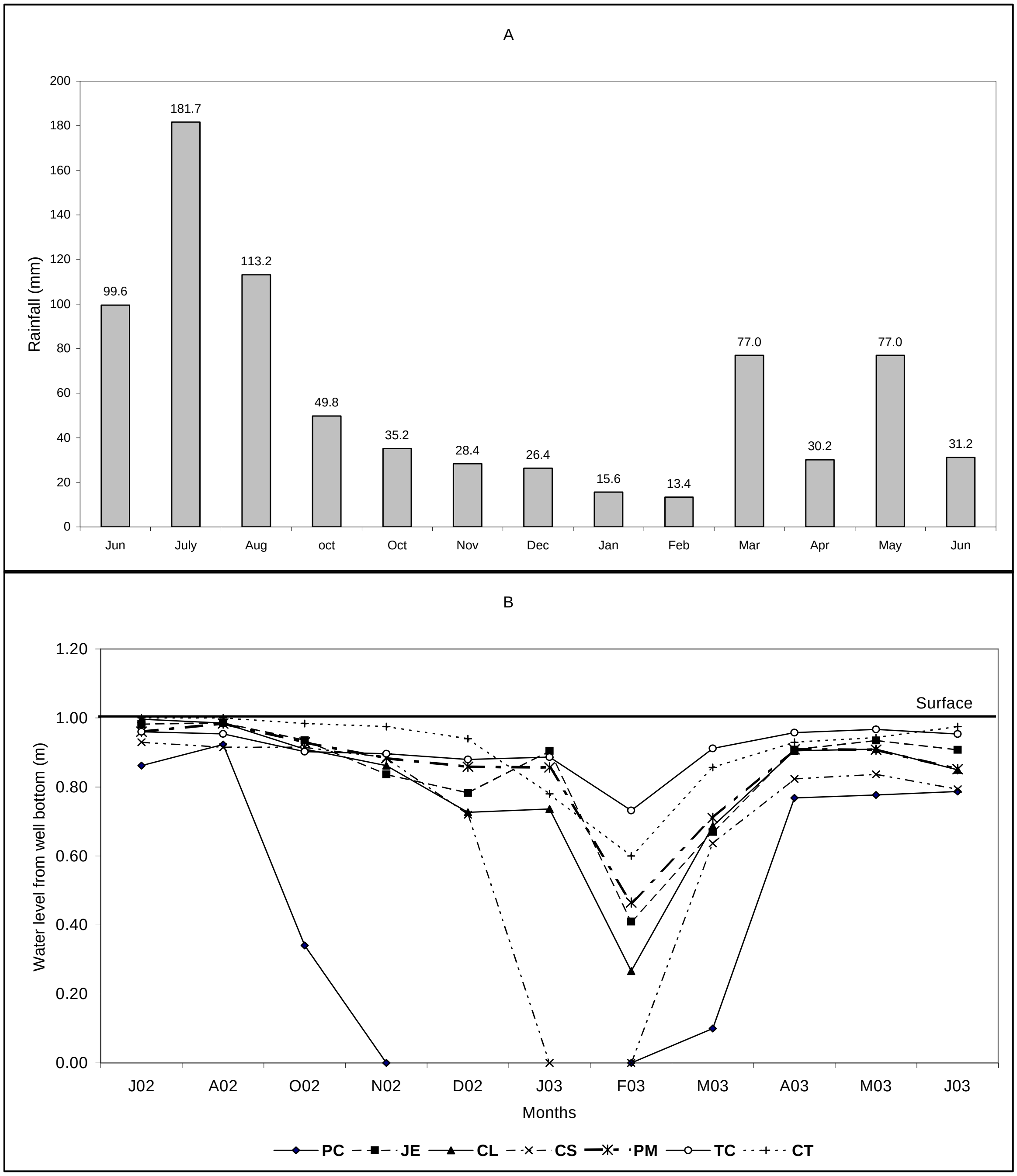

Figure 3.3 (A) Total monthly rainfalls for Middelvlei in the study year June 2002 to June 2003. (B) Monthly plant community water level hydrographs showing the mean monthly water level fluctuations. PC = *Populus canescens* Forest; JE = *Juncus effusus* Sedgeland; CL = *Cyperus longus* Sedgeland; CS = *Cliffortia strobilifera* Shrubland; PM = *Pennisetum macrourum* Grassland; TC = *Typha capensis* Reedswamp and CT = *Cyperus textilis* Sedgeland. A larger scale on water level in areas accupied by individual plant community is displayed in Appendix 3.

3.3.2.2. Seasonal water level fluctuations

Seasonal mean average rainfalls are highest in winter (84.3 mm), autumn (61.7 mm) and spring (32.7 mm) while summer had the lowest rainfall (16.2 mm). Consequently the plant community water table levels were highest in winter when rainfall was high and lowest in summer when low rainfalls were realised, an with the exception is the *Cliffortia strobilifera* Shrubland that, surprisingly, had the highest water level in spring as opposed to winter in other communities. It is interesting to note that although there was a change in water levels for all plant communities with fluctuation in rainfall, different communities showed remarkable differences in water levels.

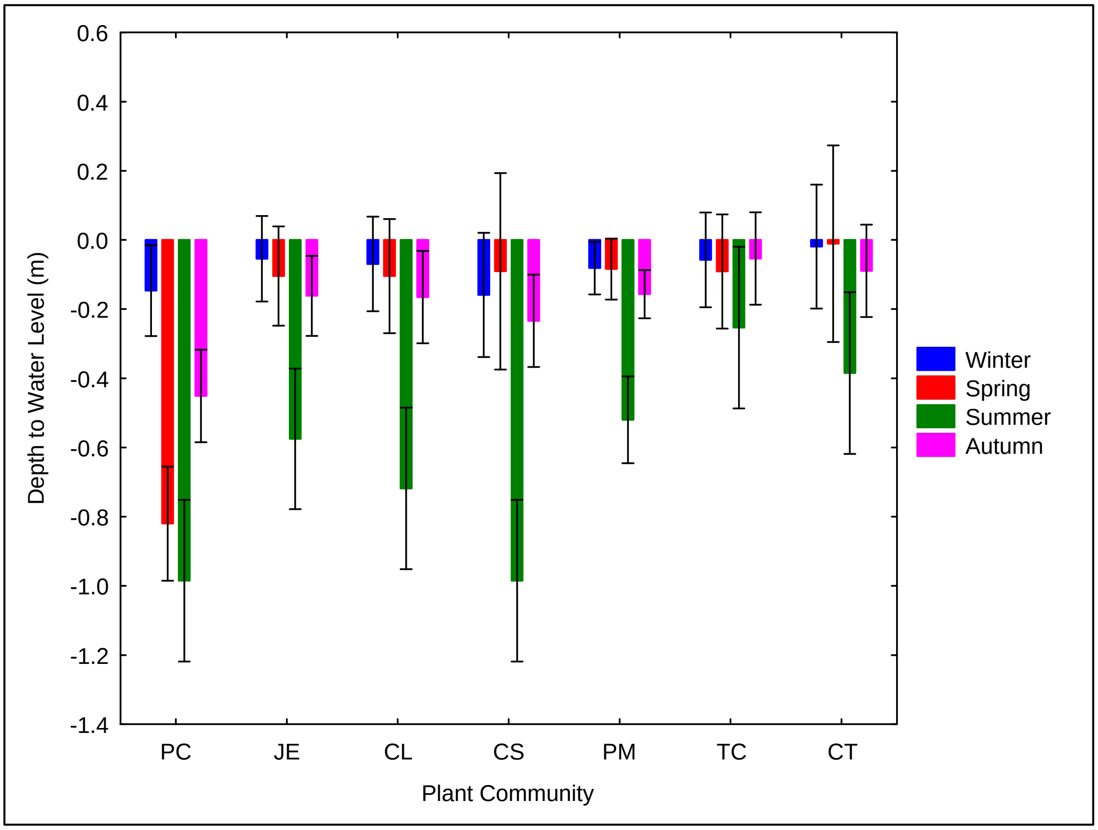

Figure 3.4 Seasonal mean water levels for plant communities in the Middelvlei Wetland System. Vertical bars are standard errors. PC = *Populus canescens* Forest; JE = *Juncus effusus* Sedgeland; CL = *Cyperus longus* Sedgeland; CS = *Cliffortia strobilifera* Shrubland; PM = *Pennisetum macrourum* Grassland; TC = *Typha capensis* Reedswamp and CT = *Cyperus textilis* Sedgeland, while the seasons are categorised as follows: autumn = March – May;

winter = June – August; spring = September – November and summer = December – February.

The most marked change in water level occurred in the *Populus canescens* Forest and *Cliffortia strobilifera* Shrubland, while the *Typha capensis* Reedswamp had the least change in water table level (Figure 3.4). The seasonal changes in plant community water levels show a similar trend to those displayed by the plant community monthly fluctuations above (Figure 3.3 B).

3.3.3 Effects of rainfall on water table depth level in areas under different plant communities

Analysis of variance (ANOVA) indicates no statistically significant differences in water levels between areas occupied by different plant communities in relation to rainfall, however subjecting these data to a Classification and Regression Tree (CART) analysis, showed differences between plant communities. This analysis splits the plant communities into three groups in respect of water table level fluctuation with rainfall (Figure 3.5). The group that responded to low rainfall (<= 29.7 mm), *Populus canescens* Forest, was categorized as a stand-alone group, while all the other communities maintained high water levels. *Populus canescens* Forest water levels dropped below 1.0 m depth at rainfalls lower than 29.7 mm.

The second group consisted of *Cyperus longus* Sedgeland, *Cliffortia strobilifera* Shrubland, *Cliffortia textilis* Sedgeland, *Juncus effusus* Sedgeland, *Pennisetum macrourum* Grassland and *Typha capensis* Reedswamp communities. These communities had water table levels not exceeding 0.4 m depth with a rainfall equal to or below 29.7 mm.

The third group consisted of all plant communities, indicating that at a rainfall greater than 29.7 mm all the plants communities had relatively high water table levels. This result shows that a threshold amount of rainfall equal to or greater than 29.7 mm is required to maintain the water table levels of all the plant communities at or near ground surface level.

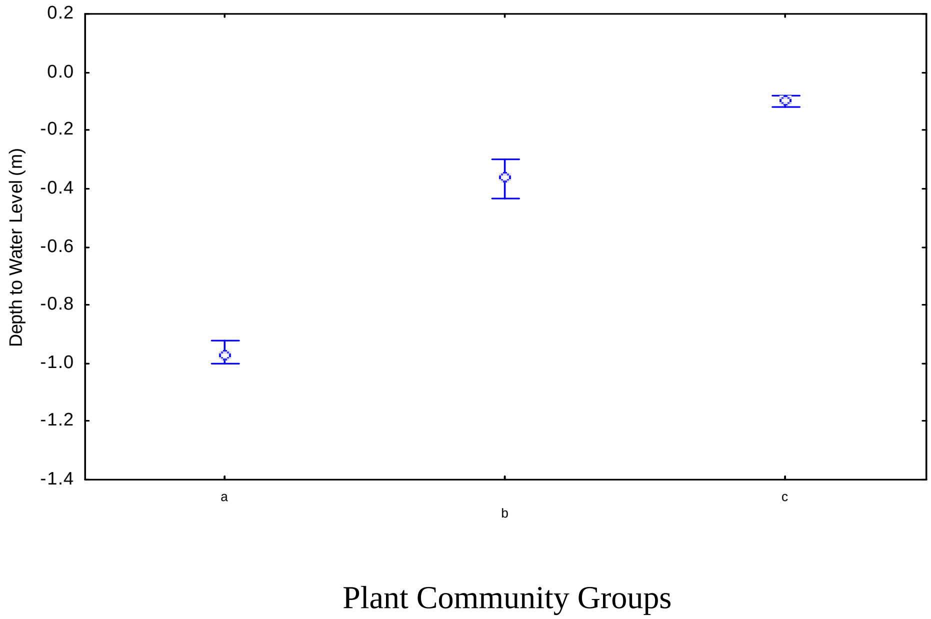

Figure 3.5 CART analysis plant community classification in respect of annual water level means with previous monthly (month before data collection) rainfall. The vertical bars denote 0.95 bootstrap confidence intervals. Community groups a) PC, monthly rainfall <=29.7 mm; b) CL; CS; CT; PM TC, monthly rainfall <=29.7 mm and; c) all communities with a previous monthly rainfall >29.7 mm.

3.3.4 Plant community inundation periods

From the data available it is not possible to determine the inundation periods for the plant communities, as it would require a longer monitoring period than one year. To get an approximate idea of the period that plants dominating each plant community could survive flooding (inundation tolerance), measurements of the plants rooted depths below the water surface and the maximum rooting of the same plants above the water surface in the lower reservoir, relative to the dam overflow level, were recorded (Figure 3.6). Different plant species have different rooting depth ranges relative to the overflow water surface level.

Unfortunately not all the plant communities, or dominant plant species defining the wetland communities, were found growing at the dam edge; hence it was not possible to compare all the communities or species.

The results indicate that a number of plant species are able to withstand long periods of inundation, since the water level in the dam examined during this study has a relatively constant level through most of the year. Using this assumption it can be presumed that the deeper-rooted plants will tolerate longer inundation periods as they remain inundated for most of the year.

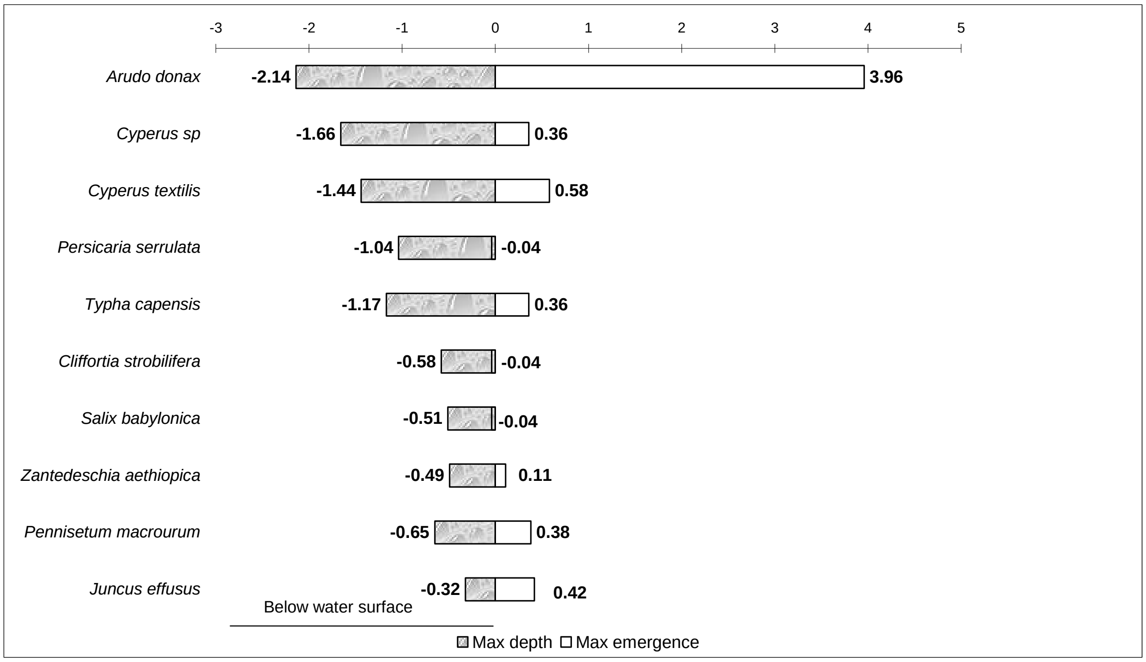

Figure 3.6 Maximum submergence depth (deepest under-water rooting) and maximum emergence rooting height (m) above the water surface, relative to dam overflow water level, for plant species growing around the lower dam. The negative (-ve, shaded) values indicate the under-water rooting while the positive (+ve, clear) indicate the rooting above the water surface.

Arudo donax displayed greatest variation in both below and above water rooting. Species such as *Salix babylonica*, *Persicaria serrulata,* and *Cliffortia strobilifera* rooted below the water surface and did not display any rooting above the water surface. It is interesting to note that these species had the narrowest rooting depth range recorded among other communities.

Among the species in the communities investigated in this study, results in Figure 3.6 indicate that *Cyperus textilis* rooted at the greatest water depth, followed by *Typha capensis*, *Pennisetum macrourum*, *Cliffortia strobilifera*, while *Juncus effusus* has the shallowest submerged rooting depth. However, this may also be interpreted that these species have the ability to withstand inundation duration in this order and a consideration of their growth requirements is important before conclusions are drawn.

3.3.5 Community water level range

The average water level ranges for the plant communities are shown in Figure 3.7. It is important to note that these ranges are tabulated for water level changes in the wells and surface water (above the surface).

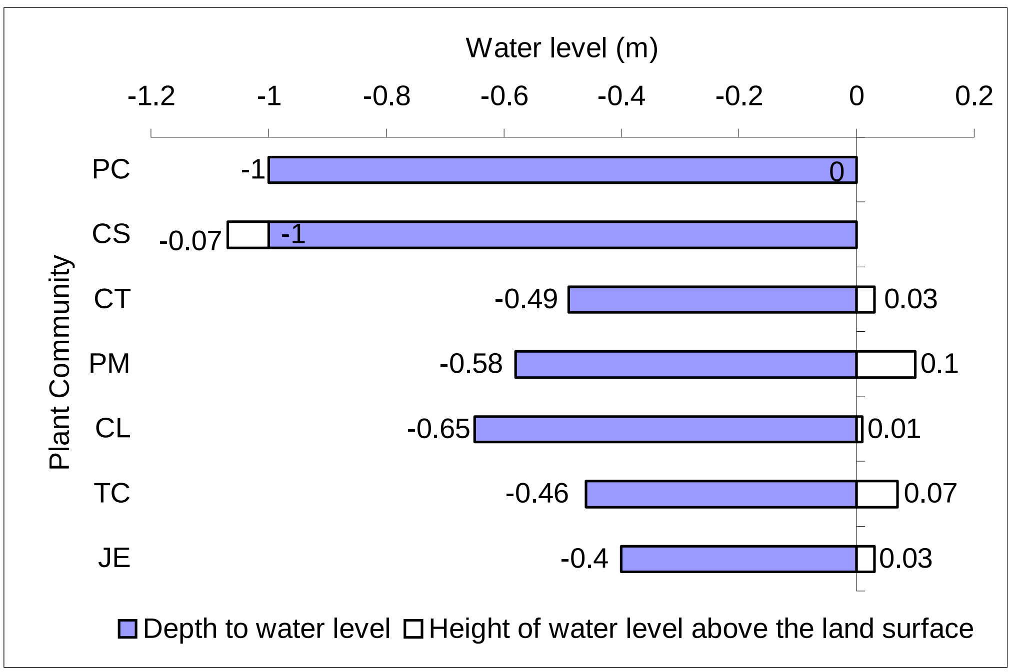

Figure 3.7 Water level ranges in various wetland plant communities at Middelvlei Wetland System. Data are measurements from the lowest standing water table depth to the highest water table recorded in each community. The negative values (-ve shaded) indicate levels below surface, positive (+ve clear) indicate water levels above surface (Note that CS

community highest water level was – 0.07 m below surface). PC = *Populus canescens* Forest; JE = *Juncus effusus* Sedgeland; CL = *Cyperus longus* Sedgeland; CS = *Cliffortia strobilifera* Shrubland; PM = *Pennisetum macrourum* Grassland; TC = *Typha capensis* Reedswamp and CT = *Cyperus textilis* Sedgeland.

Plant communities displayed varying ranges in water levels. The *Juncus effusus* Sedgeland had the lowest range with a minimum water level at -0.4 m and a maximum level at 0.03 m above the surface while the *Populus canescens* Forest had the widest range, with water level dropping from surface level to over 1.0 m below the surface.

The results show that woody plants dominated communities (*Cliffortia strobilifera* Shrubland and *Populus canescens* Forest) had the largest change in water levels, hence they can be presumed to either have a higher water demand than the grass and herbaceous plant dominated communities or, alternatively that these woody plants are intolerant of perpetually high water tables. The water levels in the area occupied by woody plant dominated communities, remained below the land surface throughout the hydrological year. The *Populus canescens* Forest had water at surface level in winter, while the water level in the *Cliffortia strobilifera* Shrubland remained below surface level at all times, the highest level recorded was – 0.07 m below the surface, this low water table level could also be attributed to woody plants having deep root systems that cause greater draw-down especially during the dry periods.

The herbaceous and graminoid dominated communities had a moderate water table range (Figure 3.7) with shallow water above the surface over part of the year and relatively high water table levels compared to the woody plant dominated communities.

It is difficult to fully predict or account for the different plants' water demands and budgets, as this involves complex factors for example species involved, rooting depth, soil water holding capacities and lateral water movements.

3.4 Discussion

3.4.1 General considerations

Many wetlands are characterized by the occurrence of relatively stable water levels, although moderate seasonal fluctuations are expected to occur from year to year. The fluctuations are, however, minimal. Large differences between high and low water table levels are often associated with riverine wetlands, where the large differences are the consequence of flooding (Stromberg & Tiller 1996).

The occurrence of relatively high stable water tables (near-surface water) in wetlands over time allows the establishment and development of plants that are adapted to saturated or inundated soils. These plants are characteristic of areas with extended wet conditions. Remarkable differences in water table levels at local scales occur in plant communities within a wetland. It is common to find clear-cut boundaries in wetland vegetation, where clear zones or stands occur that are often dominated by a single species (Chapter 2). This is a common characteristic for most wetlands. These stands are found to occur repetitively within the wetland system examined in this study (Figure 3.1).

It is generally theorised that a response to water depths by plants is expected for emergent aquatic plants (Grace 1989, Stromberg & Tiller 1996). This study reveals that near-surface water levels play a strong role in influencing the composition and distribution of wetland plant communities. Although it may be difficult to determine and separate the effect of water table depths with inundation frequency in each community, the hydrographs (Figure 3.3) display similarities in water level pattern for individual plant communities in and between transects in the wetland.

The results show that the changes in water table levels in the Middelvlei Wetland System plant communities can mainly be explained by four factors. Firstly the vegetation type; secondly rainfall; thirdly season and finally the water source, terrain and human related activities. Other environmental factors that may influence or relate to water levels and their interaction are discussed in a broader perspective in Chapter 5.

In this study the plant communities associated with graminoids and herbs (*Cyperus longus* Sedgelands, *Cyperus textilis* Sedgelands, *Juncus effusus* Sedgelands, *Pennisetum macrourum* Grasslands and *Typha capensis* Reedswamp) had narrower water table level ranges compared to tree and shrub dominated communities. Calder and Dye (2000) had similar findings, while investigating the water demand of different plants in Jonkershoek, Western Cape. The wide range in water levels for woody (tree and shrubs) communities (Figure 3.8) in this case *Pennisetum canescens* Forest and *Cliffortia strobilifera* Shrubland is attributed to the high water use or demand particularly of the dominant *Poplar* and *Cliffortia* species, a further explanation could be as a result to the high evapotranspiration rate for these communities as opposed to that of graminoids and the herbs. It is cautiously expected, in the absence of excavations, that woody plants have deeper roots than the herbaceous plants that are often shallow rooted (Canadell *et al*. 1996, Stromberg & Tiller 1996, Scott & Le Maitre 1998). In this respect the woody plants are able to draw water from deeper water table levels than herbaceous plants, thus explaining their distribution in the higher elevated areas that often experience a wide water table fluctuation range. Similarly, Calder & Dye (2000) also found that the water demand by grass and herbaceous plants was lower than that of alien or native forests in South Africa.

Rainfall also plays a major role in determining community water levels. The amount of rainfall at a particular time is closely associated to the water level in any particular plant community. During the periods of high rainfall, when the monthly mean rainfall is greater than 29.7 mm (>29.7 mm), all communities are found to have high water table levels (Figure 3.6). This is an indication that high rainfalls above monthly mean of 29.7 mm over-shadows other factors evaluated here, allowing little or minimal differences in community water levels. It is expected that in times of high rainfall, the water demand by plants is generally low. Above surface flow during peak rainfall events was correlated to high, near-surface, water levels in all the wells in all the communities.

The disparity occurring in Transect 1 (T1, Figure 3.3), compared to the other transects in the wetlands, deserves comment. The maintenance of water levels that are slightly sub-surface may have occurred as a result of the dominance of woody vegetation and high alien tree densities in this section of the wetland. Aliens are known to have a higher water demand than many native plants (Calder & Dye 2000). In this case, the lower dam might also contribute to the absence of surface flows immediately after a rainfall event or, in any event to cause a lag in their occurrence. The low water levels in transect T1 wells at time of high rainfall, may partially been a result to delayed or water flow lag as the dam fills-up.

Populus canescens is at present actively invading and replacing other wetland communities surrounding it in this system, namely, mainly the *Typha capensis* Reedswamp and *Cyperus longus* Sedgeland. A similar invasion is described by Henderson (1998).

The results also indicate that, under a condition of a minimum monthly rainfall of 29.7 mm, the competitive advantage of *Populus canescens* for moisture, and its consequent drying out of the environment, is eliminated, paving way for community co-existence should the other communities be able to tolerate the taller growth form. However, the woody plants generally stand a better competitive chance due to the presence of deep root systems. This would facilitate the draw up of deeper water by these plants. A collective draw up of deeper water by the woody plants would result in the lowering of the water table, including that in the immediate surround of the community, which would, in turn, promote the invasion by woody plants into the herbaceous communities.

Seasonal fluctuations of water table levels between plant communities occur in this wetland system. The normal weather and climatic cycles can be regarded as the key factors driving this seasonality. Other associated factors, for example; temperature, wind and humidity, should not be overlooked, however. These factors are expected to have an indirect effect on the water table, as a result of either an increase or a reduction of the water demand (evapotranspiration) of the plant communities causing a rising or lowering of the water table respectively (Chapman 1990).

Water table levels in the *Populus canescens* Forest community in winter (when leaves are absent) were high. It was observed that water levels, dropped dramatically at the start of spring (Figure 3.4 B, September to November). This can be explained by the trees high demand for water during this period of vigorous growth when increased evapotranspiration took place as compared to spring and summer when the leaves had fully developed. Xu *et al*. (2002) reported a similar trend, on the effect of the surface water depth after harvest and establishment of *Pinus taeda* (Lobolly pine).

The water sources in various sections of the wetlands as discussed earlier also play a key role in determining the water level fluctuations. Water levels in some sections are greatly influenced by effluent from the winery plant, irrigation activities and dam seepage. It is for these reasons that the water table level in these sections remains high in the driest month of the year, while that of other transects declines. It can therefore be concluded that plant communities found in these sections of the wetland, where the water table is generally high throughout the year are adapted or are able to tolerate high water levels, hence they can be considered as characteristic indicators for high water table wetlands.

3.4.2 Water level range for plant communities

The narrow ranges in water level variation measured in each of the wetland communities suggests that a small change in water level could potentially lead to loss or shift of wetland communities. This would in turn alter the wetland zonation. A decline or increase in both surface and below surface water levels would affect different plant communities in various ways. Van der Valk (1981), Cooper (1986) and Neill (1990) extensively discuss some of the changes expected in wetland plant succession as water levels change. The existence of plant communities in relation to water gradients is well-known in riverine and wetland marshes (Boucher & Jarman 1977, Boucher 1981; Cooper 1986; Grace 1989; Squires & Van der Valk 1992, Mountford & Chapman 1993, Runhaar *et al*. 1996, Stromberg *et al.* 1996). Grace (1989) demonstrated that two species of *Typha* (*T. latifolia* and *T. domingensis*) had differences in tolerance to water depths. Although the species considered in the above study differed from those in this study, a similar trend in vegetation zonation in relation to the water table is clearly displayed by the communities considered in this study.

A comparison of the same species in the dams to those found in the wetlands indicates that, despite some of the plants being found in areas having low water fluctuation ranges, they potentially can withstand longer inundation periods with higher water levels than those observed in the wetlands. This could be attributed to the higher levels of dissolved oxygen in dam water through wave action as compared to low concentrations in the near-surface water in the protected wetland environment.

Theoretically it is predicted that the distribution of the plant communities is directly related to the range of water table fluctuations in wetlands, corresponding to the magnitude of water level variation. The order that the plant communities examined in the present study respond to increases or decreases in water table levels, from the most to the least variation, or from most to least sensitive community is in the following sequence:

Juncus effusus Sedgeland < *Cyperus textilis* Sedgeland < *Typha capensis* Reedswamp < *Pennisetum macrourum* Grassland < *Cyperus longus* Sedgeland < *Cliffortia strobilifera* Shrubland < *Populus canescens* Forest.

Among the communities studied in the Middelvlei Wetland System, the *Juncus effusus* Sedgeland had the lowest fluctuation in water level, with a range of 0.43 m. The above soil surface water level recorded in this community was 0.03 m, while the water level dropped to a maximum of 0.4 m below the soil surface. Comparisons between this community and *J. effusus* plants growing in the dam, indicates that *J. effusus* has a potential to tolerate higher and lower water levels than the actual levels observed in the wetland during the study period. The *J. effusus* plants in the dam grew in water levels varying from 0.32 m below the water surface to 0.42 m above the reservior level (Figure 3.7). Hypothetically, it can be anticipated that a decline in water level exceeding 0.4 m would lead to the of this community drying out or instigate its shift to the wetter grounds. Such a shift in vegetation due to changes in water level has been reported in Lake Naivasha – Kenya, where *Cyperus papyrus* species has established and fully developed in the drawdown zone when lake water level receded (Van der Valk 1981).

The *Cyperus textilis* Sedgeland has a slightly wider inundation range than that of the *Juncus effusus* Sedgeland. The *Cyperus textilis* Sedgeland water range interval measured 0.52 m; this is an indication that, with a further decline in water level, it would be the second community to disappear should water levels change drastically. The community was rooted to a maximum depth of 0.49 m below the surface and extended to 0.03 m above the surface (Figure 3.7).

Comparisons of water levels in the *Cyperus textilis* Sedgeland, between the wetlands with *C. textilis* plants and those growing around the dam, showed that this species has an ability to grow in areas with water depths of up to 1.44 m and to extend to 0.58 m above dam water level. This is an indication that this community can withstand or tolerate longer periods and greater degree of inundation than the *Juncus effusus* Sedgeland. *Cyperus textilis* Sedgeland is expected to be found in frequently flooded or inundated areas. This characteristic explains why *C. textilis* is found growing in the wetted perimeter of rivers in the Cape (e.g. as personally observed along the Doring and Olifants Rivers). It reacts as an early or primary colonizer facilitating the establishment of other less inundation tolerant species (for example of *Phragmites australis*) (personal observation).

The *Typha capensis* Reedswamp had a water level fluctuation range of 0.53 m. The deepest water table recorded in this community was 0.43 m below the surface, while free surface water measured 0.07 m. This community is dominated by the *T. capensis* species. The comparison between the same species at the dam indicated that the community could potentially tolerate higher above surface water levels, up to 1.17 m contrary to the 0.07 m recorded in the wetlands. This explains the presence of the *T. capensis* around standing free water, with frequent flooding. However, the community establishment seems to be limited by water table depth declining sharply with lowering in the water table to a depth below 0.43 m. Grace (1989) described a similar trend on the effects of water depths in two *Typha* species where *T. latifolia* declined sharply and died out at a depth greater than 0.95 m.

Pennisetum macrourum Grassland had a water depth range of 0.61 m, with a low water table level in the wetland system of 0.58 m below the surface and free water at 0.1 m above ground surface. This community is found widely distributed in the Middelvlei Wetland System (Figure 2.2). The community tolerated relatively wet and dry regions of the wetland explaining its wide distribution. *P. macrourum* species growing at the dam indicate that this species has a potential to withstand higher free water levels than those observed in the wetland.

The water table level range of the *Cyperus longus* Sedgeland was 0.66 m ranging from shallow free surface water (0.01 m) to 0.65 m below the surface. Despite this species occurring in this wetland system and also growing along rivers in the Western Cape (personal observation), *Cyperus longus* was absent around the dams in the system.

The water level fluctuation range in the *Cliffortia strobilifera* Shrubland was 0.93 m. Unlike other communities discussed above, this community was not found in areas that had free surface water. The highest water level recorded for this community was 0.02 m below the surface. The community thus has a preference for areas that are not flooded regularly although having relatively wet soils.

The widest water table fluctuation range, compared to other communities investigated in this study, was recorded in the *Populus canescens* Forest. It was found in areas that had water at surface level dropping beyond 1.0 m depth, below the surface. The wells installed in this community dried up in the dry periods of the study. This high fluctuation of the water level in this community can be explained by *P. canescens* having a high water demand and the presence of deep roots, thus the ability to utilize water at deeper depths compared to other communities.

Although poplar trees are aesthetically pleasing and are used in a number of ways by man, the Middelvlei Wetland System appears to be under threat from this highly invasive species. Cilliers *et al.* (1998) record this species as a threat to conservation of indigenous riverine and wetland vegetation. *P. canescens* has a prolific lateral root system that is thought to be effective in arresting soil erosion, *P. canescens* is currently invading and replacing the wetland species. *Cyperus longus* Sedgeland and *Typha capensis* Reedswamp neighbouring the *P. canescens* Forest (Figure 2.2b) face the danger of elimination by this community. The lack of recruitment into these communities (*Cyperus longus* Sedgeland and *Typha capensis* Reedswamp), and the high levels of mortality in older cohorts of the poplars indicate evidence for competition mainly for near-surface water between these communities.

Populus canescens are deep-rooted trees and are therefore able to extract water from deeper soils than the less competitive herbaceous *C. longus* and *T. capensis*. These characteristics give the *Populus canescens* Forest a competitive advantage over other less competitive wetland communities, mainly the *Cyperus longus* Sedgeland and *Typha capensis* Reedswamp (Figure 2.2 b).

The competition intensifies in summer when the *P. canescens* Forest extensively sucks up water leaving the topsoil dry.

It is a general occurrence for the wetland plant communities to be found around dams and along rivers, where a high degree of zonation is evident. This is a good indication that the presence of water is a determining factor for the presence of these plant communities. However, a slightly variation in plant community water levels occur in the three localities, this may be attributed to differences in inundation period, soil aeration and rate of water flow play among other environmental factors.

3.5 Conclusion

Effective management of the wetlands and wetland resources depends on the understanding of the way in which the water balance components (rainfall, transpiration, interception, lateral runoff, infiltration, water storage and the water table) interact to form a stable, template against which wetland plant communities can develop (Gilman 1994). It is important, however, to note that the plant species present, and their spatial distribution depends on a range of environmental variables and their ability to compete and grow to maturity. This paper confirms the primary importance of hydrologic factors, with emphasis on the near-surface water gradient, to the composition and distribution of wetland plant communities.

Monitoring vegetation composition and distribution in permanent plots, would assist in assessing and evaluating the biological integrity of the wetland. Although most wetland communities are dominated by a single species, it may not be practical to monitor each species, thus for practical purposes emphasis should be put on plant communities, particularly in areas supporting sensitive indicators of change.

Future studies should incorporate the wetlands; riverine and riparian plant communities, to determine their requirements and causes of their distribution. Additional studies to investigate the water levels at the boundaries between communities are required, particularly in an attempt determine whether the relationship of the water levels between communities, is intermediate between the communities under investigation.

It would be recommended that, in order to determine feasible and sustainable activities and developments within the wetland catchment, for example, water abstraction, damming, irrigation and effluents disposal, an initiative similar to the current determination of the Instream Flow Requirements (IFRs) of rivers in South Africa (Brown & Joubert 2003; King *et al*. 2003) is necessary for wetlands. Likewise as with rivers, determination of the wetland hydrological requirement (especially the water regime) is inevitable if the wetland integrity and biodiversity is to be maintained.

Although decline in water levels is found to have negative impacts on wetlands, an increase in water levels could conversely result to negative impacts on wetlands, especially when originating from external sources (Le Maitre *et al*. 1999).

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Chapter 4: The effect of near-surface water chemistry on wetland plant communities in the Middelvlei Wetland System, Stellenbosch

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Abstract

The physico-chemical properties of seven wetland plant communities were investigated for an eleven-month period, over four seasons. Most of the water chemistry variables measured show seasonal fluctuations, within and between seasons for individual plant communities. A number of plant communities display close relationship with physico-chemical properties in some seasons, while other groups of communities are neither affected by seasonal changes nor by the amount of rainfall.

A short-term storage of water chemistry constituents by herbaceous macrophytes is not of much significance from a near-surface point of view, especially in the Mediterranean climate. Seasonal variation in near-surface water chemistry is particularly prevalent during spring when active plant growth takes improving the near-surface water quality. The improvement in water quality can be sustained by harvesting the vegetation to prevent incycling of nutrients and other constituents resulting in a build-up in the system.

Annual effect (Long-term) of near-surface water chemistry by plant communities show little effect in the Middelvlei Wetlands System longitudinal water quality conditions, compared to seasonal effects (short-term) that are clearly defined.

This study primarily identifies the water chemistry constituent associated with individual wetland plant communities in the Stellenbosch Area and determines the relationship between these communities and selected physico-chemical wetland conditions. This relationship serves as a basis for the assessment of the status of the communities in the wetland system and for the prediction of their condition and their effect on the wetland.

Key words: Plant communities; Water quality; Chemical constituents; Nutrient levels

4.1 Introduction

The South African Government has recognized the importance of protection of water resources, leading to the insertion of a clause in the South African Water Act (Act No. 36, August 1998) that stipulates that the maintenance of the quality, quantity and reliability of water is a requirement to maintain the ecological health of aquatic systems.

4.1.2 Water quality in wetlands

The term water quality is used to describe the physical, chemical, biological and aesthetic properties of water, which determines its fitness for a variety of uses and for the protection of the health and integrity of aquatic systems (DWAF 1996). The water chemistry of wetlands is primarily a result of the following factors; geologic and geographic setting, source of inflowing water, type of soils, vegetation and human activities within or near the wetlands.

A range of parameters determines water chemistry constituents, parameters considered for monitoring or analysis in any particular situation depends on the intended purpose of the water. This study focuses on the near-surface water chemistry constituent within various wetland plant communities (Chapter 2), with emphasis placed on conditions favouring the protection of wetland or aquatic systems, of which most are controlled or influenced by constituents that are either dissolved or suspended in water.

Four constituent-specific criteria are used to assess water quality in South Africa (DWAF 1996), mainly:

- Toxic constituents; this includes the inorganic constituents (e.g. Al, Cu, Mn, NH_4^+) and organic constituents (e.g. phenol, atrazine).
- System variables; these are constituents that regulate essential ecosystem processes; they determine the aquatic system biota characteristics and natural seasonal cycles (e.g. pH, Conductivity, Dissolved Oxygen).

- Non-toxic inorganic constituents; these are constituents that are naturally found in the aquatic system. Their level of concentration usually depends on the localized geochemical, physical and hydrological processes. High concentrations of these constituents may cause toxic effects in the system.
- Nutrients: These are usually non-toxic constituents, although high concentrations may stimulate eutrophication (e.g. nitrates, phosphates) that may have negative effects on the ecosystem.

The above categories are based on the effect that the constituents may have on aquatic biota in relation to the problems experienced in South African aquatic systems (DWAF 1996).

4.1.3 Water quality in relation to wetland plants

The ability of vegetation to improve water quality through uptake of nutrients, metals and other contaminants is well documented (Gersberg *et al*. 1986, Reddy *et al*. 1989). Wetlands purify water through a number of processes that include the filtration and sedimentation of suspended particles from the water system and accumulation or assimilation of nutrients in the plant vegetative matter. Most of these nutrients taken up by wetland plants are released and recycled in the wetland when the vegetation dies and decomposes, thus the plants act only as temporary nutrient traps through the assimilation process (Richardson & Craft 1993). Nutrients can be removed from the wetland system through managed vegetation harvesting, such that the harvesting takes place when the vegetation has accumulated a pre-determined quantity of nutrients. Sedimentation immobilizes pollutant constituents in areas where wetlands systems have not been interfered with for long periods (Boto & Patrick 1979), such as in wetlands where full successional vegetation development is allowed to proceed. This process slows water flow speed, reducing water energy and thereby its potential to transport sediments.

A literature review on wetland vegetation and water quality reveals that most research concentrates on the ability of the particular vegetation to improve surface water quality, while very little research is done on the sub-surface water or near-surface groundwater, particularly in respect of the role of individual wetland plant communities. The relationship between water quality and particular assemblages of wetland plants is unclear. The in-depth investigation into subsurface/near-surface water quality in relation to individual plants is particularly important in respect of the functioning of constructed wetlands.

Malan & Day (2002) emphasize that the subjection of rivers to environmental impacts, such as pollution, invasion of riparian and aquatic habitats by alien fauna and flora and excessive abstraction of water, can impair the water quality in them by causing changes in the concentrations of the constituent chemicals and to the water regime. As much as this applies to rivers, exposure of the same factors to wetlands would equally affect the water quality in wetland systems.

Studies in North America, Europe and some parts of Africa have demonstrated the importance of both natural and constructed wetlands in improving water quality (Gaudet 1979, Denny 1985, Denny 1989, Hammer 1989, Kansiime & Nabulega 1999, Okurut 2000). The ability of wetlands to filter and transform nutrients and other constituents to active status for availability to plants has resulted in the construction and use of artificial wetlands for water purification, this system is well developed in the United States of America. Internationally, countries are increasingly adopting the practice of constructing artificial wetlands in the treatment of wastewater, sewage and even to remedy acid mine wastewater.

According to Hammer (1992) the water purification function of the wetlands depends primarily on four principal components, mainly wetland substrate, vegetation, water, and microbial populations. Despite the fact that plants have long been associated with water quality improvement, a big debate exists between botanists and microbiologists about the actual biological assemblages responsible for the purification of the water (microbial activities or plants). Although neither of these can be ruled out or dismissed individually, there is a strong argument for the bacteria responsible for degrading the pollutants having a close association with the constituent wetland plants. The wetland plants introduce oxygen to the generally oxygen deficient soil through their roots, creating an oxidized root zone where bacterial transformations of nitrogenous and other compounds can occur (Good & Patrick 1987). This process is evidenced by the presence of oxidised zones in the wetland soils in close relation to the plant root systems. High organic matter content (carbon) in wetlands also provides a suitable environment for microbial activity (Obenhuber & Lowrance 1991).

Investigation as to whether the association is plant species specific, or is entirely environment driven or both would be of great value to ecologists and water engineers. This kind of information is useful to determine which plants are appropriate in vegetating constructed wetlands and in wetland rehabilitation.

4.1.4 Wetlands Assessment

Methods for evaluating or assessing aquatic system health have not been fully developed to identify the wetland system quality and integrity adequately for their protection and health restoration. Chemical constituents and physical condition of water have been widely applied in wetland assessment. The advantage of using chemical variables is that they are quantifiable and therefore directly comparable, but chemical variables alone cannot give a total reflection of the wetland condition. Assessment of the dynamic interactions between the physical, chemical and biological attributes is necessary to determine the overall condition of a wetland.

Chemical monitoring is a highly skilled and expensive method for wetland assessment. Its sustainability may be limited by financial constraints and by lack of suitable expertise. This limitation calls for a need to develop easier and affordable wetland assessment methods and criteria that will facilitate their rapid assessment without the requirement of highly skilled personnel and high costs. Though initial training is essential, this kind of assessment technique would ensure that wetland conditions are monitored widely and at regular intervals, especially if targeted to voluntary monitoring services, a system that has been applied successfully in North America (US EPA 1993).

Monitoring techniques that use simple biological assemblages that are easily recognisable, identifiable and have a pronounced response to environmental changes are necessary to determine the wetland condition, for effective and practical management purposes.

The use of plant species or of vegetation as indicators for wetland condition has long been an objective for assessing water quality (Stanford 1994). In South Africa invertebrate macrofauna have been positively and widely used to determine water quality in rivers, using the South Africa Scoring System (SASS) (Dallas *et al.* 1998), but no adequate procedures for wetland assessment have been put in place. Whereas the SASS system has been applied successfully in rivers, its application in wetlands is not practical, the reason being that wetlands are very specific, for example not all wetlands are dominated by surface water, some have interstitial or subsurface water only, while others are seasonal. Jones (2002) found that invertebrate macrofauna are limited in the Western Cape wetlands; hence an alternative assessment system for wetland areas using assemblages other than invertebrates needs to be sought.

Studies have shown that nutrients and water levels are some of the major factors determining the distribution of aquatic macrophytes, and that floristic composition depends on wetland alkalinity and conductivity variation. This finding serves as a strong basis for the argument that wetland plant communities can serve as good indicators of the wetland condition particularly in the identification of dissolved solids and nutrients associated with individual communities. An added advantage in using macrophytes as indicators of wetland condition is that they are easily observable and any changes in community composition or in abundance of individual species would suggest when, how and why an ecosystem might be experiencing changes (Ali *et al*. 1999).

The aim of this chapter is to investigate the relationship between wetland plant communities and water quality in a natural wetland system while a further aim is to define an hierarchy of factors that may, in turn, determine the distribution of wetland plant communities. The study addresses the following questions:

- Are there significant differences in near-surface water chemistry variables in areas occupied by different plant communities?
- What is the influence of near-surface water chemistry on wetland plant community distribution and composition?

- Can wetland plant communities be considered as effective and practical indicator assemblages of near-surface water condition in the Middelvlei Wetland System?

4.2 Methods

4.2.1 Water sampling and analysis

Water samples were collected from 39 wells (sites) in seven wetland plant communities identified and described in Chapter 2. Samples were collected on a monthly basis for eleven months during summer, spring, winter and autumn in the period between July 2002 and June 2003.

The water samples were analysed for the following parameters:

- System variables (physical parameters) – pH, temperature, redox potential, and dissolved oxygen.
- nutrients - nitrates and phosphates and
- inorganic constituents - calcium, magnesium, sodium and potassium.

The choice of the water chemistry parameters was based on the potential chemicals used as agricultural fertilizers in the farms around the study area. They are therefore not totally based on their importance in determining the water quality of the wetland or aquatic ecosystems. A further limitation on the chemical parameter tested in this study was as a result of a constrained budget available for water analysis, as a result anions though important were not considered in this study.

4.2.1.1 Field analysis

Temperature, pH, redox potential and dissolved oxygen were determined *in situ.* A Wissenschaftlich Technische Werkstatten (WTW) pH/mV 330 meter was used to measure the pH, temperature and water redox potential, while dissolved oxygen was measured using a Dissolved Oxygen meter kit (WTW Oxi meter 330).

4.2.1.2 Laboratory analysis

Water samples were collected on a monthly basis from 39 sites (Figure 2.2), between July 2002 and June 2003, the water samples were stored in new 250 ml plastic bottles. The bottles were rinsed with the water drawn from each sample site prior to filling them with water drawn from each well. Filled bottles were stored on ice in cool boxes (4-5 hours) before being transported back to the laboratory where they were stored in a dark cold room at 4 ^{o}C prior to analysis.

The water was prepared for analysis by filtering it through Whatman No.42 filter paper to remove particulate matter. Analysis for phosphate (orthophosphate or active phosphates) and nitrates was conducted within 48 hours after collection as per the Australian guidelines (Water Watch Victoria 2000).

Phosphorous was tested using a Hanna Phosphate Ionic Specific Meter (ISM) kit, Model, HI 93717 accurate to ±0.5 mg/l at 12.0 mg/l. Nitrates were tested using a Hanna Nitrate ISM kit, Model HI 93728, accurate to ±0.5 mg/l ± 10% of reading. The samples were tested for nitrate-nitrogen in mg/l and then converted to nitrate (NO_3^-) in mg/l by multiplying by a factor of 4.43 as instructed in the instrument manual.

The cations sodium, calcium, potassium and magnesium were analysed using the atomic absorption flame spectrometer (AA Spectrometer) model AA 1275.

All the equipment and apparatus used were calibrated using the recommended standard solutions before commencement and during the analysis session when required. The Water Watch Victoria (2000) and the South African Bureau of Standards (SABS) ISO (1987) standard procedures were applied to all water analyses.

No sampling was undertaken during September 2002, and tests for the nutrients during the autumn were not included in the analysis due to a technical problem with the testing equipment.

4.2.2 Data Analysis

Both parametric and non-parametric statistical models were applied in the analysis of water quality constituents from each plant community.

Multivariate analysis (ANOVA) (Zar 1999, Elzinga *et al*. 2001) was run with Kruskal-Wallace correlation coefficients at 0.95 confidence intervals (using Bonferonni adjustments) and was used to test for any significant differences between the plant communities and the following environmental variables: calcium, sodium, potassium, magnesium, redox potential, dissolved oxygen and pH.

Nonparametric tests were performed to test for significant differences between the plant communities and ortho-phosphates (active phosphate) and nitrates since these data were not normally distributed.

All the above cations and nutrients were subjected to Classification and Regression Tree (CART) analysis (Breiman *et al*. 1984, Steinberg *et al*. 1995, Steinberg & Colla 1997). This is a non-parametric test used to analyse and predict continuous dependent variables in a regression tree, by partitioning the data into relatively homogeneous (low standard deviation) terminal nodes taking the mean value observed in each node as its predicted value and giving the goodness of fit.

The CART application grouped the plant communities into homogeneous groups in relation to the environmental variables and the seasonal (summer, spring, winter and autumn) effects. A further test was performed on ortho-phosphates and nitrates in relation to rainfall to determine whether the amount of rainfall for the previous months and the month of sampling had any implication on their concentration within the plant communities to assist in the possible prediction of their sources.

4.2.3 Terminology

In this chapter we refer to plant communities to designify the area the communities occupy. The plant communities initials as follows: PC = *Populus canescens* Forest; JE = *Juncus effusus* Sedgeland; CL = *Cyperus longus* Sedgeland; CS = *Cliffortia strobilifera* Shrubland; PM = *Pennisetum macrourum* Grassland; TC = *Typha capensis* Reedswamp and CT = *Cyperus textilis* Sedgeland (refer to Chapter 2 for community descriptions), while the seasons are categorised as follows: autumn = March – May; winter = June – August; spring = September – November and summer = December – February.

4.3 Results

4.3.1 General introduction

Water quality data were collected from 39 wetland plots in the wetland system. The wetland sites were grouped into plant communities as described in Chapter 2. Data for the wetland plots were collected over an 11 month-sampling period. The data collected are presented in four seasons (autumn, summer, winter and spring), no autumn data were available for nitrates and phosphates due to unavoidable technical reasons. It is worth noting that although the data are presented in seasons, the values are all the results of a one-off seasonal sampling effort as no seasons were repeated. The samples may however reflect short-term changes in a particular variable or, alternatively, they may totally fail to detect episodic variability.

Low sample replication per community is also an important factor to consider in the interpretation of this data, some changes or analytical errors within the plant community chemical constituents may remain undetected. The low replication of samples to a larger extent was due to time and analysis cost constraints.

4.3.1 Physical and chemical data

Analysis of variance (ANOVA) results indicate that there is a significant difference between communities in respect of pH levels, redox potential, potassium, magnesium, sodium and calcium concentrations, whereas nutrients (nitrates and phosphates) and dissolved oxygen do not differ significantly between plant communities, but differ in water samples taken from sites where each plant community is taken. Classification and Regression Tree (CART) (non-parametric) analysis and ANOVA with the data indicates strong seasonal variation between communities in both nutrients and dissolved oxygen.

The chemical and physical data collected from plant communities at different sites over the hydrological year (ANOVA analysis) indicates seasonal variation and grouping of the communities in respect of both physical and chemical constituents similarities with low standard deviations (CART analysis).

4.3.1.1 pH

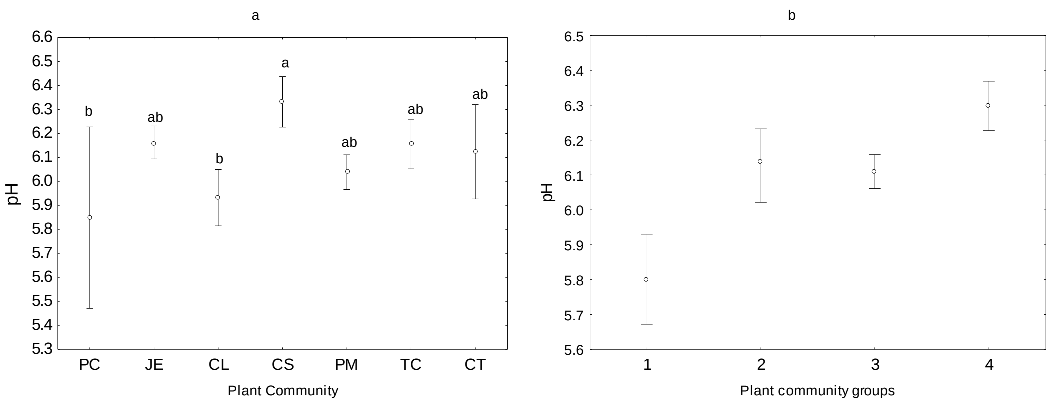

Figure 4.1 Plant community pH levels, a) Analysis of variance (ANOVA) for plant communities. Data are community-weighted means; Different lowercase letters above data bars indicate that the means are significantly different. P = 0.0014; F =3.7154. Plant community codes are: PC = *Populus canescens* Forest; JE = *Juncus effusus* Sedgeland; CL = *Cyperus longus* Sedgeland; CS = *Cliffortia strobilifera* Shrubland; PM = *Pennisetum macrourum* Grassland; TC = *Typha capensis* Reedswamp and CT = *Cyperus textilis* Sedgeland. b) Seasonal community pH analysis, data indicate bootstrap community groups pH means at 95% confidence intervals (CART). Numerals on the x-axis are community group categories and do not signify the community numbers.

ANOVA results indicated that at a 95% confidence interval, there is a significant difference in pH levels (p <0.0086) between the *Populus canescens* Forest, the *Cyperus longus* Sedgeland and the *Cliffortia strobilifera* Shrubland. No significant difference occurs between the *Juncus effusus* Sedgeland, *Pennisetum macrourum* Grassland, *Typha capensis* Reedswamp and *Cyperus textilis* Sedgeland communities, with p-values greater than 0.5. Greater differences in pH levels were displayed between the *Cliffortia strobilifera* Shrubland (p <0.0086) and the *Populus canescens* Forest, compared to the *Cyperus longus* Sedgeland (p <0.0248) (Figure 4.1a).

The results clearly indicate that the *Populus canescens* Forest, had slightly acidic pH values ranging from 5.9-5.65, while the *Cliffortia strobilifera* Shrubland had higher pH levels (6.2-6.3) leading to neutrality compared to other communities. Apart from the *Populus canescens* Forest and the *Cyperus longus* Sedgeland, which had slightly acidic conditions, all the other plant communities generally have rather neutral pH, ranging from 6.0 to 6.4.

Seasonal variations in pH levels occur between plant communities. Subjecting the data to CART analysis results in four groups (Figure 4.1b) namely: Group (1), consisting of the *Cyperus longus* Sedgeland, *Populus canescens* Forest, *Pennisetum macrourum* Grassland and *Typha capensis* Reedswamp, had a low pH (5.8) in autumn, while in the same season, Group (2), consisting of the *Cliffortia strobilifera* Shrubland, *Cyperus textilis* Sedgeland and *Juncus effusus* Sedgeland, was almost neutral (6.15). Groups (3 and 4) were grouped in respect of their similarity in pH in spring, summer and winter. Group (3), consisting of the *Populus canescens* Forest, *Cyperus longus* Sedgeland, *Cyperus textilis* Sedgeland, *Juncus effusus* Sedgeland and *Pennisetum macrourum* Grassland, displayed a slight decrease in pH from that of Group (2), while the *Cyperus longus* Sedgeland, *Populus canescens* Forest and *Pennisetum macrourum* Grassland had an increase in pH in these seasons from the low pH levels experienced in autumn. Group (4), consisting of the *Cliffortia strobilifera* Shrubland and *Typha capensis* Reedswamp, had the highest average pH (6.3) in summer, spring and winter.

From the above results it can generally be concluded that the near surface water in the *Typha capensis* Reedswamp and the *Cliffortia strobilifera* Shrubland is more acid than in the other communities. A general trend of low pH levels were recorded in autumn for all the other communities apart from the *Juncus effusus* Sedgeland and the *Cyperus textilis* Sedgeland, which had fairly constant pH levels irrespective of the season.

4.3.1.2 Redox potential

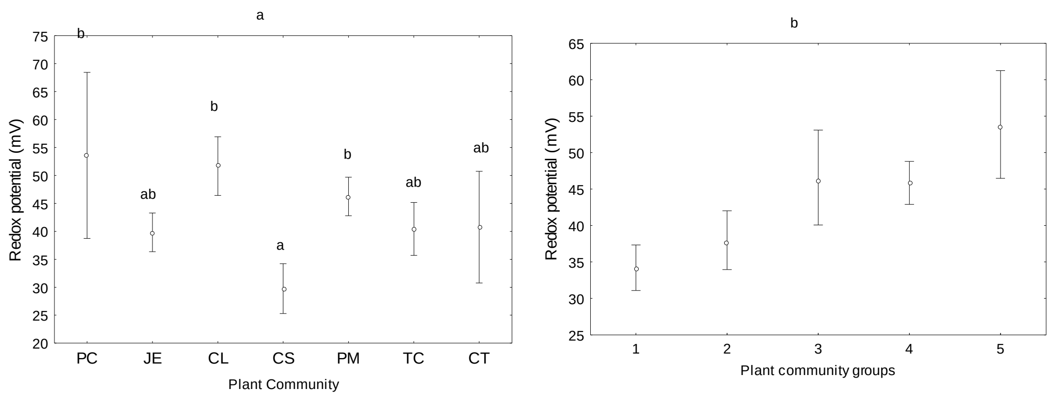

Figure 4.2 Plant community redox potential levels, a) Analysis of variance (ANOVA) for plant communities. Data are community-weighted means; Different lowercase letters above data bars indicate that the means are significantly different. P = 0.0002; F =4.5437. Plant community codes are: PC = *Populus canescens* Forest; JE = *Juncus effusus* Sedgeland; CL = *Cyperus longus* Sedgeland; CS = *Cliffortia strobilifera* Shrubland; PM = *Pennisetum macrourum* Grassland; TC = *Typha capensis* Reedswamp and CT = *Cyperus textilis* Sedgeland. b) Analysis of the seasonal redox potential per community with bootstrap community groups redox potential means at 95% confidence intervals (CART). Numerals on the x-axis are community group categories and do not indicate community numbers

There is a significant difference ($p<0.002$) in redox potential between the group consisting of the *Populus canescens* Forest, *Cyperus longus* Sedgeland and *Pennisetum macrourum* Grassland and the *Cliffortia strobilifera* Shrubland. No significant difference occurred between other communities (Figure 4.2a).

Seasonal grouping of the redox potential levels of plant communities using CART analysis (Figure 4.2b) realized five groups. Group (1), consisting of the *Cliffortia strobilifera* Shrubland, *Cyperus textilis* Sedgeland, *Juncus effusus* Sedgeland and *Typha capensis* Reedswamp, included water samples with low redox potentials (31-37 mV) in winter and spring compared to the other communities. Group (2), composed of the *Cliffortia strobilifera* Shrubland and *Juncus effusus* Sedgeland, had slightly higher redox potentials (34-42 mV) in autumn and spring than that of Group (1) above. Group (3), consisting of the *Cyperus textilis* Sedgeland and *Typha capensis* Reedswamp, had a higher redox potential (40-54 mV) than Group (2) in autumn although Group 4, composed of the *Cyperus longus* Sedgeland, *Populus canescens* Forest and *Pennisetum macrourum* Grassland, displayed a similar trend in spring, summer and winter, although Group (4) had a smaller range (43-49 mV). Group (5), consisting of the *Cyperus longus* Sedgeland, *Populus canescens* Forest and *Pennisetum macrourum* Grassland, had the highest redox potential (47-62 mV) occurring in autumn. The pattern of redox potential demonstrates a similar pattern to that of plant community pH levels. The conductance increased as the samples tended to become alkaline. It is noted that all plant communities generally had a high redox potential in autumn compared to other seasons.

4.3.2 Chemical constituents (anions)

Results indicate that anions had a similar trend to that of the physical parameters. Significant differences are realized between plant communities, this is an indication that the plant communities differed in response to the chemical parameter concentrations. Seasonal variations and fluctuations in the chemical parameter concentrations between communities and within communities are also found to occur within the wetland system (Table 4.1).

4.3.2.1 Potassium

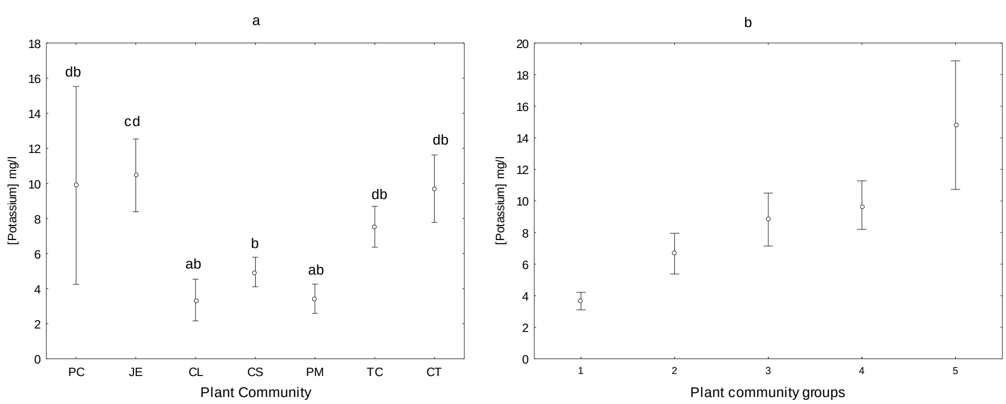

Figure 4.3 Plant community potassium levels, a) Analysis of variance (ANOVA) for plant communities. Data are community-weighted means; Different lowercase letters above data bars indicate that the means are significantly different. P = 0.0000; F = 13.648. Plant community codes are: PC = *Populus canescens* Forest; JE = *Juncus effusus* Sedgeland; CL = *Cyperus longus* Sedgeland; CS = *Cliffortia strobilifera* Shrubland; PM = *Pennisetum macrourum* Grassland; TC = *Typha capensis* Reedswamp and CT = *Cyperus textilis* Sedgeland. b) Seasonal community potassium analysis, data indicate bootstrap community groups potassium means at 95% confidence intervals (CART). Numerals on the x-axis are community group categories and do not signify the community numbers.

Significant differences occur between various plant communities (Figure 4.3a), the most remarkable being between the *Cliffortia strobilifera* Shrubland and the *Juncus effusus* Sedgeland ($p < 0.0000$).

The highest potassium concentration (10.5 mg/l) was encountered in the *Juncus effusus* Sedgeland (Figure 4.3a), which was closely followed by the *Populus canescens* Forest and the *Cyperus textilis* Sedgeland, which generally had a high potassium concentration (~10.0 mg/l) during the hydrological year. The *Typha capensis* Reedswamp had an intermediate concentration in comparison to other communities, and the *Cyperus longus* Sedgeland, *Cliffortia strobilifera* Shrubland and *Pennisetum macrourum* Grassland had the lowest concentrations of all the communities (Figure 4.3a).

Five distinct groups were identified on the basis of seasonal variation in potassium concentrations between communities. Group (1), consisting of the *Cyperus longus* Sedgeland, *Cliffortia strobilifera* Shrubland and *Pennisetum macrourum* Grassland, had low potassium concentrations all the year round irrespective of season. Group (2), composed of a single community, the *Typha capensis* Reedswamp, had a higher potassium concentration than Group (1) during summer, spring and winter. Group (3), consisting of the *Cyperus textilis* Sedgeland, *Juncus effusus* Sedgeland and *Populus canescens* Forest, had higher potassium concentrations than Group (2) in the same seasons. Despite Group (4), composed of the *Cyperus textilis* Sedgeland and *Typha capensis* Reedswamp, in autumn, having higher potassium concentration than Group (3) during summer, spring and winter, Group (5), consisting of the *Juncus effusus* Sedgeland and *Populus canescens* Forest, had the highest potassium concentration in autumn (Figure 4.3b).

The results generally show that the *Cyperus longus* Sedgeland, *Cliffortia strobilifera* Shrubland and *Pennisetum macrourum* Grassland are associated with low potassium concentrations throughout the year, while in autumn the *Populus canescens* Forest, *Juncus effusus* Sedgeland and *Cyperus textilis* Sedgeland recorded the high potassium concentration (Table 4.1).

4.3.2.2 Sodium

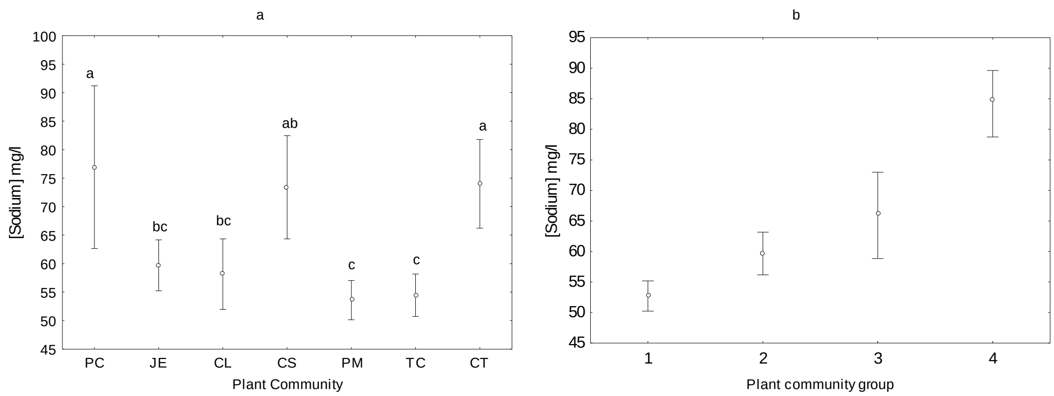

Figure 4.4 Plant community sodium levels, a) Analysis of variance (ANOVA) for plant communities. Data are community-weighted means; Different lowercase letters above data bars indicate that the means are significantly different. P = 0.0000; F = 10.568. Plant community codes are: PC = *Populus canescens* Forest; JE = *Juncus effusus* Sedgeland; CL = *Cyperus longus* Sedgeland; CS = *Cliffortia strobilifera* Shrubland; PM = *Pennisetum macrourum* Grassland; TC = *Typha capensis* Reedswamp and CT = *Cyperus textilis* Sedgeland. b) Seasonal community sodium analysis, data indicate bootstrap community groups sodium means at 95% confidence intervals (CART). Numerals on the x-axis are community group categories and do not signify the community numbers.

Significant differences occur between communities (Figure 4.4a), indicating that various communities responded differently towards sodium concentrations. The *Populus canescens* Forest and *Cyperus textilis* Sedgeland were significantly different from the *Pennisetum macrourum* Grassland, *Typha capensis* Reedswamp, *Juncus effusus* Sedgeland and *Cyperus longus* Sedgeland group (p< 0.00000), while the *Cliffortia strobilifera* Shrubland was significantly different from the *Pennisetum macrourum* Grassland and *Typha capensis* Reedswamp group (p< 0.005 and 0.0005) respectively (Figure 4.4a)

Among the communities studied during the hydrological year, the *Populus canescens* Forest has the highest sodium concentration (~77 mg/l), followed closely by the *Cyperus textilis* Sedgeland and *Cliffortia strobilifera* Shrubland, respectively. The *Pennisetum macrourum* Grassland and *Typha capensis* Reedswamp had the lowest concentration, with the *Juncus effusus* and *Cyperus longus* Sedgelands having concentrations slightly above the latter group (~54 mg/l).

Seasonal variation in sodium concentrations realized four group categories (Figure 4.4b). The spring and winter Group (1), consisting of the *Cyperus longus* Sedgeland, *Juncus* *effusus* Sedgeland, *Pennisetum macrourum* Grassland and *Typha capensis* Reedswamp, had low sodium concentration, the lowest among the plant communities. Group (2) consisted of the same community group; the groups had a slight increase in sodium concentration in summer and autumn. Group (3), consisting of the *Cliffortia strobilifera* Shrubland, *Cyperus textilis* Sedgeland and *Populus canescens* Forest, in the summer, spring and winter seasons, had higher sodium concentrations than Group (4) in summer and autumn. Group (5), consisting of the *Cliffortia strobilifera* Shrubland, *Cyperus textilis* Sedgeland and *Populus canescens* Forest, had the highest concentration recorded in the hydrological year occurring in autumn (Figure 4.4b).

These results indicate that the *Populus canescens* Forest, *Cliffortia strobilifera* Shrubland and *Cyperus textilis* Sedgeland are associated with high sodium concentrations in the four seasons of the year, while the *Cyperus longus* Sedgeland, *Juncus effusus* Sedgeland, *Pennisetum macrourum* Grassland and *Typha capensis* Reedswamp can be associated with low sodium concentration. There was a general increase in sodium concentration in all the communities during autumn.

4.3.2.3 Magnesium

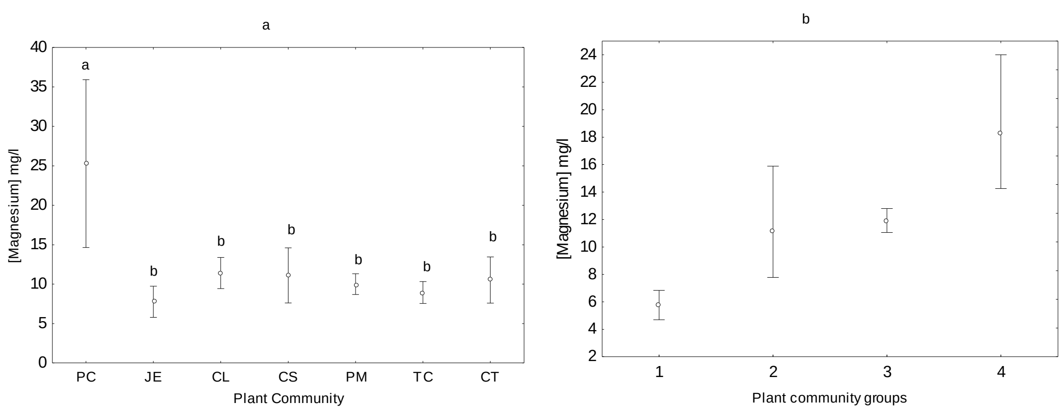

Figure 4.5 Plant community magnesium levels, a) Analysis of variance (ANOVA) for plant communities. Data are community-weighted means; Different lowercase letters above data bars indicate that the means are significantly different. P = 0.0000; F = 12.041. Plant community codes are: PC = *Populus canescens* Forest; JE = *Juncus effusus* Sedgeland; CL = *Cyperus longus* Sedgeland; CS = *Cliffortia strobilifera* Shrubland; PM = *Pennisetum macrourum* Grassland; TC = *Typha capensis* Reedswamp and CT = *Cyperus textilis* Sedgeland. b) Seasonal community magnesium analysis, data indicate bootstrap community groups magnesium means at 95% confidence intervals (CART). Numerals on the x-axis are community group categories and do not signify the community numbers.

A remarkable difference is displayed between the *Populus canescens* Forest and all the other communities. The *Populus canescens* Forest differed significantly, $p < 0.0000$, from all the other communities. It had a relatively high magnesium content with a mean of 25 mg/l (Figure 4.5a), all the other plant communities were not significantly different ($p<0.05$).

Seasonal variations between communities in magnesium concentration, realized through CART analysis, resulted in four groups (Figure 4.5b). Of these groups, two groups had similarities in Mg concentration in autumn and summer, while the other two had similarities in spring and winter. Group (1), comprising the *Juncus effusus* Sedgeland, *Pennisetum macrourum* Grassland and *Typha capensis* Reedswamp, had the lowest Mg concentration, occurring in autumn and summer, while group (2), consisting of the *Cyperus longus* Sedgeland, *Cyperus textilis* Sedgeland and *Populus canescens* Forest, had higher concentrations in the same seasons. Winter and spring had higher Mg concentrations than those experienced in summer and autumn. Group (3), composed of the *Juncus effusus* Sedgeland, *Pennisetum macrourum* Grassland and *Typha capensis* Reedswamp, had lower concentrations than Group (4), consisting of the *Cliffortia strobilifera* Shrubland, *Cyperus textilis* Sedgeland and *Populus canescens* Forest in winter and spring. This trend shows that the *Cyperus textilis* Sedgeland and *Populus canescens* Forest are seasonally associated with higher Mg concentration than the other communities, while the *Juncus effusus* Sedgeland, *Pennisetum macrourum* Grassland and *Typha capensis* Reedswamp are associated with low concentrations in each season.

All the plant communities had low magnesium concentrations in summer and autumn, the levels increased in winter and spring (Table 4.1). The increase in magnesium levels can be explained by the nutrient loading from the surrounding farms, after the rains.

4.3.2.4 Calcium

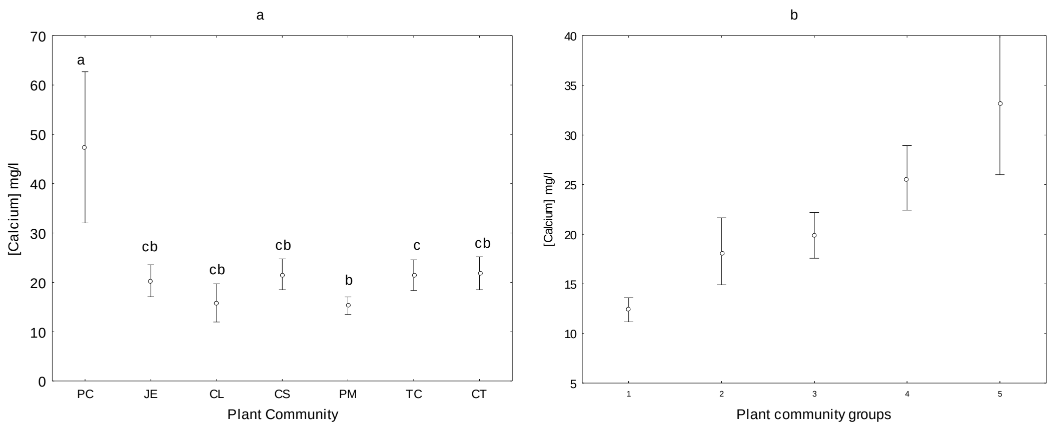

Figure 4.6 Plant community calcium levels, a) Analysis of variance (ANOVA) for plant communities. Data are community-weighted means; Different lowercase letters above data bars indicate that the means are significantly different. P = 0.0000; F = 17.576. Plant community codes are: PC = *Populus canescens* Forest; JE = *Juncus effusus* Sedgeland; CL = *Cyperus longus* Sedgeland; CS = *Cliffortia strobilifera* Shrubland; PM = *Pennisetum macrourum* Grassland; TC = *Typha capensis* Reedswamp and CT = *Cyperus textilis* Sedgeland. b) Seasonal community calcium analysis, data indicate bootstrap community groups calcium means at 95% confidence intervals (CART). Numerals on the x-axis are community group categories and do not signify the community numbers.

The ANOVA results indicate that the *Populus canescens* Forest, *Typha capensis* Reedswamp and *Pennisetum macrourum* Grassland communities have significant differences in calcium concentration from the other communities. The *Populus canescens* Forest has a p-value of 0.0000, showing a significant difference to all other plant communities. This community is associated with high calcium levels, while the *Typha capensis* Reedswamp and *Pennisetum macrourum* Grassland communities have a significant difference with a p-value of 0.002, these communities are associated with low calcium levels (Table 4.1).

The *Populus canescens* Forest has high calcium concentrations throughout the year irrespective of season while the *Cyperus textilis* Sedgeland, in contrast, has low calcium content in all seasons. All the other communities generally have high calcium levels in summer and autumn.

4.3.2.5 Seasonal plant community water quality levels

Seasonal variations in water quality occur in and between communities. It is rather difficult to generalize about the various water quality levels portrayed by different communities. A summary of the Middelvlei Wetland System plant community water quality is given in Table 4.1.

Table 4.1 Middelvlei Wetland System plant community water chemistry constituent levels. Seasonal cations levels, pH and redox potential levels for plant communities, * indicates the parameter level, the higher the number of *, the higher the level. AS = all seasons, A = autumn, W= winter, SP = spring.

Parameter	Season	PC	JE	CL	CS	PM	TC	CT	Min –Max Level
Calcium	AS	*****						*	***** 82.8 mg/l
	S	*****	*****	****	****	****	*****	*	* 5.7 mg/l
	A	*****	*****	****	****	****	*****	*	
	W	*****	*	*	***	*	***	*	
	SP	*****	*	*	***	*	***	*	
Dissolved Oxygen	S	***	***	**	**	**	**	***	***** 2.4 mg/l
	A	***	***	**	**	**	**	***	* 0.3 mg/l
	W	****	****	*****	*****	*****	****	****	
	SP	***	***	*	*	*	*	***	
Redox Potential	S		**		**		***	***	***** 97.5 mV
	A	*****	**	*****	**	*****	***	***	* 20.6 mV
	W	***	*	***	*	***	*	*	
	SP	***	*	***	*	***	*	*	
Potassium	AS			*	*	*			***** 27 mg/l
	S	***	***	*	*	*	**	***	*1 mg/l
	A	*****	*****	*	*	*	****	****	
	W	***	***	*	*	*	**	***	
	SP	***	***	*	*	*	**	***	
Magnesium	S	**	*	**	*	*	*	**	***** 46 mg/l
	A	**	*	**	*	*	*	**	* 2.3 mg/l
	W	*****	***	***	*****	***	***	*****	
	SP	*****	***	***	*****	***	***	*****	
Sodium	S	***	**	**	***	**	**	***	***** 98 mg/l
	A	*****	**	**	*****	**	**	*****	* 34 mg/l
	W	***	*	*	***	*	*	***	
	SP	***	*	*	***	*	*	***	
pH	S	***	***	***	*****	***	*****	***	*****6.5
	A	*	***	*	***	*	*	***	*4.5
	W	***	***	***	*****	***	*****	***	
	SP	***	***	***	*****	***	*****	***	

From the above results, there is a clear indication that some communities can be associated with particular levels of water quality; it may not be possible to peg a particular concentration to each community, but rather a general range can be given that can be associated with a particular community.

4.3.3 Nutrients (Phosphate and Nitrates)

Multivariate ANOVA analysis shows no significant difference in nutrient concentrations between plant communities. A comparison of the concentration of nutrients, ortho-phosphates and nitrates between plant communities and season are shown in Figures 4.7 and 4.9 respectively.

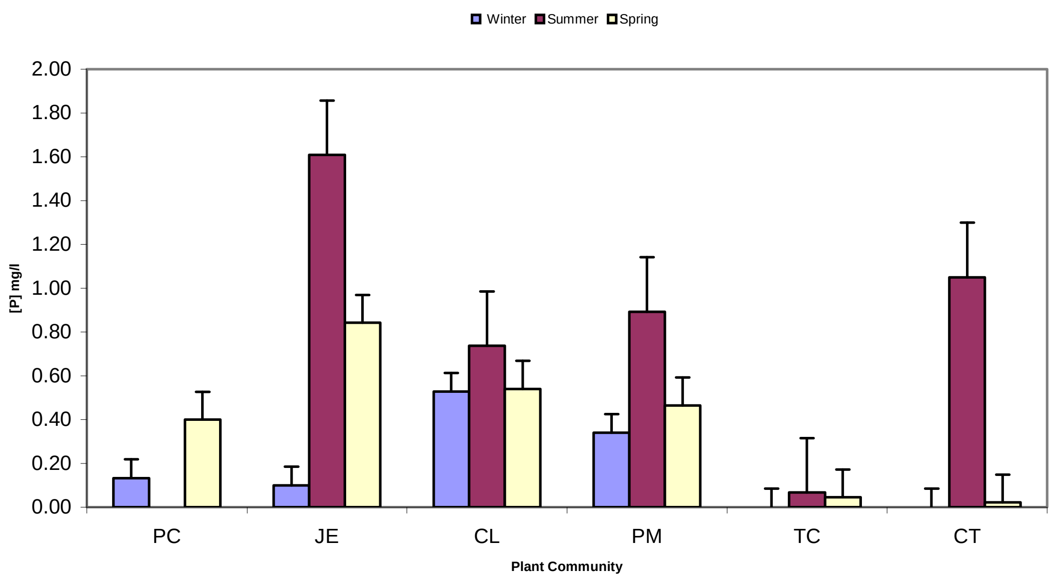

Figure 4.7 Mean seasonal ortho-phosphate concentrations (mg/l) for plant communities. Vertical bars are ± SE. PC = *Populus canescens* Forest; JE = *Juncus effusus* Sedgeland; CL = *Cyperus longus* Sedgeland; CS = *Cliffortia strobilifera* Shrubland; PM = *Pennisetum macrourum* Grassland; TC = *Typha capensis* Reedswamp and CT = *Cyperus textilis* Sedgeland, while the seasons are categorised as follows: autumn = March – May; winter = June – August; spring = September – November and summer = December – February.

The results indicate a clear seasonal disparity or differences in phosphate concentrations present in water samples collected from various plant communities despite showing no significant difference when ANOVA is applied. A plot of phosphate concentration versus seasons between plant communities gives distinct differences in concentration for each community (Figure 4.7). The phosphate concentration in each community varies between seasons, a general trend indicates that higher phosphate concentrations are experienced in summer in all the communities, followed by spring whereas winters have the lowest concentrations.

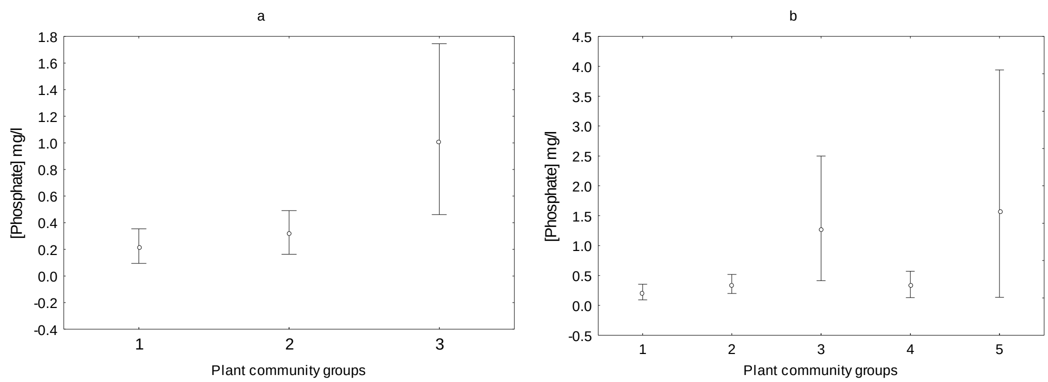

Figure 4.8 Seasonal community phosphate/rainfall analysis, a) at current monthly rainfall, b) at the previous month rainfall. Data indicate bootstrap community groups phosphate means at 95% confidence intervals (CART). Numerals on the x-axis are community group categories and do not signify the community numbers (see text).

Subjecting the phosphate data to CART analysis, two community groups were obtained in relation to their closeness in phosphate concentration levels with monthly rainfall levels (Figure 4.8a).

Group (1), consisting of communities *Cyperus longus* Sedgeland, *Cliffortia strobilifera* Shrubland, *Populus canescens* Forest and *Typha capensis* Reedswamp, have low phosphate concentrations (0.2mg/l) in all seasons irrespective of rainfall variation. Group (2), consisting of the *Cyperus textilis* Sedgeland, *Juncus effusus* Sedgeland and *Pennisetum macrourum* Grassland, has phosphate concentrations related to the amount of rainfall; hence variations are noted between seasons. At a monthly total rainfall below 29.7 mm, these communities have low phosphate levels (0.3mg/l), while the concentration increases to ~1.0 mg/l with the increase in total monthly rainfall above 29.7 mm.

A further investigation to determine whether the plant communities respond to rainfall time lag (previous month rainfall) in phosphate loading for various seasons and the previous monthly rainfall volumes using CART analysis yields five distinct groups (Figure 4.8b.).

Group (1) consists of the same communities as Group 1 above (*Cyperus longus* Sedgeland, *Cliffortia strobilifera* Shrubland, *Populus canescens* Forest and *Typha capensis* Reedswamp), this group has a low phosphate concentration <0.5 mg/l through all the year, irrespective of seasonal rainfall fluctuations.

Group 2 (*Cyperus textilis* Sedgeland, *Juncus effusus* Sedgeland, and *Pennisetum macrourum* Grassland) communities have their phosphate levels fluctuating with seasons. In summer and spring these communities have an average phosphate concentration of 0.5 mg/l. This concentration is independent of the rainfall amounts.

Group 3 (*Pennisetum macrourum* Grassland and *Cyperus textilis* Sedgeland) these communities have a high phosphate level (1.25 mg/l) correlated to a previous total monthly rainfall of < 77 mm, this phosphate level drops significantly with an increase in the previous months total rainfall of > 77.5 mm, to ~0.5 mg/l in autumn and winter. The *Juncus effusus* Sedgeland has the highest phosphate concentration of approximately 1.5 mg/l in autumn and winter, irrespective of the rainfall fluctuations.

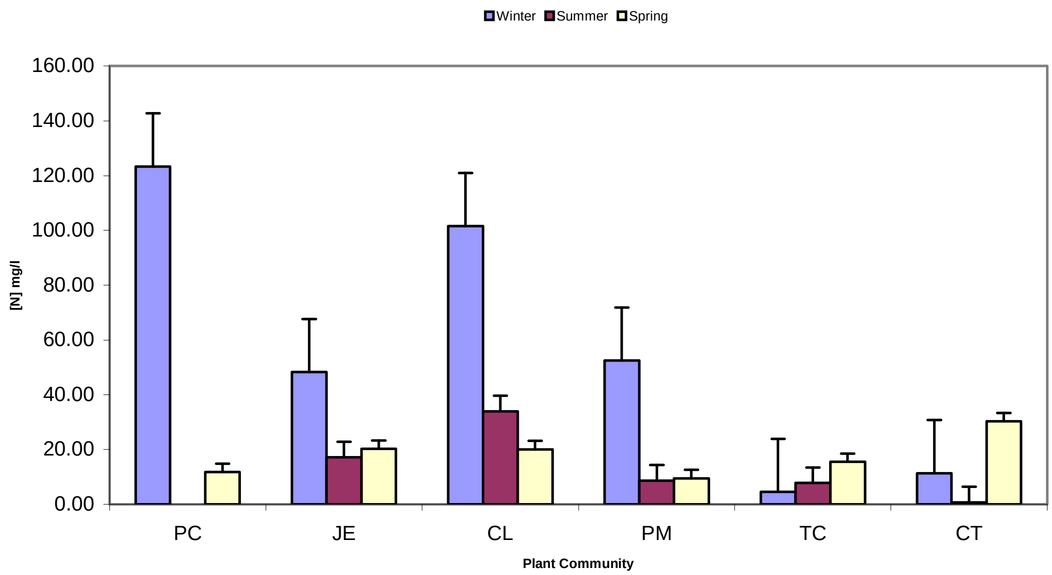

Figure 4.9 Mean seasonal nitrate concentrations (mg/l) for plant communities. Vertical bars are ± SE. PC = *Populus canescens* Forest; JE = *Juncus effusus* Sedgeland; CL = *Cyperus longus* Sedgeland; CS = *Cliffortia strobilifera* Shrubland; PM = *Pennisetum macrourum* Grassland; TC = *Typha capensis* Reedswamp and CT = *Cyperus textilis* Sedgeland, while the seasons are categorised as follows: autumn = March – May; winter = June – August; spring = September – November and summer = December – February.

Distinct nitrate level differences between communities are demonstrated in these results. The fluctuation occurs between seasons within and between the communities. The *Populus canescens* Forest, *Juncus effusus* Sedgeland, *Cyperus longus* Sedgeland and *Pennisetum macrourum* Grassland experience high nitrate levels in winter while the *Typha capensis* Reedswamp and the *Cyperus textilis* Sedgeland show high nitrate concentrations in spring. The results indicate that the *Typha capensis* Reedswamp and the *Cyperus textilis* Sedgeland can be associated with low nitrate levels; it may be worth noting that the *Typha capensis* Reedswamp has the lowest nitrate concentration in winter centrally to other plant communities. The results also indicate that summer and spring seasons have generally low nitrate concentrations in all the communities.

Comparing the phosphate and the nitrate concentrations (Figure 4.7 and 4.9), it is clearly noticeable that nitrates are generally high when the phosphates are low and *vice versa* for most communities.

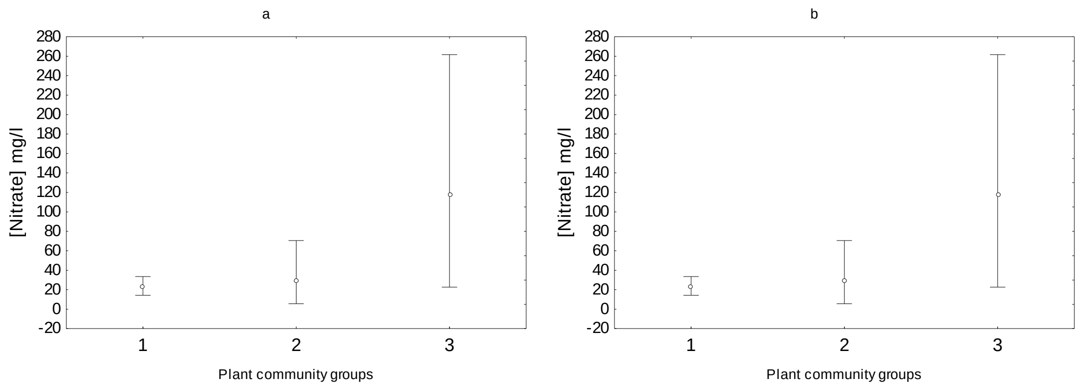

Figure 4.10 Seasonal community nitrate/rainfall analysis, a) at current monthly rainfall, b) at the previous months rainfall. Data indicate bootstrap community groups nitrate means at 95% confidence intervals (CART). Numerals on the x-axis are community group categories and do not signify the community numbers.

Subjecting the nitrate data to CART analysis gave a similar trend to that of phosphate. The plant communities nitrate concentrations both with and without a month time lag gave a similar trend, yielding three community groups (Figure 4.10).

Group (1) consists of communities (*Cliffortia strobilifera* Shrubland, *Cyperus textilis* Sedgeland, *Juncus effusus* Sedgeland, *Pennisetum macrourum* Grassland and *Typha capensis* Reedswamp) that were not affected by seasons or rainfall fluctuations, the nitrate levels for these communities remained low all the year round.

The other two groups responded to changes or fluctuations in rainfall. Group 2, consisting of the *Cyperus longus* Sedgeland and *Populus canescens* Forest, and a total monthly rainfall of <53.7 mm, has an average nitrate concentration of 40 mg/l, increasing with increasing rainfall to an average of 120 mg/l at a monthly rainfall > 53.7 mm. A rainfall time lag analysis did not reflect any differences in nitrate concentrations.

4.3.4 Water chemistry constituent in the Middelvlei Wetland System

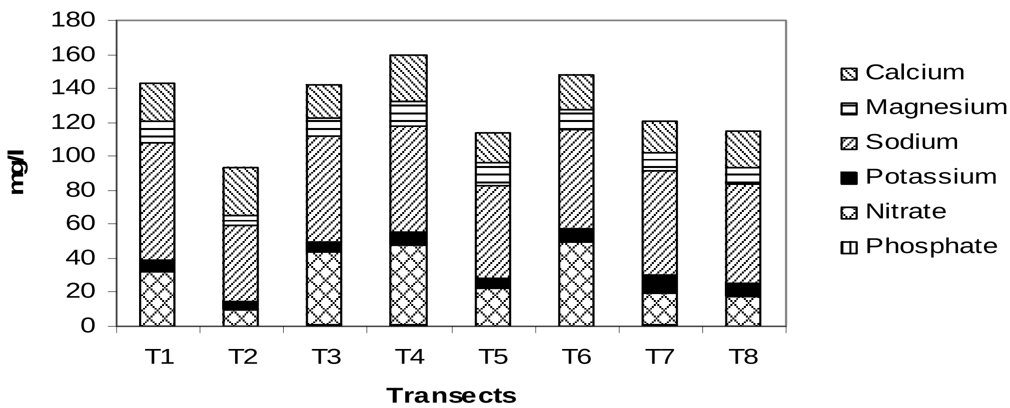

Figure 4.11 Water chemistry mean annual constituents levels along the Middelvlei Wetland System longitudinal gradient, from low to higher elevation, transect T1 to T8 respectively, the X – axis is not to scale.

The chemical characteristic of the near-surface water in the Middelvlei Wetland System are presented in Figure 4.11. Trends along the longitudinal wetland gradient show no specific pattern that can be strongly associated to wetland vegetation. The water chemistry constituents varied in each transect. Sodium remained high throughout the year, while phosphate was in minute levels. Transect 2, which is dominated by the *Typha capensis* Reedswamp, had low nitrate, sodium and magnesium and slightly higher calcium level than the other transects. Nitrate displayed the highest and most haphazard variation between transects, while sodium remained considerably high all along the wetland gradient. Phosphate levels remained low throughout the year. Transect 8 located near the Middelvlei Winery effluent inlet into the wetland had relatively low constituents levels compared to other transects below it.

The near-surface water quality varied both in seasonal and space along the wetland gradient (Figure 4.12). Low pH levels occur between Transects 3 and 7, the lowest pH levels occurring in autumn. Redox potential is inversely proportional to pH levels in all the seasons.

The high nitrate levels in the middle section of the wetland system, between transects 2 and 7 in winter, could be as a result of nitrate loading from the surrounding farms after rain. Potassium, sodium and calcium levels are generally also high after the first autumn rains.

Transect 2 had relatively low potassium, sodium and magnesium levels in all seasons, calcium has an inverse trend, remaining at high levels in all season. Low levels of near-surface water quality constituents, mainly; nitrate, phosphate, potassium, sodium and calcium are generally experienced in spring, apart from magnesium, which is high in this season.

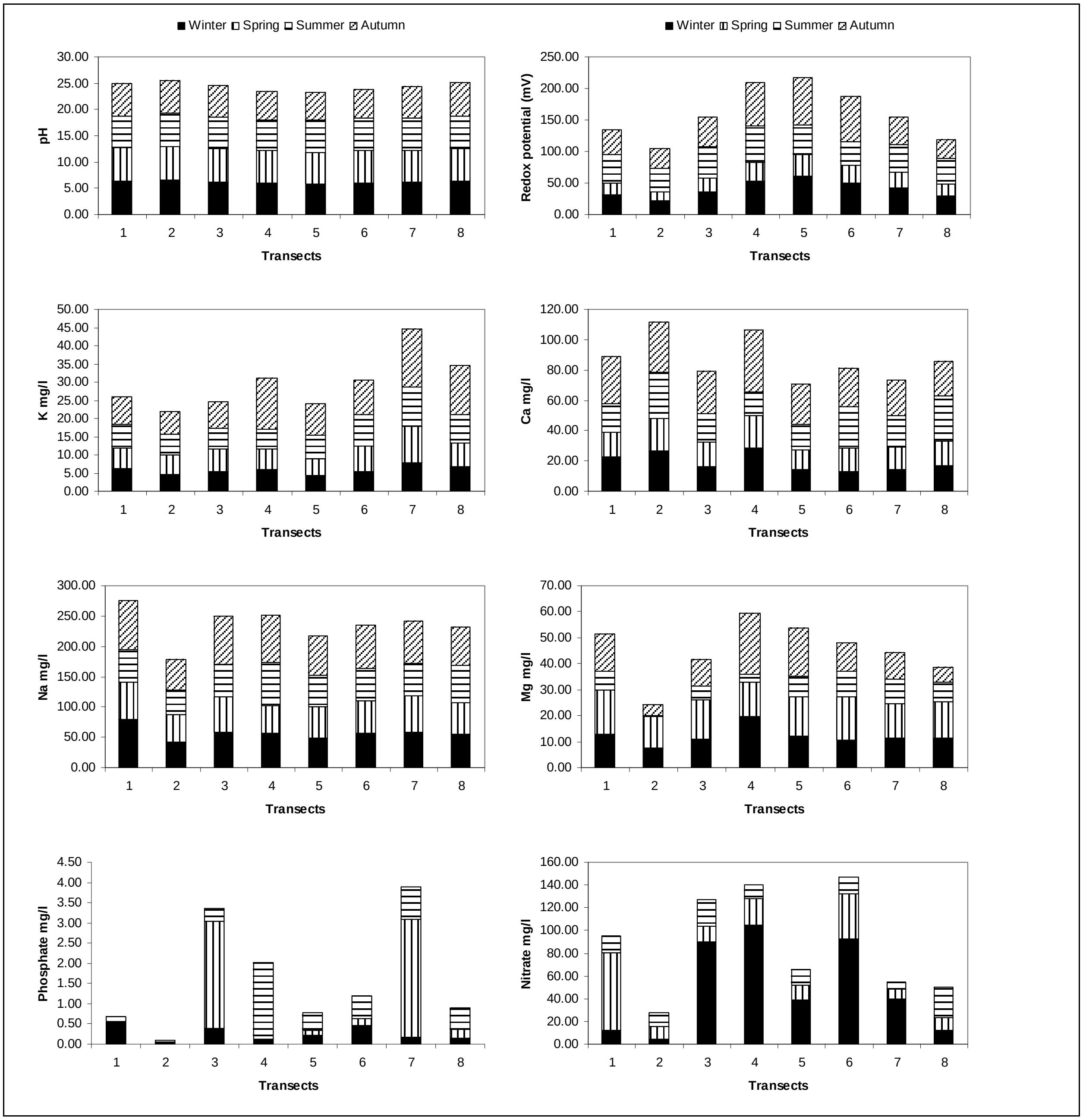

Figure 4.12 Middelvlei Wetland System longitudinal gradient seasonal variations in ground near-surface water chemistry parameters, the stacked column graphs represent the seasonal variation along the wetland longitudinal gradient for each transect, transect no.1 and 8 are located at the lower and higher elevated section of the wetland respectively. K = Potassium; Na = Sodium; Mg = Magnesium and Ca = Calcium.

4.4 Discussion

It is difficult to associate plant communities with particular environmental variables, as these variables change from time to time, moreover the plant communities may not have any visible indication of some short-term changes. However, this study shows that selected wetland communities can be associated with various levels of physical and chemical constituents. For example, the *Populus canescens* Forest is associated with high levels of sodium, calcium and magnesium, although it may not be practical to assign particular concentrations for each constituent to every individual plant community.

It is noted, however, that some constituents and physical factors can be reliably predicted in particular plant communities, where distinct differences occur. Some parameters show variation in every community, making it difficult to make any practical meaningful diagnosis for a particular constituent level.

4.4.1 Acidity and Alkalinity (pH)

South Africa's Target Water Quality Range (TWQR) of pH values for all the aquatic systems, demands that the pH value should not vary from the range of the background pH values for specific sites and time of day by > 0.5 of pH unit, or by 5 % (DWAF 1996).

Fresh waters in South Africa are well buffered with more or less neutral pH values ranging between 6 and 8. The pH of the water is determined by the relative proportions of the major ions in the water, which is largely determined by geological and atmospheric influences. If the waters drain catchments containing certain types of vegetation, the pH may drop as low as 3.9 due to the influence of organic acids (DWAF 1996). Jones (2002) found that pH and conductivity were the best explanatory variables in the classification in the Western Cape. This study supports these findings as various plant communities display distinct pH and redox potential signatures, hence a wetland characterized by a particular vegetation type or community can be diagnosed to have a particular range of pH or conductivity level.

4.4.2 Dissolved Oxygen (DO)

Dissolved oxygen in wetlands is found at very low levels (Mitsch & Gosselink 2000), tending towards zero. Despite the fact that there were no significant differences in dissolved oxygen levels between plant communities, the literature (Hammer & Bastian 1989), suggests that wetland plants have the ability to transport atmospheric gases (e.g. oxygen) down into the roots. It can therefore be predicted that different plants will have different abilities and capacities to transport and store oxygen, depending on the nature and density of their root systems. However, for this study, the conditions and the methodology applied would not give appropriate results as the data collections at various sites were undertaken at different times of the day. Oxygen levels fluctuate depending on the time of the day that the data collection is taken at each particular site. However, seasonal characterization gave distinct dissolved oxygen level groupings for each plant community.

4.4.3 Magnesium

Magnesium levels of the wetlands are higher in the winter and spring, which can partially be explained by high water influx caused by rainwater from the surrounding farms into the wetland. Hence, this suggests that wetlands act as a sink for farm fertilizers. Magnesium did not serve as a good indicator for any particular plant community in the wetland system.

4.4.4 Sodium

All plant communities displayed high sodium levels, well above that of other constituents. Contrary to magnesium levels, sodium levels decreased in the winter and spring seasons, indicating that the sodium source is not directly the result of rain, although a dilution effect as a result of rains could could be a contribution factor. This is further supported by the general consistent increase in sodium concentration in areas covered with most plant communities in the dry autumn period.

4.4.5 Potassium

Two potassium level groups are easily distinguished in this study, plant communities that have lower potassium concentrations in all seasons (*Cyperus longus* Sedgeland, *Cliffortia strobilifera* Shrubland and *Pennisetum macrourum* Grassland) and those that have higher potassium levels (*Populus canescens* Forest, *Juncus effusus* Sedgeland, *Typha capensis* Reedswamp and *Cyperus textilis* Sedgeland). These two community groups can easily be used to identify wetland areas that are characterized by high and low potassium levels. Caution should be taken before this finding is generalized as there is a need to determine the source of the potassium or if the particular communities with high potassium levels are located in areas of high fertilization, as potassium is common in fertilizers applied in gardens and on farms.

4.4.6 Calcium

Calcium content of water in the Middelvlei Wetland System shows distinctive differences between several plant communities, with high calcium levels occurring in the *Populus canescens* Forest and low levels of calcium in the *Cyperus textilis* Sedgeland, over all the seasons. These two communities serve as good indicators of high and low calcium levels respectively, however, variation in calcium concentrations are present in other communities during different seasons.

4.4.7 Nutrients

In many wetlands, net primary production (NPP) and decomposition are limited by availability of nutrients, primarily nitrogen and phosphorus (Aerts *et al*. 1992, Mitsch *et al*. 1979, Bridgham *et al*. 1996), although other constituents for example calcium and potassium may sometimes play a major role in limiting plant productivity. Many freshwater wetlands have been documented as being phosphorus limited (Bridgham *et al*. 1996, Craft 2001).

Seasonal patterns of uptake and release can partially explain the nutrient level trends witnessed in this study. In temperate climates, seasonal patterns of nutrient retention and release or differences in retention rates will persist especially where biological rather than chemical processes dominate (Mitsch & Gosselink 2000). Most of the phosphorus is stored in the soil as organic compounds or bound with aluminium, iron or calcium, which are not readily available to plants (Richardson 1985, Mitsch & Gosselink 1993, Qualls & Richardson 1995).

In seasons when the plants grow actively, high rates of nutrient uptake is expected, this rate is in turn anticipated to reduce in cold weather (winter) as a result of diminished microbial activity, slowing down the nutrient uptake process (Mitsch & Gosselink 2000). It can therefore be argued that high concentrations of nutrients in near surface water would be expected in winters as opposed to spring and summer when active growth is experienced. Contrary to this expectation high nutrient levels occurred in summer in the Middelvlei Wetland System, while the lowest levels were experienced in spring in all the plant communities investigated.

Among all the plant communities considered in this study, the *Typha capensis* Reedswamp, followed by the *Cyperus textilis* Sedgeland had low nutrient levels irrespective of the season. This explains the distribution of the *Typha capensis* Reedswamp in areas where there is presence of free surface water around the dams A similar finding by Withers *et al.* (2002) indicated that the distribution of *Typha capensis* Reedswamp is highly correlated to the presence of freshwater within the generally saline Rietvlei Wetland System, hence an increase in this community could indicate presence of freshwater within the Midlevlei Wetland System. The finding in this study, however, differs from Withers *et al*.'s (2002) findings in that the community's distribution is not related to increased eutrophication, as low nutrients levels were prominent in areas occupied by the community.

A comparison of the phosphate and nitrate concentration results indicates an inverse relationship. When there are high nitrogen levels in a community, low phosphates are experienced in the same community at that particular season. This observation triggers a need to investigate the plant community's seasonal phosphate: nitrate ratio in order to determine what seasons a plant community may be most efficient in extracting nitrates and phosphates.

4.4.8 General Middelvlei Wetland System near-surface groundwater quality

It is generally postulated that the water quality improves as it flows through a wetland, from the inlet to the outlet. Often the vegetation is associated with changes in water quality. However, this may apply to surface water, but may not be generalised to the near-surface groundwater as studies in natural wetlands receiving wastewaters have demonstrated that wetlands can be very effective in reducing suspended solids and nutrients concentrations in the short term, but some functions break down over the long term (Johnston 1989). Johnston (1989) further argues that although vegetation helps to slow the water down and filter out particles, mineral sediment deposition is mainly a physical settling process. This helps to reduce turbidity while a considerable amount of contaminants are adsorbed to particles and are effectively removed from the circulating water. This deposition can hence be considered to play a role in improving surface water quality.

The results from this study indicate that very little change in near-surface groundwater quality takes place along the wetlands longitudinal gradient. The anticipated low levels of water constituents in Transect 1 located close to the wetland outlet has a tendency of an increase trend in sodium, magnesium, potassium and nitrate levels. After the macrophytes lifespan, they fall to the surface, releasing much of their nutrient contents into the sediments through decomposition followed by subsequent leaching into the near-surface groundwater. Uptake of nutrients by vegetation may be considered to be a direct short-term, but not a long-term benefit for near-surface water quality. However, seasonal variations should not be ignored, especially in spring, when active vegetation growth phase is expected and there is high nutrient uptake by plants. During this period a temporal improvement in water quality occurs. Harvesting of the vegetation after this phase would be of much benefit to improving the near-surface water quality, as nutrients would be removed from the wetland system.

A further explanation for the long-term little changes in near-surface groundwater quality could be a result of the non-point pollution source, as the Middelvlei Wetland System is surrounded by farms and settlements, hence there is a high possibility of waste and pollutants gaining entry into the system from various points. This makes it difficult to detect any changes in water quality along the wetland longitudinal gradient *per se*. Further detailed study of each potential pollution entry point should take place to determine the affectivity of the wetlands in the reduction of nutrient levels.

The low water chemistry constituent levels in Transect 2 supports the conclusion drawn above that the *Typha capensis* Reedswamp can survive in low nutrient levels conditions, and is associated with relatively freshwater, compared to other plant communities examined in this study.

4.5 Conclusions

The wetland plant communities investigated in this study display a variety of environmental, physical and chemical conditions. All the communities are unique and differ from one another although certain similarities are also present. The plant community's water quality is not strictly restricted to a specific constituent or environmental variable, but is a product of a combination of variables. This therefore makes it difficult to fully and clearly separate the plant communities at particular water quality levels and preferably to group them according to particular degrees of dominance or concentrations of constituent variables.

The differences in nutrient, physical and chemical constituents in each plant community are a good indication that different plant communities play different roles in the wetlands function. It is virtually impossible, to separate each plant community on a single factor, rather, these communities can be identified by the presence or absence of a suite of constituent factors. This is also an important feature in diagnosing the wetland health or condition.

It may be deemed necessary, before concrete conclusions about the health of a wetland are made, to investigate whether the association between plant communities and different nutrient and chemical constituent levels are a direct result of plant communities functioning efficiency or inefficiency to extract nutrients and other constituents from the near-surface water system or whether the communities growth and development are favoured by these conditions.

If the first case above is found to be correct then the communities may be useful in extracting nutrients and other constituents from the wetland system, and if the second case is correct then these plant communities can serve as useful tools, in the assessment of wetland nutrient levels, in such a way that the presence or absence of some particular plant community could signify various nutrient and chemical levels in a particular wetland.

This information would be of value in the development of constructed wetlands, in making choices on the best-suited plants for a wetland depending on its intended purpose. The constituents intended to be extracted and the type of waste or effluent entering the constructed wetland should determine the plants to be used. Use of activity-based plants (plants fo a particular function) in constructed wetlands would be of importance in creating objective oriented, and high efficiency wetlands. Variation of constituents with seasons for plant communities would also be of importance in wetland management planning and decision making, e.g. what season suits the harvesting of a particular community depending on its function or time of maximal nutrient assimilation.

It is important, however, for management purposes, to protect and conserve the indigenous wetland plants communities, each community seems to play a different role in the system. Caution should be taken in regard to the introduction of exotic plants into a wetland system, as this would adversely interfere with wetlands natural functions among other adverse consequences.

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Chapter 5: Integration between plant communities and abiotic factors in the Middelvlei Wetland System, Stellenbosch, South Africa

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Abstract

Moisture gradients and inundation periods, determined by water table levels, are known to be primary determinants of vegetation patterns in wetlands. The relationship between wetland plant communities, wetland hydrology and water quality has not been investigated previously in detail in the Western Cape. This study is aimed at investigating the role played by wetland hydrology and water quality in determining wetland plant community distribution in the Middelvlei Wetland System, Stellenbosch, Western Cape.

Plant community differences along water level, pH, redox potential and nutrient gradients are examined and are found to play a key role in determining the community patterns. Soil textures in relation to nutrient levels also play a role in determining the distribution of plant communities. Poorly drained soils retain water long enough to accomplish pollutant removal.

Water level is found to play a major role in determining the levels of nutrients and chemical constituents in the wetland. Higher levels of nitrates and chemical constituents occur at low water levels (drier conditions lead to a low water table) while phosphates increase with a rise in water table. This is evidence of phosphate loading in the wetland.

The integration of all the environmental variables together does not indicate a simple relationship between a single factor and the distribution of a plant community, although the degree of wetness (water level and inundation period) is the most important environmental variable measured accounting for vegetation patterns within the Middelvlei Wetland System. The distribution of plant communities is therefore determined by many interacting environmental variables with complex relationships that are not easily detectable using direct gradient analysis.

Keywords: gradient; nutrients; plant communities; water level; water table; soils

5.1 Introduction

The classification of vegetation is a potentially useful tool for decision-making and other management purposes, for example, in the rapid assessment of wetlands. This is true only if the vegetation types are clearly discernible, causal factors are readily interpretable and the information can be extrapolated to give understandable, sensible and desirable representation of the environmental status of a particular system. There is therefore a need for predictive models of vegetation-environment relationships (McDonald 1995) such that the vegetation types can be viewed in association with easily measurable environmental factors, such as water table levels, nutrient levels or degree of salinity. Such models would guide environmental managers in making scientifically based decisions.

Much literature exists regarding the classification of the Cape fynbos vegetation based on the environmental influences using indirect gradient analysis such as Principal Component Analysis (PCA) and Detrended Correspondence Analysis (DCA) (Bond 1981, Campbell 1986). McDonald (1987) went a step further comparing indirect to direct gradient analysis using Canonical Correspondence Analysis (CCA) to quantify the relationship between fynbos communities of the southern Langeberg and the environmental variables that best explained these communities. These methods have demonstrated that a predictable structure in lowland vegetation, in relation to environmental factors, exists. However, few investigations have been undertaken to determine if such predictive models (direct analysis) are applicable to wetlands found within the Fynbos Biome.

This chapter aims to classify wetland vegetation found within the Middelvlei Wetland System, (located in the Fynbos Biome) in relation to a number of environmental variables using direct gradient analysis, with the following objectives:

- To determine whether the distribution of wetland plant communities is correlated to particular environmental variables and
- to determine the major environmental variables that are associated with a particular community for prediction of the wetland condition.

5.2 Methods

Vegetation, water chemistry elements and water levels were sampled for 38 plots in eight transects through the Middelvlei Wetland System. The plant communities identified in Chapter 2 were correlated with the physico-chemical variables mainly, water level (WL), pH, redox potential (RP), potassium (K), sodium (Na), magnesium (Mg), calcium (Ca) and nutrients consisting of phosphates (P) and nitrates (N) (Chapters 3 and 4).

Soil samples were collected from the 39 sites, to a depth of 1.0 m and analysed for soil texture by mechanical sieved using nested sieves (Black 1965). The soil texture analysis considered three horizons (A, B and C), and were grouped in the following five categories for each horizon: % Stones, % Course sand, % Medium sand, % Fine sand and % Clay and Silt.

Canonical Correspondence Analysis (CCA) was used to determine the direct relationship between vegetation data and environmental variables (Borcard *et al*. 1992; Jean & Bouchard 1993). Five data sets were subjected to CCA analysis, these were:

- plant communities and all environmental variables;
- plant communities and nutrients (phosphate & nitrates);
- plant communities, chemical constituents, clay and silt;
- plant communities, redox potential and water level, and finally,
- plant communities, water level and nutrients (phosphate & nitrates).

In the majority of cases, sodium, magnesium, potassium, calcium, nitrate, phosphate and water level variables were standardised through a log transformation, to make all variables equally important instead of concentrating on the variables with large figures. The results obtained were in turn used to determine or assess the importance of the environmental variables to the distribution of wetland communities (Ter Braak 1987; Brown *et al*. 1993).

5.3 Results

The plant community groups considered in the CCA analysis in this Chapter are represented by the following symbols:

○ *Pennisetum macrourum* Grassland (PM)

◇ *Typha capensis* Reedswamp (TC)

► *Cyperus longus* Sedgeland (CL)

● *Populus canescens* Forest (PC)

□ *Juncus effusus* Sedgeland (JE)

◆ *Cliffortia strobilifera* Shrubland (CS)

✳ *Cyperus textilis* Sedgeland (CT)

5.3.1 Ordination of plant communities and all environmental variables

The CCA analysis between the plant communities and all the environmental variables are presented in Figure 5.1.

The biplot for all the environmental variables gives no clear pattern or distinctions between plant communities. Detailed scrutiny of this biplot indicates that the *Juncus effusus* Sedgeland is positively related to a high water table (WL), while the *Populus canescens* Forest displays a strong negative correlation to a high water table, indicating that this forest is generally associated with a decline in the height of the water table.

The *Cliffortia strobilifera* Shrubland is associated with soils having medium sized sand particles in the A-Horizon, while the *Pennisetum macrourum* Grassland displays no correlation to any environmental variable.

The sandy soils correlate positively to low nitrate levels; thus low nitrates are associated with sandy soils, while high nitrates levels in the A - Horizons are associated with a high content of clay and silt in soil.

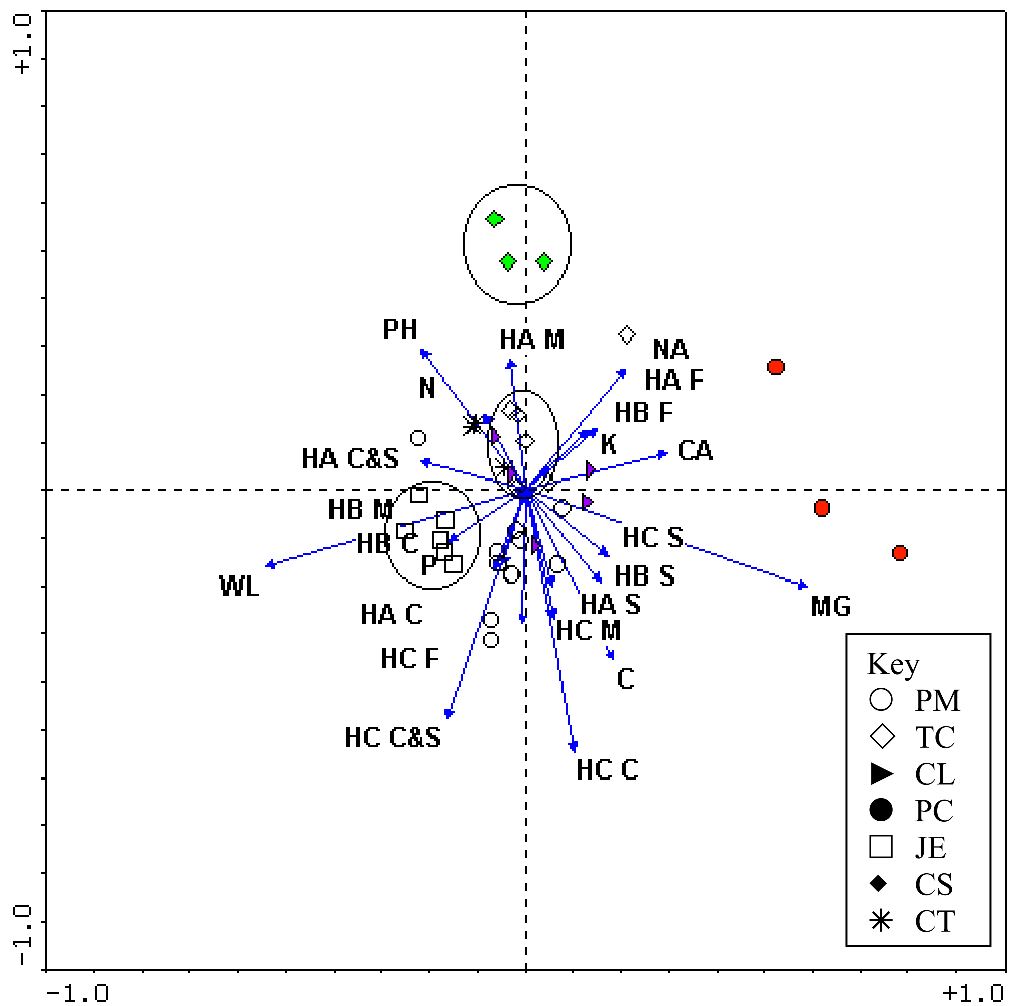

Figure 5.1 Canonical Correspondence Analysis CCA biplot for plant communities and the environmental variables including the soil texture for the three horizons; Horizon A = HA; B = HB and C = HC, grouped into categories; % stones = S, % coarse sand = C, % medium sand = M; % fine sand = F and % clay & silt = C & S. water level = WL; redox potential = RP; phosphate = P; nitrates = N; sodium = Na; magnesium = Mg; potassium = K; calcium = Ca. Plant communities are represented by different symbols; PC = *Populus canescens* Forest; JE = *Juncus effusus* Sedgeland; CL = *Cyperus longus* Sedgeland; CS = *Cliffortia strobilifera* Shrubland; PM = *Pennisetum macrourum* Grassland; TC = *Typha capensis* Reedswamp and CT = *Cyperus textilis* Sedgeland..

5.3.2 Nutrients (phosphate and nitrates) ordination

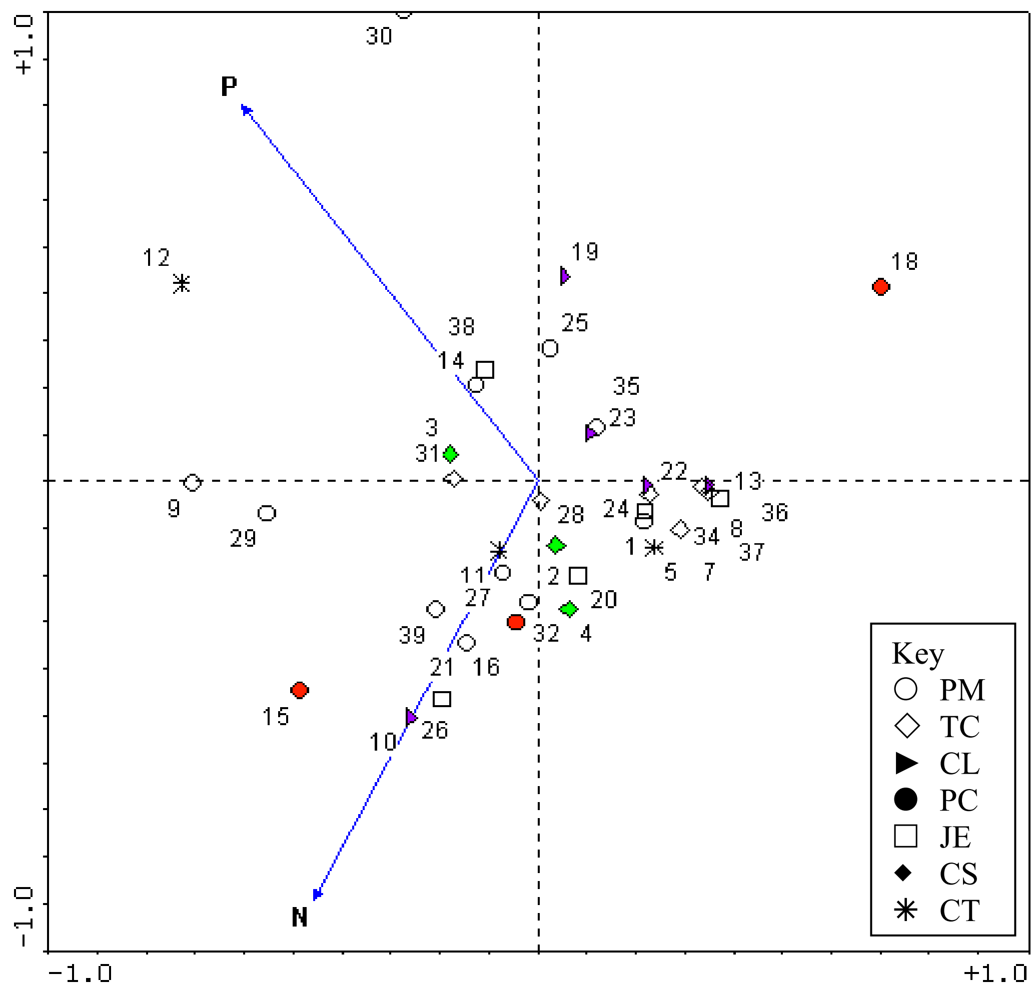

Figure 5.2 CCA biplot for plant communities and nutrients (phosphate and nitrates), phosphate = P; nitrates = N. Numbers refer to sample plots. PC = *Populus canescens* Forest; JE = *Juncus effusus* Sedgeland; CL = *Cyperus longus* Sedgeland; CS = *Cliffortia strobilifera* Shrubland; PM = *Pennisetum macrourum* Grassland; TC = *Typha capensis* Reedswamp and CT = *Cyperus textilis* Sedgeland.

A number of plant communities have predictable association with nutrients, though the biplot only contains the general nutrient data for the full year, without any seasonal considerations.

The biplot illustrated in Figure 5.2 indicates that the *Populus canescens* Forest seem to associate with low phosphate levels and high nitrate concentrations. The *Pennisetum macrourum* Grassland correlates positively with low phosphate for most plots, apart from plots 9 and 14, which are found located at the edges of the wetlands bordering on citrus and the olive orchards respectively. The *Cliffortia strobilifera* Shrubland correlates negatively with high phosphate levels and positively with high nitrate levels, while the *Typha capensis* Reedswamp has a strong negative relationship with both phosphate and nitrate levels. Other plant communities had no clear gradient correlation to nutrients.

5.3.3 Chemical constituents, redox potential, water level, nutrients clay and silt ordination

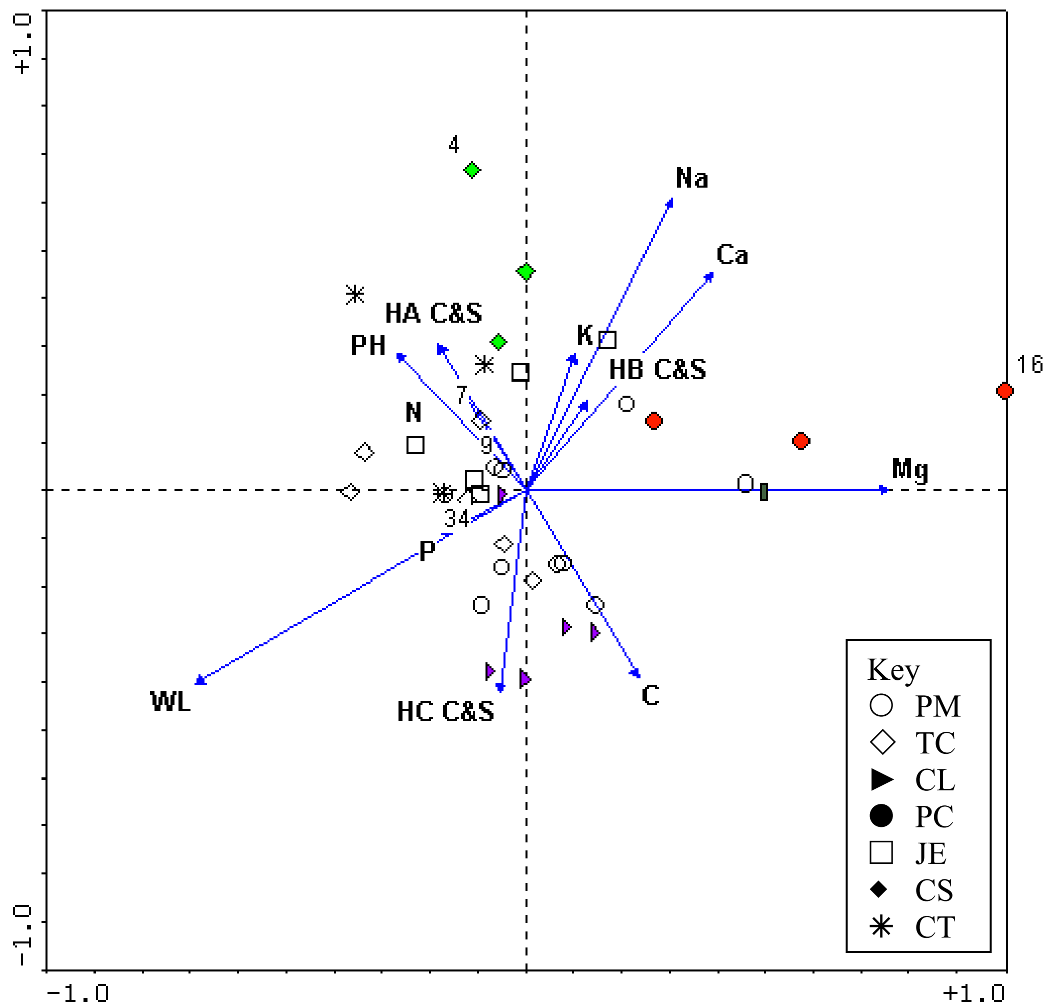

Figure 5.3 CCA biplot for plant communities, chemical constituents, water level, nutrients, clay and silt. Water level = WL; redox potential = RP; phosphate = P; nitrates =N; sodium = Na; magnesium = Mg; potassium = K; calcium = Ca; % clay and silt = C& S. PC = *Populus canescens* Forest; JE = *Juncus effusus* Sedgeland; CL = *Cyperus longus* Sedgeland; CS = *Cliffortia strobilifera* Shrubland; PM = *Pennisetum macrourum* Grassland; TC = *Typha capensis* Reedswamp and CT = *Cyperus textilis* Sedgeland.

There is no strong correlation between the environmental variables evaluated with the vegetation in this biplot; however the biplot does show a clear relationship between the environmental factors themselves. The results show that the chemical constituents (Ca, K and Na) increase with the lowering of the water table (low water level). The pH increases with the reduction of the redox potential. P concentration increases with an increase in clay and silt content in the C- Horizon in areas associated with a high water table.

5.3.4 Redox potential, pH and water level ordination

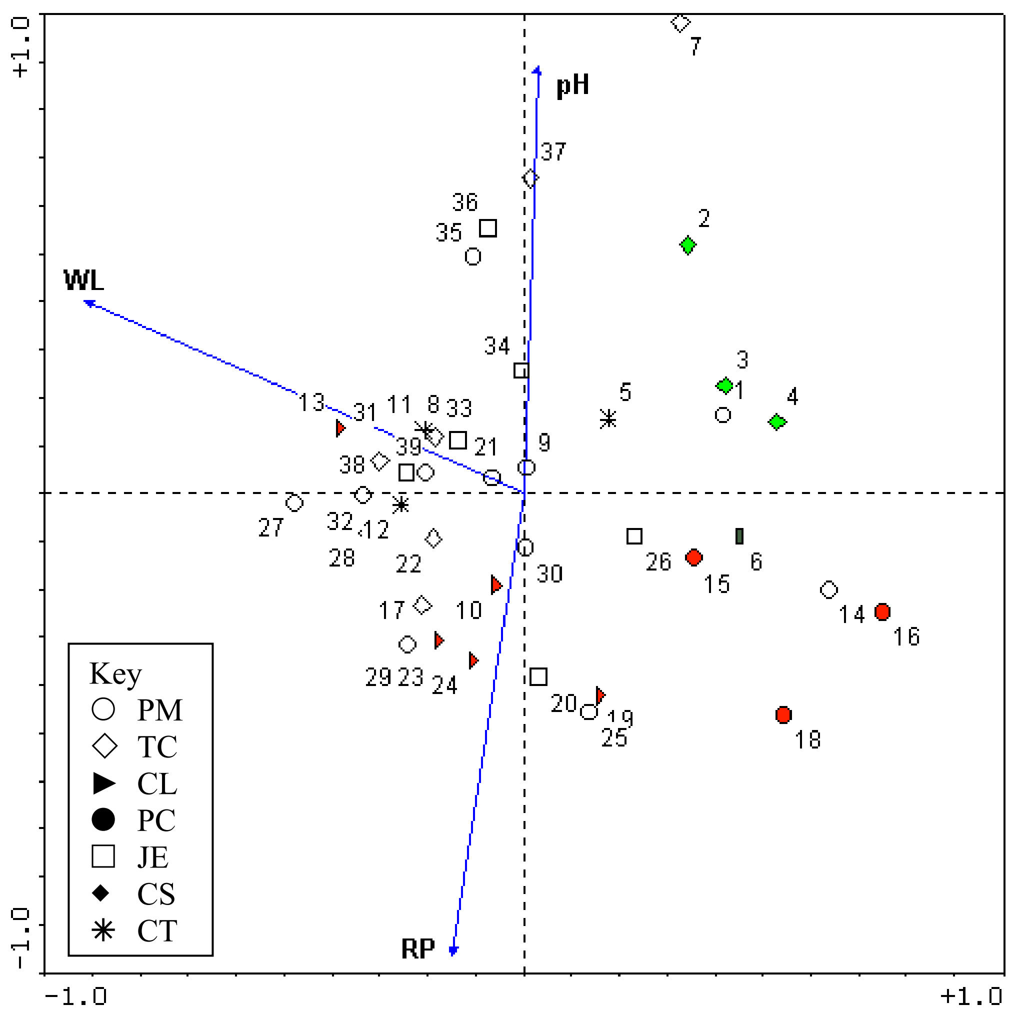

Figure 5.4 CCA biplot for plant communities, water level, pH and redox potential. Water level = WL; redox potential = RP. Numbers refer to sample plots. PC = *Populus canescens* Forest; JE = *Juncus effusus* Sedgeland; CL = *Cyperus longus* Sedgeland; CS = *Cliffortia strobilifera* Shrubland; PM = *Pennisetum macrourum* Grassland; TC = *Typha capensis* Reedswamp and CT = *Cyperus textilis* Sedgeland.

The results (Figure 5.4) indicate that, *Cyperus longus* Sedgeland is positively correlated with an increase in redox potential and low pH levels. The *Populus canescens* Forest is negatively correlated with an increase in pH levels and water table level, The *Typha capensis* Reedswamp correlates positively with water table rise (WL) while the *Cliffortia strobilifera* Shrubland is positively correlated with a rise in pH levels and a decrease in redox potential, the community is also positively related to a low water table.

From the biplot diagram it is noticeable that some sites had relatively high pH levels (34, 35, 36 & 37), these plots are located at the section of the wetland where the winery effluents enter the wetland system. An exception is Site 7 with a relatively high pH level compared to areas occupied by other communities. It is located at the lower side of the wetland, this occurrence is attributed to the presence of a horse stable located above this site.

5.3.5 Water level and nutrients ordination

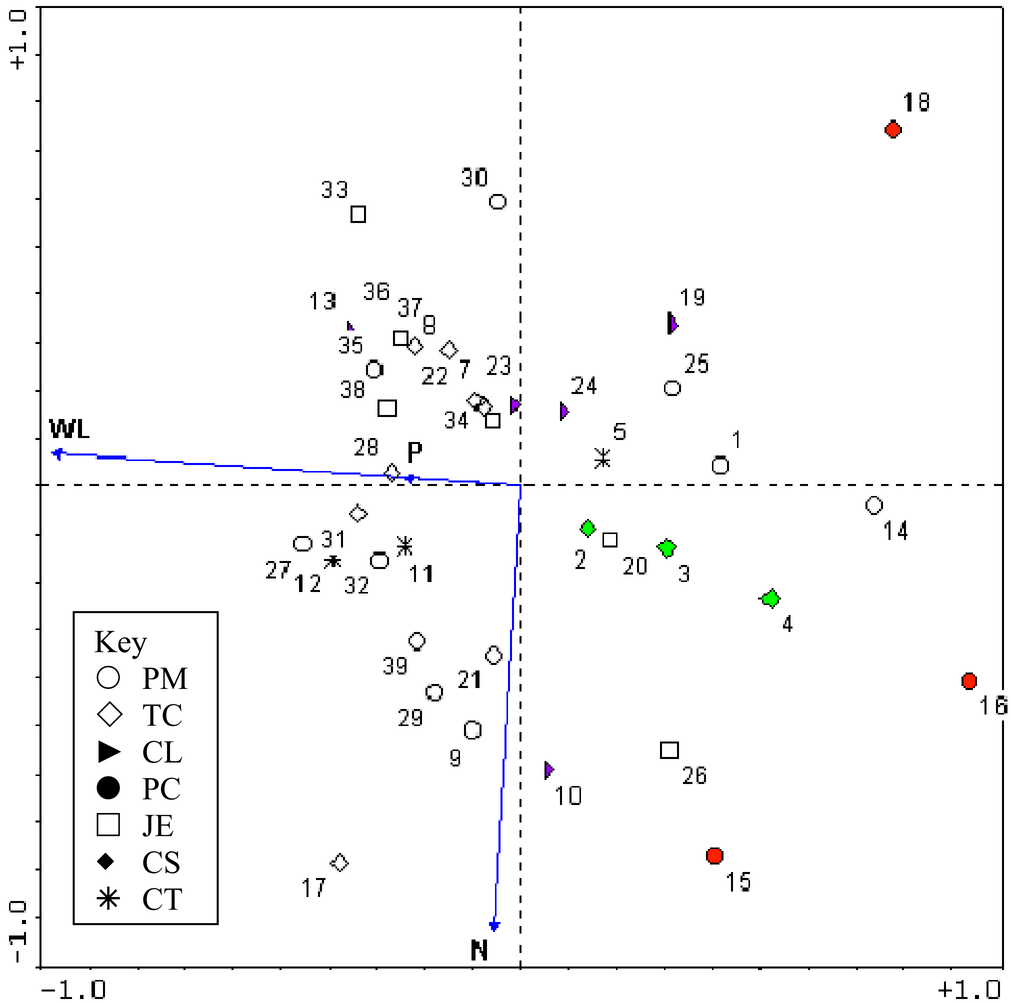

Figure 5.5 CCA biplot for plant communities, water level, nutrients (phosphates & nitrates). Water level = WL; phosphate = P; nitrates = N. Numbers refer to sample plots. PC = *Populus canescens* Forest; JE = *Juncus effusus* Sedgeland; CL = *Cyperus longus* Sedgeland; CS = *Cliffortia strobilifera* Shrubland; PM = *Pennisetum macrourum* Grassland; TC = *Typha capensis* Reedswamp and CT = *Cyperus textilis* Sedgeland.

The ordination biplot for water table and nutrients (Figure 5.5) indicates that only three communities (TC, PC & CS) are associated to the three environmental variables, mainly; the *Typha capensis* Reedswamp has a positive correlation with a rise in water table and phosphate increase, but is negatively correlated with an increase in nitrates. The *Cliffortia strobilifera* Shrubland is negatively correlated with an increase in phosphates and a rise in the water table while the *Populus canescens* Forest is negatively correlated with a rise in water table, and an increase in phosphate levels. The *Populus canescens* Forest shows no specific correlation with nitrates as some sample plots have high nitrate levels while others have low levels, giving no clear pattern for any prediction, although this was originally anticipated due to the nearby presence of farm cottages.

5.4 Discussion

At a plant community level the Canonical Correspondence Analysis (CCA) analysis did not yield clear environmental variable gradients. This can be attributed to small-scale sampling (Bond 1981) and to the low number of samples considered for each community. The results agree with McDonald's (1995) findings, in his study of the vegetation of the southern Langeberg, that a low number of samples do not give clearly distinct relationships between plant communities and the environmental variables. A larger number of samples would be necessary to minimize the arbitrary outliers. Considerably fewer environmental variables would be most appropriate if small numbers of samples are subjected to the CCA analysis.

Community differences are apparent in some plant communities along the water level, pH, redox potential and nutrient gradients, an indication that these environmental variables play a role in plant community distribution.

The degree of wetness (water level) is the most important environmental variable measured accounting for vegetation patterns within the Middelvlei Wetland System. This is in agreement with the findings of Davis *et al*. (1996), Runhaar *et al*. (1997) and Kotze (1999). In a study investigating the classification of general wetlands in the Western Cape, using environmental variables, Jones (2002) found that pH and conductivity were most important in wetland differentiation; the same factors in this study seem to have a major role in determining the wetland vegetation distribution and water quality status.

In this study, low nitrogen levels are associated with reduced sand content in the A-horizon. Desbonnet *et al*. (1994) found that that poorly drained soils are doubly efficient in removal of nitrogen than well-drained soils, and that sandy soils are least efficient in removing nitrogen due to their high porosity level. The efficiency of wetlands in nitrogen removal is associated with the long residence period of the water in the saturated soils (Cooper 1990). Poorly drained soils contain a high organic content that promotes the growth and maintenance of denitrifying bacteria leading to higher levels of nitrogen removal (Nicholas 1983; Groffman *et al*. 1991).

Calcium, potassium and sodium levels increase with an increase in fine sand content in the A- and B-horizons of the soils, while in coarse sand, Ca, K and Na levels are concurrently lower in the same horizons. Although the gradients observed in this analysis are not distinct, it appears as if the soil texture in each horizon plays some role in the removal and the concentration of various chemical constituents in wetland soils. *Typha capensis* Reedswamp distribution correlates positively to fine sand, while the *Cyperus textilis* Sedgeland distribution was not influenced by soil texture, this finding is with the same as that of Withers *et al*. (2000), although in the present study, the *Typha capensis* Reedswamp is negatively correlated with a high percentage of fine sand in the C-horizon.

Growth forms should not be ignored, when considering the findings of this study, as the woody-stemmed species generally have deeper and more developed root systems than the graminoids or herbs. Plants with root systems greater than 0.6 m deep may be effective in removal of pollutants from groundwater (Ehrenfeld 1987, Groffman *et al*. 1991). Woody vegetation in poorly drained areas has been associated with greater denitrification levels than woody vegetation found in well-drained areas. The woody vegetation creates a better lining and growth condition for denitrifying microbes (Groffman *et al.* 1992). Plants with shallow root systems are effective in removing pollutants in near-surface water in waterlogged areas where their roots are in direct contact with water (Desbonnet *et al*. 1994). It is therefore advisable that future studies using direct analysis in this type of wetland include the growth form and rooting depths where appropriate.

5.5 Conclusions

The relationship between vegetation and abiotic factors in the Middelvlei Wetland System poses interpretation difficulties due to the complexity of interactions found in the system. However, some patterns such as the water gradient are indicated in the analyses conducted here. The degree of wetness (water level) is the most important environmental variable measured accounting for vegetation patterns within the Middelvlei Wetland System. Secondary variables, such as, pH, redox potential and nutrient gradients, all vary between plant communities and probably play a role in their distribution. It appears as if soil texture in each horizon plays some role in the removal or in the concentration of various chemical constituents in the wetland soils. It is not appropriate to generalize these patterns at this stage, as the short-term changes in wetland vegetation could influence a number of interacting factors that may not have been addressed or detected in the short period during which this study was undertaken. There is a need for a longer period of observation and associated analysis before conclusive generalisations for Western Cape wetlands, at least, can be drawn.

This study gives a basic insight into the relationship between the vegetation and abiotic factors. A further in-depth investigation, over a longer period, is necessary to confirm, and to develop hypotheses about how and why these relationships occur. There is also a need to verify or evaluate the findings in other wetlands in the region, a further step in investigating the environmental requirement for the same communities found around dams and along rivers would enhance the understanding of the distribution and zonation of these plant communities.

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Chapter 6: Management Implications and recommendations from Study

6.1 Introduction

Many natural urban wetlands, the so-called "urban open areas" have been degraded or lost in the course of settlement, industrial and urban development; these wetlands could be regarded as most vulnerable, considering the high rate of urban development and expansion (Archibald & Batchelor 1992, Cilliers *et al*. 1998, Van Wyk *et al*. 2000).

The Middelvlei Wetland System is one of the few urban wetlands that have not been highly degraded. It is well evidenced (Cilliers *et al*.1998) that the urban wetlands are under pressure for urban development, farming and water abstraction for irrigation purposes.

The Middelvlei Wetland System serves as a recreational area for the neighbouring Onderpapegaaiberg Suburb, and for Horizon House, an institution for the mentally handicapped. The ecological importance of the Middelvlei Wetland System includes the provision of habitats for many waterfowl and other birds, wastewater treatment and also holds a rich biodiversity.

An effort to conserve and manage urban wetlands to ensure natural functioning and maintenance of biodiversity has been initiated in some municipalities in South Africa; a good example is the Durban Metropolitan Open Space System (D' MOSS). This programme considers wetlands as an important part of urban landscape (Roberts 1993; Cooper & Duthie 1992), as the wetlands harbour numerous indigenous plants. These landscapes are also considered to be important to man and wildlife (Cooper & Duthie 1992) and their integration into urban planning is ecologically crucial.

To enhance an effective wetland management, there is a need for phytosociological studies of the open areas, as presence or absence of some species in these biotopes may often serve as a bio-indication of disturbance or pollution in them (Starfinger & Sukopp 1994).

Vegetation can be a useful tool to assess the integrity of a wetland. Several aspects can be examined in a study of this nature. In the context of this study, environmental factors associated with plant communities have been described and discussed, in relation to the Middelvlei Wetland System at Stellenbosch. Although it was not possible to consider all factors in this study, the number of factors considered gave results that can be used to describe the condition and make recommendations about the management of the wetland.

6.2 Synthesis

6.2.1 Vegetation

Vegetation in the Middelvlei Wetland System generally consists of plant communities that are single species dominated, and are well delineated such that a change in community spatial distribution is easily noticeable. The plant communities have been exposed to effluent related to winery industry for over 10 years and hence these communities appear have stabilized under this condition. It can be assumed that the present affected communities are able to withstand the effluent.

The Middelvlei Wetland System has few plant communities, consisting of relatively few plant species. A paucity of species makes it easier to monitor community and species dynamism. Although plant communities are important in determining the wetland condition, the findings of this study indicate that plant communities alone, may not be adequate to interpret all the environmental conditions of the wetland. The environmental variables in wetlands interact in a complex way, such that it may not be practical to distinguish the traits for each variable in each particular community. A selection of a number of key variables would essentially be of great additional importance to the use of plant communities as indicators or as symptoms for selected environmental factors.

6.2.2 Hydrology

The distribution of each plant community in the Middelvlei Wetland System is highly dependent on specific different water level gradients, including particularly, depth to standing water and inundation periods. This is useful to predict water level changes in the event of any visible composition or spatial changes in wetland plant communities.

Extended periods of increase or decline of near-surface water would cause plant communities to change in composition and to shift or migrate, changing their location in the landscape, during which process a transitional zone would be created between the relevant communities. A change in water regime would significantly alter the type and distribution of the communities, causing a vegetation shift either towards dry or arid adapted vegetation, in the case of reduced water level such as through increased wetland drainage; or a shift towards aquatic vegetation in the case of an increase in water supply into the wetland.

Considering wetland vegetation hydro-dynamism, the exotic *Populus canescens* Forest trees appear to be actively invading the wetland by lowering the water table during their growing period through rapid transpiration rates. This allows displacement of other wetland species; it is well known that not many other species are able to grow under a dense *Populus canescens* canopy (Cilliers *et al.* 1998).

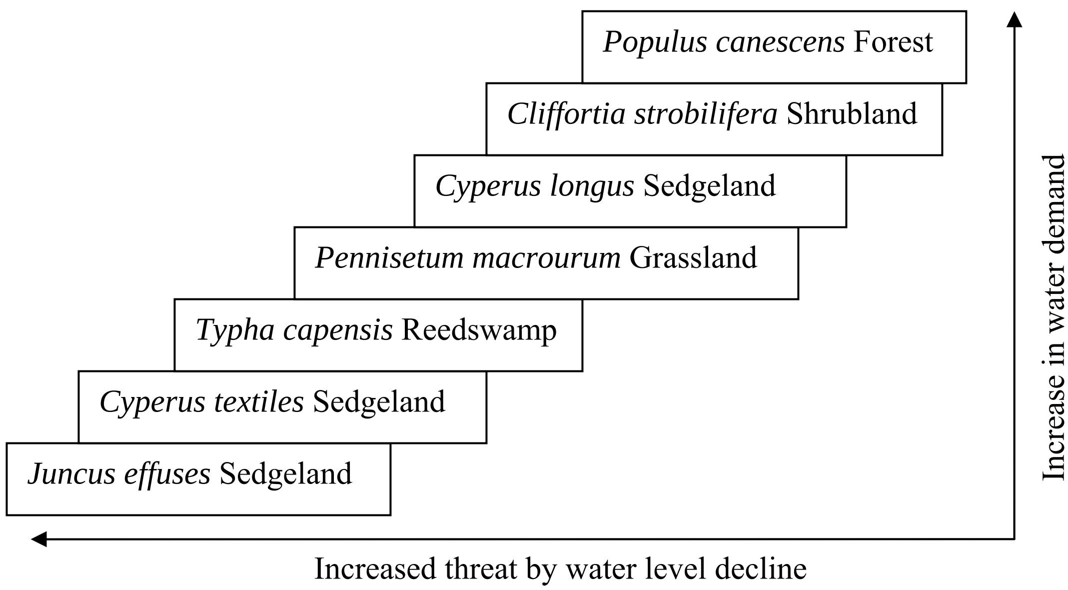

Figure 6.1 Middelvlei Wetland System plant communities water demand and threat in event of water decline.

Juncus effuses Sedgeland was found to be restricted in areas that had high water table, while *Populus canescens* Forest would survive low water table in the order they are placed in Figure 6.1.

A wide geographical distribution of *Cyperus textilis* and *Typha capensis* indicate that these two species are commonly found growing along rivers and around dams. In the wetlands investigated here, these species are found to be restricted to areas that often have extended periods of inundation, which is probably the reasons for their wider distribution along rivers and around dams.

6.2.3 Water Chemistry

The near-surface water constituents of the Middelvlei Wetland System are found to vary between different communities. The variations depend on the constituent in question and on the season. It is therefore important to understand the water quality dynamism of each community. This understanding is useful in predicting the water quality condition expected for each community during a particular season. It is not practical to generalize about the water quality condition for each community as variation occurred between seasons and among the chemical constituents (Table 4.1). Table 6.2 gives a general preference by plants to particular levels of water constituents, for the year without considering the seasonal variations.

Table 6.2 Water chemistry constants levels in areas covered by plant communities

Variable	Range	Rating levels						
DO	0.3-2.4 mg/l	Low	Low	Low	Low	Moderate	Moderate	Moderate
pH	4.5-6.5	Moderate	Low	Moderate	Low	Moderate	Low	Moderate
K	1-27 mg/l	Low	Very low	Very low	Very low	Moderate	Moderate	Moderate
Ca	5.7-82 mg/l	Moderate	Moderate	Moderate	Moderate	Moderate	Very low	High
Mg	2.3-46 mg/l	Low	Low	Moderate	Low	Low	Moderate	Moderate
Na	34-98 mg/l	Moderate	Low	Low	Low	Low	Moderate	Moderate
Community		TC	PM	CS	CL	JE	CT	PC

6.3 Importance of findings from the study

6.3.1 Natural wetlands

Studies such as this provide capacity to predict the inundation requirements for the management of wetlands and rivers. The information obtained from this study contributes to information that can be used in the development of a wetland rapid assessment scheme for wetlands that would cut monitoring costs.

The mapping of the vegetation serves as a baseline for monitoring any future spatial and compositional changes in the plant communities, hence any decrease or expansion of any community could be measured, by overlaying future vegetation maps on this reference map. The community compositional information can also be used to monitor any directional changes in time.

Some of the wetland plant communities found in the wetland system examined in this study also grow along rivers; the information obtained in this study is potentially very useful to determine the flow requirements of rivers in the region. This information could be used to explain changes taking place along longitudinal and horizontal river gradients, whereby presence and distribution pattern of a particular plant community would signify or be associated to particular environmental conditions.

6.3.2 Constructed wetlands

This study provides information that is important for wetland rehabilitation and constructed wetlands (artificial wetlands) use. The selection of plants required for the wetland should be determined by the functions and requirements for which a particular wetland is intended as much as by the water inundation depth and period. This further determines the type of constructed wetland that would suit the purpose for which it is intended. For example an emergent constructed wetland would require plants that are able to grow rooted to the substratum. The constructed wetland could either be a Horizontal Surface Flow System or a Sub-surface Flow System (Okurut 2000).

Horizontal Surface Flow Systems are characterised by above surface water flow as well as through rooting medium flow in a shallow basin. A consideration of water level requirements for particular plant species is crucial to their successful survival.

Sub-surface Flow Systems are characterised by infiltrated water through the porous medium with little or no water exposed on the surface (Brix & Schierup 1989). Species water level and water quality requirements are important in making decisions and choices about the plants that are of functional importance for the wetland.

6.4 Recommendations

The invasion of this wetland system by *Populus canescens* trees should be actively controlled. Uprooting the trees, or use of suitable actively controlled commercial herbicides to poison the stems would be most appropriate to remove the fast spreading and regenerative suckers, to prevent further invasion.

The change in community areas and the successional trends therein should be monitored; this would give clear indications of any environmental changes taking place in the wetland. The findings of this study are valuable to extrapolate or predict the type and direction of environmental changes taking place in this or in similar wetlands.

The wetland should be conserved to improve or maintain its current relatively natural state. Anthropogenic influences that alter the wetland water regime or initiate negative changes to the wetland should be avoided at all costs or the implications of such changes should be thoroughly investigated so that informed decisions can be taken before any such changes are introduced. Changes include activities such as draining or filling of the wetland for other land uses and developments, such as agriculture roads and settlement; the introduction of new species, with no prior advise on the consequences that may result; channelling wastewater from urban or farming areas directly into the wetland, this promotes or facilitates the introduction of new plant species, as is well evidenced in the lower wetland of the Middelvlei Wetland System. Where possible a vegetated terrestrial buffer between the agricultural activities and the wetland would be appropriate, to minimize wash or nutrient loading directly into the wetlands.

A monitoring programme to monitor changes and trends in the wetland would be of much importance in understanding the wetland condition and the changes taking place in time, these changes in turn should be examined to determine their correlation to any changes in land use activities in or around the wetland.

The construction of new or the enlargement of present dams should be avoided; this not only affects the flow water through the wetland, but also influences the vegetation type and distribution within the seepage area and the positive effects of the wetlands on water quality.

6.5 Future Research

- A longer duration exceeding one-year is necessary to draw proper conclusions about the functioning of a wetland system such as this. A repeat of seasonal data for a number of years would be useful in understanding trends in wetland condition.
- Investigation into inundation periods for individual plant communities is crucial, to determine the duration requirements of a particular community.
- There is a need to investigate the role plants play in the alteration in the nutrient content of the near-surface water. Further research on the nutrient assimilation rates for plant communities in different seasons is necessary to determine periods of maximum assimilation levels by the plants and hence to determine the minimum size necessary for efficient functioning by each community and for the most appropriate harvesting time, in the event of wetland nutrient off-loads.
- Investigation into microbial association with plant communities (root zone and surface) is a useful avenue for research in determining or making choices on the plants to use for constructed wetlands, depending on the contents of the effluent and wastewater treatment requirements.
- Investigation into the species recruitment requirements for individual plant communities would be useful to predict possible trends and community changes in the event of environmental condition changes. It would further help in designing constructed wetlands that would support community regeneration and sustainability.
- Map out a wider distribution of the communities examined in this study within South Africa, e.g. along rivers, to find out any functional relationship between

the communities found along rivers and wetlands, to determine their requirements in comparison to the outcome of this study. This would be important in creating generalised theories regarding the presence or absence and distribution of particular plant communities.

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Glossary

Abiotic: those components of an ecosystem that are not living. Also used for physical and chemical influences upon organisms, e.g. humidity, temperature, pH and salinity.

Abstruction: the removal of water from a water body or aquifer, usually for human consumption or use.

Alien species: a species introduced to a region or environment where it is not indigenous.

Anaerobic: living or occurring in the absence of oxygen.

Anoxic: condition in which oxygen is absent

ANOVA: Analysis of variance.

Anthropogenic: man-made or caused by man.

Aquatic plants: emergent plants, such as sedges, reeds and rushes, rooted in the sediment and protruding above the water surface. Free floating plants such as water lilies and submerged plants

Bioindicator: biological organisms used as indicators of the state of the ecosystem.

CART: Classification and Regression Tree Analysis.

Catchment: the area drained by a river and all its tributaries; also referred to as a drainage basin or a watershed.

CCA: Canonical Correspondence Analysis

Change in wetland character: ecological impairment or imbalance in any of the processes and functions that maintain the wetland and its products, attributes and values.

Dentrification: the conversion of nitrates or nitrite to gaseous product (nitrogen), by bacteria.

GIS: Geographic Information System.

Isolines: lines joining areas of the same water level.

m.a.s.l: meters above sea level

Near-surface water: Water found near the surface, either below or slightly above the land surface that interacts with the wetland vegetation roots.

PCA: Principal Component Analysis.

pH: a measure of acidity of water, in which pH 7 is neutral, values above 7 are alkaline and values below 7 are acidic.

Redox potential: scale indicating the reduction (addition of electrons) and oxidation (removal of electrons) for a given material. The position on the scale is expressed as an electric potential in millivolts, normally in the range 0-1300 or 0-1400 mV. The pH of the sample must be known as this can alter the reading.

SCWG: Soil Classification Working Group.

APPENDICES

Appendix 1: Definitions of floristic terms and abbreviations, as used in this text.

Grid reference: The quarter degree grid reference system for referencing maps.

Aspect: sector (after correction for deviation)

Slope:

L = level ($0-2^0$)

G = gentle ($2-10^0$)

M = moderate ($10-45^0$)

S = steep $>45^0$

Substrate:

C = clay

A = silt

S = sand

L = loam

O = organic

Vegetation Cover: Recorded in percentage, representing the total percentage cover could get above 100%.

Wetness

S = surface water

W = wet but no surface water

M = moist, soil sowing high signs of water logging

D = dry or well drained soil

Braun-Blanquet cover-abundance symbols

r = very rare, usually only a single individual, cover less than 0.1% of the area, more than 30 crown diameters between individuals.

+ = present but not abundant and cover less than 1% of area, individuals 8-30 crown diameter apart.

1 = numerous but covering less than 1% of the relevé area, or covering between 6-25% of the area independent of abundance, individuals 1-2 diameters apart.

2 = very numerous and covering less than 5% of the relevé area, or covering between 6-25% of the area independent of abundance, individuals 1-2 diameter apart.

3 = covering 26-50% of the relevé area, independent of abundance. Individuals less than 1 diameter apart.

4 = covering 51-75% of the relevé area, independent of the abundance.

5 = covering between 76-100% of the relevé area, independent of the abundance, crowns touching to overlapping.

Appendix 2: Species list for the Middelvlei Wetland System

ARACEAE * = exotic species

Zantedeschia aethiopica (L.) Spreng.

ASTERACEAE

Senecio pterophorus DC.

CYPERACEAE

Cyperus longus L.

Cyperus textilis

JUNCACEAE

Juncus effuses L

OLEACEAE

Olea europaea L. *subsp. Africana* (Mill.) P. S. Green.

ONAGRACEAE

Oenothera sp.

OXALIDACEAE

Oxalis sp.

PHYTOLACCACEAE

Phytolacca octandra L.

POACEAE

Pennisetum macrourum Trin.

POLYGONACEAE

Persicaria serrulata (Lag.) Webb & Moq.

ROSACEAE

Cliffortia strobilifera L.

SALICACEAE

Populus canescens (Ait.) J.E. Sm.*

SCROPHULARIACEAE

Halleria elliptica Thunb.

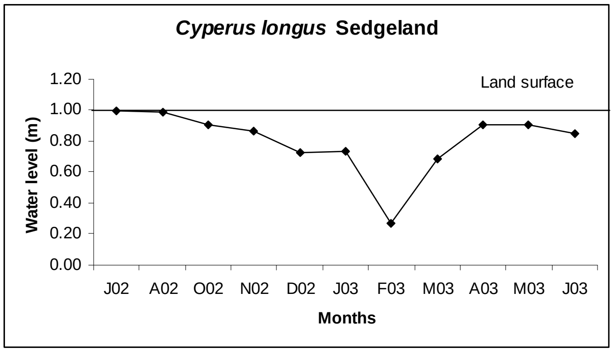
SOLANACEAE

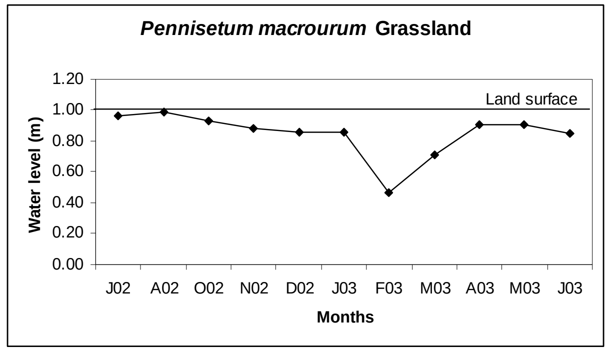
Solanum mauritanum L.

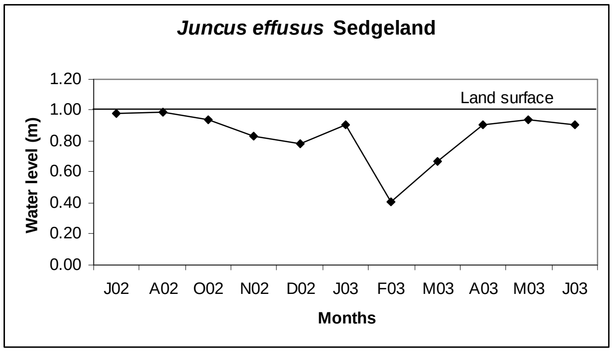
TYPHACEAE

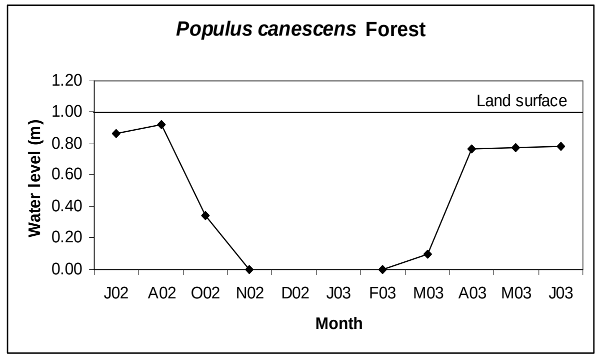
Typha capensis (Rohrb.) N.E.Br.

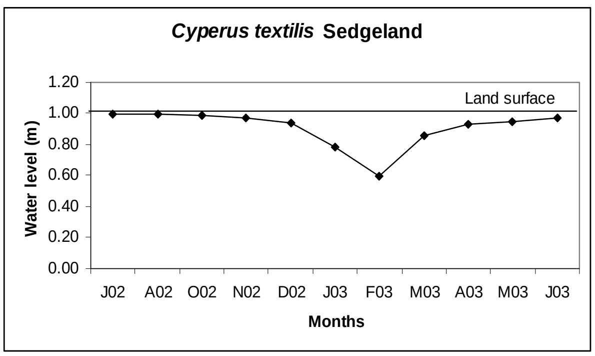
Appendix 3: Mean monthly plant community water levels

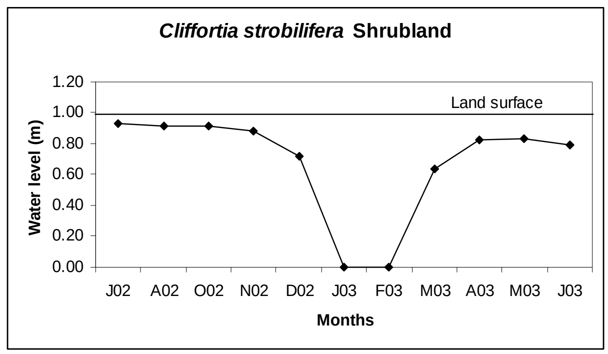


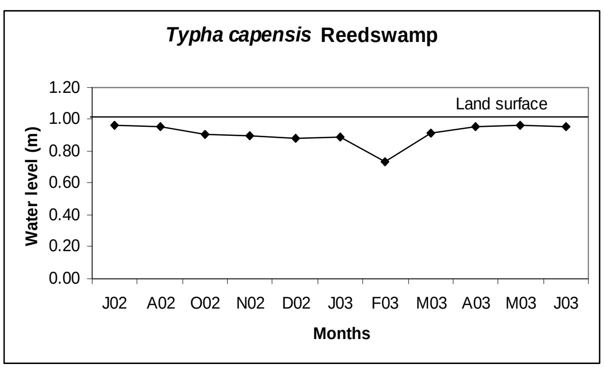












Appendix 4: Cations mean monthly concentration in mg/l in Middelvlei Wetland System between July 2002/ June 2003.

	Jul	Aug	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
PC	1.89	7.49	13.00						18.00	3.00	15.67
JE	1.0	8.9	7.0	7.0	8.8	10.3	15.0	15.0	15.0	14.8	13.3
CL	0.3	3.1	3.7	1.3	5.5	9.0		5.5	4.3	3.0	3.0
CS	0.4	3.8	5.0	2.0	4.0			6.3	5.7	5.7	5.3
PM	0.4	4.1	5.2	3.8	5.3	3.0	1.0	4.0	3.3	3.0	3.7
TC	0.7	6.4	6.7	3.3	3.5	3.0	7.3	10.0	9.0	7.7	7.0
CT	1.3	14.0	15.0	12.0	10.0	10.0	7.0	10.0	8.7	10.0	10.7

Sodium

	Jul	Aug	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
PC	61.3	38.0	62.0						98.0	94.7	86.3
JE	56.3	64.0	54.5	52.8	52.0	63.3	51.0	63.3	67.5	67.8	64.8
CL	47.7	53.7	53.3	55.0	57.5	65.0		73.0	56.7	62.0	67.0
CS	51.0	61.0	79.0	61.0	50.0			68.0	81.0	79.0	87.3
PM	49.8	51.0	53.3	53.1	54.0	61.0	67.0	61.3	54.5	55.5	61.3
TC	37.3	42.3	49.7	41.0	51.0	48.0	52.7	61.7	43.0	49.3	49.3
CT	52.0	51.0	62.0	58.0	62.0		52.5	88.7	82.7	85.3	82.0

Magnesium

	Jul	Aug	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
PC	32.0	17.0	21.0						26.3	49.0	21.0
JE	13.8	14.3	11.5	13.8	1.3	5.7	1.0	2.3	5.0	6.3	6.5
CL	12.7	14.3	15.3	13.7	4.5	3.0		8.0	9.0	11.3	13.3
CS	14.0	22.0	25.0	19.0	0.0			5.3	10.7	8.7	11.7
PM	11.8	9.8	13.6	14.0	3.3	7.0	4.0	3.3	7.0	10.3	9.3
TC	9.3	8.3	14.3	11.7	3.0	1.5	1.3	2.7	3.7	4.3	5.7
CT	18.0	16.0	21.0	26.0	4.0		4.0	8.3	8.3	9.7	9.3