THE EFFECT OF DEVELOPMENT ON SEASONAL WETLANDS ON THE CAPE FLATS, WESTERN CAPE, SOUTH ARICA

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I am indebted to the love and support of my parents and sisters.

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TABLE OF CONTENTS

LIST OF APPENDICES

ABSTRACT

Seven decades ago, the pre-eminent limnologist, Miss Edith Stephens described the Cape Flats as "a paradise for the aquatic biologist". At that time the area was characterised by numerous temporary or seasonal wetlands that filled and dried in concert with the seasons. Since Miss Stephen's observations, the number of seasonal wetlands on the Cape Flats has dwindled alarmingly and very few remain. This dissertation attempts to account for this and provide guidance for the management of the remaining seasonal wetlands.

The dissertation shows how development (characterised by the urban and agricultural land-use) has radically altered the nature of seasonal wetlands and that *Typha capensis* can be used as an indicator of the ecological value or integrity of these wetlands. Two case studies have been selected to test this premise.

The various interrelationships between vegetation, hydrology, nutrients, land-use and ecological value are explored and the proliferation of wetland communities of *Typha capensis* is shown to be an indicator of negative impacts on seasonal wetlands. The literature review indicates that the proliferation of *Typha capensis* signifies a decline in habitat diversity and biodiversity (species richness). *Typha capensis* has been shown to be influenced by streamflow and nutrient input (the plant thrives in shallow areas, permanently inundated with nutrient-rich waters). Therefore, changes to the total area occupied by *Typha capensis* can be used to illustrate how development has affected the hydrology, habitat diversity, biodiversity and ecological value of seasonal wetlands.

The primary source of information was aerial photography, of varying scales, dated from the early 1940s to 2000 and acquired from the Department of Land Affairs: Land Surveys and Mapping. Identifying, mapping and interpreting land-use changes and changes to *Typha capensis* formed the basis of the research. Water chemistry information, obtained from the Scientific Services Department of the City of Cape Town, and an extensive literature review supplemented the photographic information.

Zeekoevlei/ Rondevlei wetland and the Khayelitsha wetlands are used as case studies. Together they have been affected by a significant range of impacts generated by different manifestations of development including Wastewater Treatment Works, high-income

residential areas, catchment hardening, manipulation of drainage patterns, informal settlement, informal grazing, agricultural runoff and horticultural market gardens.

The pattern of land-use change within the selected wetlands' catchments (Lotus River catchment and Kuils River catchment), the impacts of the observed land-use changes, and the impacts to Zeekoevlei/ Rondevlei and the Khayelitsha wetlands with respect to seasonality, *Typha capensis* and ecological value are presented and discussed in detail. In general, urban areas have increased over time to dominate the two catchments. Agricultural areas were consolidated into a few areas while the areas of open space diminished rapidly. Surface and stormwater runoff from "hardened" catchments, irrigation of farmland, and treated effluent from Wastewater Treatment Works all drastically increased. In addition, the concomitant influx of nutrients (nitrates, nitrites and phosphorus) polluted the rivers and wetlands, making them eutrophic and promoting the proliferation of large stands of *Typha capensis*. The impact of these changes was the loss of seasonality, habitat diversity and biodiversity.

Specific recommendations are made for the long term management of Zeekoevlei, Rondevlei and the Khayelitsha wetlands. The proposed management strategy is based on selected management objectives i.e. what is the wetland being managed *for*? It might not be possible to fully rehabilitate them to a pristine state but management as recreational areas, conservation areas and even educational areas is possible. Key points of the recommended management plans include:

- maintaining the winter drawdowns at Zeekoevlei/ Rondevlei;
- implementation of a dredging and *Typha* clearing programme;
- strategically placed reed beds to purify inflow;
- a fire programme for the Khayelitsha wetlands; and
- instating an environmental awareness course at the Khayelitsha wetlands.

The importance of an Integrated Catchment Management Plan is emphasised. Catchments should be managed as a whole, recognising the relationships between planning, land-use and water resources.

CHAPTER ONE

1 INTRODUCTION

About seven decades ago, the eminent limnologist, Miss Edith Stephens, called the Cape Flats area of Greater Cape Town a paradise for the aquatic biologist (Stephens, 1929). Back then, the Flats was characterised by several large permanent shallow lakes (vleis) and numerous temporary or seasonal wetlands that filled only in winter (Southern Waters, 2000). The definition of a wetland, according to Wyatt (1995), is an area of land that is flooded or saturated with water for varying periods of time and that has a distinctive soil type and plant community pattern. Seasonal wetlands are wetlands that fill only during the rainy season (or flash flood event) and that gradually dry between rainy seasons. Since Miss Stephen's observations, these seasonal wetlands have been at the receiving end of a steadily increasing supply of pollutants, including nutrients, and of numerous changes to the hydrological systems to which they belong. Some of the beneficial functions of wetlands include providing a habitat for a wetland-dependent plants and animals, providing a stop-over point for migratory birds, a water purifying function, a water storage function, maintaining habitats, providing a source of food and fodder for people and their livestock respectively, providing an aesthetic landscape for people to enjoy, and providing a recreational area for people to swim, sail, fish etc (Ng'weno, 1992; World Bank, 2002; Hoehn *et al.*, 2003). Seasonal wetlands provide many of these functions in addition to the unique services they provide. Ng'weno (1992) states that seasonal wetlands are usually habitats for rare plants and provide crucial breeding grounds for amphibians and insects. He adds that during breeding and migration season, seasonal wetlands provide vital food for birds and mammals. Far from the wastelands that they are often described as (Davies and Day, 1998), wetlands (including seasonal wetlands) are sites of high productivity and biodiversity (Keddy, 2000; Keddy and Fraser, 2000). For example, over 225 species of birds have been recorded from one area of seasonal wetlands near the Carnivore Restaurant in Nairobi (Ng'weno, 1992). Herremans (1999) in a survey of all major wetlands in Botswana, showed that waterbird diversity and densities were highest at small ephemeral pans. Therefore conservation of wetlands is key to the conservation of freshwater biodiversity, locally, regionally and globally, a view supported by Getzner (2002) and the World Bank (2002).

The number of seasonal wetlands on the Cape Flats has dwindled alarmingly (J King, pers. comm.) as they are turned into permanent wetlands or have been eradicated altogether. Day, King and Harding (unpublished, cited in Southern Waters, 2000) attribute the severely reduced number of seasonal wetlands to the effects of urbanisation on the Cape Flats. In South Africa, at least 50% of all wetlands have been lost or degraded to the point where they no longer provide their beneficial functions (Dini, 2000). The South African situation appears to reflect a global trend and Hollis (1994) cites several examples to this effect. In England, from 1947 to 1982, freshwater wetlands were reduced by 52% (Hollis, 1994). In Roman times, 10% (approximately 3 million ha) of Italy was covered with wetlands. By 1972 this had diminished to just 190 000 ha (Hollis, 1994). In the lower 48 states of the USA, 53% of wetlands were lost between the 1780s and 1980s (Hollis, 1994). Put another way, this represents a loss of 60 acres of wetland every hour (Dahl, 1990, cited in Hollis, 1994). In New Zealand, wetlands have become one of the rarest ecosystems (Burns, 1982; cited in Jones *et al.*, 1995) with an estimated less than 8% of the original wetlands now remaining (Department of Conservation, 1990; cited in Jones *et al.*, 1995). In China, about 30% of the lakes and 60% of the marshes have disappeared as a result of drainage for agriculture and desertification; local industry has resulted in the pollution of 80% of the existing wetlands along the Yangtze River; and more than 30% of the freshwater lakes are eutrophic (Maitland and Morgan, 1997). Australia has lost approximately 120 000 km^2 of wetlands in the last

200 years, which represents a loss of about 50% of the original area of wetlands (Mitchell, 1994; cited in Jensen, 2002)

As Maltby *et al.* (1994) note, the extent and quality of natural wetland resources on the international scale are being substantially modified by human activities. Globally, wetland degradation and/ or loss is a result of direct actions, such as drainage and construction, or indirect actions such as agricultural or industrial pollution, regulation of streamflow and abstraction of groundwater (Day, 1987; Gitonga, 1992; Jones *et al.*, 1995, Keddy, 2000; Bohn and Kershner, 2002). As catchments are being developed (industrial, agricultural and residential development), there has been a concomitant decline in the ecological health of these wetlands. A survey by the United States Department of Agriculture found that urbanisation was the cause of wetland loss in nearly all surveyed watersheds (96%) and may account for as much as 58% of total wetland loss in the United States of America (Opheim, 1997; cited in Ehrenfeld, 2000). On a global scale, agricultural activities rival urbanisation in terms of impacts on wetlands. Williams (1991; cited in Jones *et al.*, 1995) estimates that globally, approximately 1 606 000 km^2 of wetlands had been drained by 1995, primarily for agriculture and food production.

In the context of their ecological values and functions, and their alarming rate of disappearance on a global and regional scale, the aim of this dissertation is to determine the impact that development has had on seasonal riparian wetlands on the Cape Flats. Because riparian wetlands are intimately dependent on the quantity and quality of the water entering them (Dugan, 1988; Jones *et al.*, 1995; Chagué-Goff *et al.*, 1999; Jensen, 2002; Luger and Brown, 2003), the effects of development are examined by investigating the effects of increased streamflow and nutrient loading on seasonal wetlands. Rondevlei, Zeekoevlei and the Khayelitsha wetlands on the Cape Flats, Cape Town Metropolitan Area, South Africa have been selected as case studies (Chapter 4).

In order to achieve the above-mentioned aim, a few key research questions need to be posed. “How can the present ecological value of a wetland be measured?”, “what are the useful measures of the impacts of development on seasonal wetlands over time?”, “how can the changes to inflow and nutrient loading be measured over time?” and “is there a reliable, measurable indicator of ecological value that can be used over time?”. Arising from the need to answer these questions, the following objectives were formulated:

1. propose a means of estimating ecological value over time;
2. provide an approximate estimate of the current ecological value of the two wetlands;
3. identify changes to inflow and nutrient inputs over time;
4. describe and account for the changes in land-use over time;
5. map the changes to the area occupied by *Typha capensis* as an indicator of the effects of development on seasonal wetlands; and
6. show how development has affected the ecological value of the selected wetlands.

The following chapter lays the foundation for the study. In exploring the relevant literature and explaining relationships among and between the key components of this dissertation, it lays the basis for the methods (Chapter 3) used to achieve the stated objectives and gives credibility to the results (Chapter 5).

CHAPTER 2

2 BACKGROUND TO STUDY AND REVIEW OF RELATED MATERIAL

2.1 Introduction

As alluded to in Chapter One, the main goal of this dissertation is to investigate how development has, by altering the inflow and nutrient input, impacted on certain seasonal freshwater wetlands. Keddy *et al.* (1994) and Cronk and Fennessy (2001) point out that changes to hydrology and nutrient input are widely known to cause changes to wetland plant communities. Therefore, it is argued that impacts on wetland ecosystems can be assessed by illustrating the changes in the wetland vegetation as development within catchments increases. This chapter aims to explain the rationale behind this argument. It explores, firstly, the relationship between wetland vegetation and the ecological value of the wetland, i.e. how an assessment of vegetation community patterns may be used to infer ecological value. Secondly, the relationship between inflow/ nutrient input and wetland vegetation is explored. Thereafter, the relationship between development, altered inflow/ nutrient input and ecological value can be inferred.

2.2 Ecological value of wetlands

Ecological value is defined by Kotze and Breen (1994, p 15) as being the "maintenance of biotic diversity through the provision of habitat for wetland-dependent species". According to the Convention on Biological Diversity (signed by 150 countries on 5 June 1992 at the United Nations Conference on Environment and Development in Rio de Janeiro) biotic diversity, or biodiversity, is defined as the variability among living organisms and the ecological complexes of which they are part, including diversity within species, between species and of ecosystems (Gaston and Spicer, 1998). "Biotic diversity" as used in the Kotze and Breen (1994) definition of ecological value refers to the number of different species occurring in a wetland ecosystem (Section 2.2.1 below elaborates on the definition of biodiversity). "Habitat" refers to a physical area or substratum that provides space for a microorganism, plant or animal to live (Begon *et al.*, 1996). Kotze and Breen's (1994) definition of ecological value is a good starting point but it fails to address the relativity of ecological value i.e. against what standard is ecological value (through maintenance of biodiversity and habitat) measured? Something is clearly missing. It is argued that a wetland ecosystem that has ten different (but ubiquitous) species is not more ecologically valuable than a wetland ecosystem that has five endemic species. Human-induced changes in seasonal wetlands often result in truncated biotic assemblages, heavy with generalists. These, often ubiquitous, generalists are able to survive in the modified ecosystem while the unique and rarer plants and animals that are dependent on seasonal wetlands in a relatively pristine state are lost. So, it is not the maintenance of biodiversity *per se* that is critical but rather the degree to which the original species composition is maintained that is the key determinant of ecological value. Keddy (2000) cites two examples where the modification of pristine ecosystems has increased biodiversity locally, but has reduced the overall ecological value of the wetland. The first example is of salt marshes on the east coast of North America. Changes to hydrology resulted in the salt marshes becoming less saline and the number of species of bird increasing by as much as five times. However, the new birds were generally birds that commonly occurred in other freshwater wetlands, while the specialised bird species, associated with natural salt marshes were lost. The second example is based in the New Jersey Pine Barrens, where many rare plants occurred due to the infertile (nutrient-poor) soil. This infertility meant that carnivorous plants were well represented in the local plant communities. Human activities resulted in increased nutrient input into the ecosystem and a concomitant increase in number of plant species (almost three times as many). However, this increase in species richness was due mostly to the invasion of alien species better adapted to the higher soil nutrient levels. The increase in biodiversity was at the expense of the rare endemic, and therefore more valuable, species. Hence, the ecological value of the ecosystem was reduced.

Therefore, for the purpose of this dissertation the Kotze and Breen (1994) definition of ecological value has been slightly expanded. From this point onwards, the ecological value of a seasonal wetland is defined as the degree to which the original biodiversity is maintained, through the provision of habitat for wetland dependent species, in the absence of human intervention. Human intervention refers to any human action that markedly alters the driving forces, e.g. herbivory and flood regime, already affecting ecosystem structure and functioning (Kotze and Breen, 1994). Following this train of thought to its logical conclusion, it is clear that a wetland ecosystem in a pristine state is more valuable than one that has been disturbed, even though the latter may have a greater biodiversity. The definition of ecological value refers to the inherent value of an ecosystem and precludes any value relative to human use or aesthetic appreciation.

A fundamental point associated with the definition is that ecological value is integrally associated with biodiversity and habitat diversity. Habitat diversity refers to the range of different types of habitats that can support a range of different plant and animal organisms. Some of the factors that determine habitat diversity in seasonal wetlands are water depth, fluctuating water levels and diversity of plant communities (Huston, 1994 and Keddy, 2000). These two aspects of diversity can be used to assess the changes to the ecological value of seasonal wetlands. An assessment of habitat diversity can be used to infer biodiversity (Huston, 1994) and similarly, biodiversity can be used to infer ecological value. Thus, by showing how habitat diversity and biodiversity has changed over time, one can show how the ecological value of seasonal wetlands has changed over time. Again, it must be stressed that according to our definition, ecological value is assessed relative to pristine conditions. Hence assessments of an ecosystem's habitat and biodiversity must be made relative to the ecosystem's pristine state.

One may ask why the definition of ecological value used in this dissertation does not take a wetland's ecological processes (e.g. photosynthesis, nutrient cycling and groundwater recharge and discharge) into account. In fact these natural processes are addressed, albeit not explicitly. Biodiversity and habitat diversity are indicators of ecological value and certainly, the unimpeded functioning of a wetland's ecological processes can be regarded as another indicator of ecological value. However, this would be harder to determine, especially in the context of a Master's dissertation. Given that a pristine seasonal wetland is at its highest ecological value it stands to reason that at its highest ecological value, the natural processes that would have occurred in a seasonal wetland would remain unchanged.

2.2.1 Vegetation as an indicator of ecological value

Globally, wetlands provide distinctive habitats for numerous species of plants and animals. Biotic diversity, or biodiversity, can be measured on several scales, ranging from genetic diversity between individuals in a population to diversity of populations within a habitat. Gaston and Spicer (1998) state that biodiversity is also commonly described at different spatial levels. For example, for species diversity, alpha diversity refers to the number of species within a habitat and beta diversity refers to the turnover of species between habitats. Most often, biodiversity is measured as species richness (alpha) diversity. Gaston and Spicer (1998) provide three reasons for this:

- species richness acts as an "integrator" of many facets of differences in biodiversity (i.e. species richness can act as a surrogate for the different types of biodiversity as it positively correlates with other measures of biodiversity);
- species richness is usually easily measurable in practice; and
- substantial amounts of information already exist on patterns in species richness (and can be readily extracted from existing museum collections and associated literature).

For all these benefits, species richness as an indicator of biodiversity does have few limitations. For example, it does not take into account rarity. Begon *et al.* (1996) discuss the example of two communities, each with the same ten species, some of which are rare. Intuitively, the community with equal numbers of individuals belonging to each of the ten species, seems more diverse than the community with most of the individuals belonging to the common species and just a few individuals of the rarer species. Yet both communities have the same species richness. Gaston and Spicer (1998) describe another example. One would think that a community composed of ten very different species (e.g. ranging from mice to zebra) would be more diverse than a community composed of ten species of closely related species of mice. Again, this is belied by the fact that both communities would have the same species richness.

In terms of seasonal wetlands, and this dissertation, time and financial constraints prevent a comprehensive assessment of a wetland ecosystem's species richness. However, this is not necessarily a problem, for as discussed above, impacts on seasonal wetlands need to be made relative to their pristine state and it would have been quite a difficult task to determine species richness (and the changes thereto) over time. Therefore, an indication of biodiversity needs to be inferred from some other aspect of the wetland ecosystem.

There are a number of reasons why vegetation is argued to be the key to assessing biodiversity. Foremost among these is the fact that vegetation is the most visible and easily measured manifestation of biodiversity. In addition, vegetation plays a critical role in maintaining biodiversity of wetland animal species by providing food, shelter and maintaining habitat diversity. The abovementioned reasons are further substantiated when one considers the three key services (from Maltby *et al.*, 1994) provided by wetland ecosystems:

- wetland ecosystem (i.e. biophysical) functions: flood control, nutrient transformation, productivity and habitat development or maintenance;
- wetland products: forests, wildlife, fisheries and grazing resources (for human and wildlife populations); and
- wetland attributes: biological diversity, uniqueness and/ or cultural heritage.

Vegetation plays a key role in all three of these aspects.

- Wetland ecosystem functions

Wetland vegetation offers resistance to flooding water and tends to break a strong single stream of water into many smaller, less strong streams. Wetland vegetation purifies water by removing nitrate, nitrites and phosphorus. And lastly, wetland plants themselves provide a variety of habitats for different wetland species. Hence, by playing a role in flood control, nutrient transformation, habitat development and maintenance, the type of vegetation influences ecosystem functioning (Kotze and Breen, 1994; van Oorschot, 1994; Reddy and D'Angelo, 1994; Kotze, 1997). A study by Murphy *et al.* (1994) shows that plants may be used as an indicator of wetland ecosystem functioning. The study shows that wetland plant assemblages are found in defined hydrological and geomorphic units (or defined habitat units) and are a product of the different pressures (e.g. trophic status, hydrology) acting on the ecosystem. The study concludes that changes in the plant assemblages can be used as a biotic indicator of conditions affecting the functioning of a wetland ecosystem.

- Wetland products

Wetlands have a variety of "products" that are beneficial to the natural ecosystem and to humans. Some of these products include wildlife, fisheries and grazing resources, which are all undeniably dependent on vegetation, via provision of habitat and food (Kotze and Breen, 1994).

- Wetland attributes

In providing the above functions and products, wetlands develop certain attributes. Attributes of wetlands include being a unique natural area in an urban context; being a biodiversity hotspot; and even becoming, to some degree, a cultural heritage to communities living around them. In the Western Cape, where the indigenous flora is world-renowned and used for a variety of purposes by local communities, wetland vegetation is both scientifically unique and a cultural heritage. When managed properly wetlands (e.g. Rondevlei, and the Edith Stephens wetland park on the Cape Flats) are aesthetically pleasing and can be used as an educational resource.

In terms of biodiversity, different plant communities are very good indicators of different habitats. This is because plant communities are sedentary and react to a number of environmental factors. They are therefore an effective means of evaluating habitat diversity (O'Callaghan, 1985; Klimas, 1988). As habitat diversity can be used to infer biodiversity (Huston, 1994), it stands to reason that vegetation can be used as an indicator of biodiversity (and hence ecological value) of wetlands.

Huston (1994) states that the number of species in an area is strongly correlated with its spatial heterogeneity. Plants actually increase spatial heterogeneity via the accumulation of sediment around their bases (as a result of the movement of water) as well as via the vertical structure and complexity contributed by roots, stems, branches and leaves (Huston, 1994). The leaves of plants provide a refuge for young or small animals as well as provide sites for fish to lay their eggs and act as a nursery after hatching. By creating microhabitats for the micro fauna and flora, the presence of water plants leads to an increase in diversity of other plants and animals (Glen, 1996). The microfauna benefits directly from the increase in the rate of oxygen production by wetland vegetation during the day. In addition, the wetland vegetation decelerates the passage of water, protecting small organisms from being washed away.

The leaves of emergent macrophytic plants provide a substrate for epiphytic organisms, which are a food source for browsers. In turn, browsers are a food source for fish. The larvae of some insects and even certain fish (e.g. stickleback) use submerged macrophytes as nesting material (Petr, 1993; cited in Glen, 1996). Other insects (e.g. some mayfly nymphs) use the stems of emergent macrophytes as a burrowing substrate, while the aerial parts of the emergent plants provide nesting material and nesting sites for a large number of birds, insects and spiders. Many herbivorous fish (e.g. grass carp) eat submerged plants and/ or small floating plants (Sculthorpe, 1967; cited in Glen, 1996).

It can therefore be seen that wetland vegetation acts as the foundation for an often complex food web. Due to its key role in maintaining biodiversity through the provision of spatial heterogeneity (habitat diversity), wetland vegetation can therefore be used as an indicator of ecological value. It follows on that tracing the changes to wetland plant communities over time is a means of charting changes to the ecological value of the selected wetlands.

2.2.2 The effect of land-use on inflow

Most of the water in riverine wetlands is derived from the surrounding catchment. Accordingly, the quantity and quality of water flowing into wetlands are strongly influenced by land-use activities that impact on the drainage of their catchments (Kotze, 1997; Tong and Chen, 2002). In his study of land-use data collection methods, O'Callaghan (1985) identifies several types of land-use. His study has been used to inform the selection of land-uses that are relevant to this study, *viz.*:

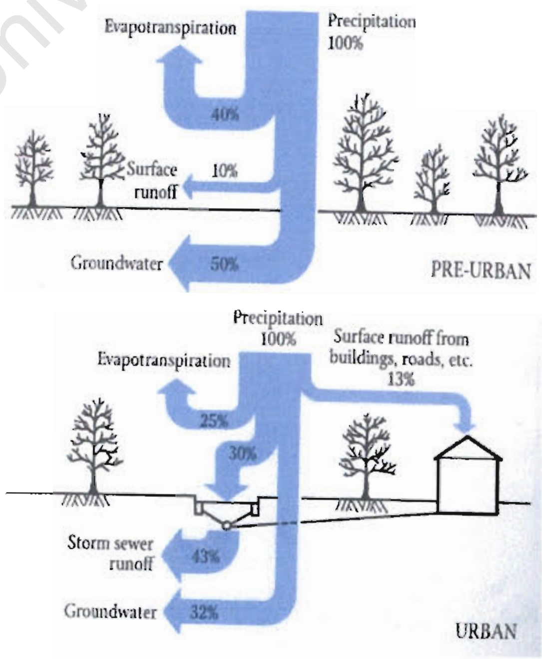
- wetland – areas that are seasonally or permanently inundated with water, have characteristic waterlogged soils and associated aquatic vegetation. These include areas dominated by *Phragmites australis* (reeds), *Typha capensis* (rushes), *Scirpus nodosus* and *Juncus kraussii* (sedges) and herbs and grasses, e.g. *Cotula coronopifolia*, *Paspalum vaginatum* and *Sarcocornia* spp.
- open space – areas of bare ground, indigenous vegetation (the various fynbos communities) and invasive alien vegetation (usually Australian acacias).
- agricultural – areas used for crop cultivation or grazing.
- urban – the built environment, including residential areas, industrial areas, Wastewater Treatment Works (WWTWs), roads and railways.

These land-uses were selected because each of them have specific consequences for inflow and nutrient input (e.g. urban land-use tends to "harden" the surface of the catchment, increasing runoff, while WWTWs discharge copious amounts of nitrogen, phosphorus and treated effluent into wetland systems each day (Tong and Chen, 2002; Luger and Brown, 2003). Agricultural land-use, while not significantly affecting the volume of runoff, usually contributes significant amounts of nutrients from fertilisers to wetland systems (Tong and

Chen, 2002). The urban and agricultural land-uses together comprise the "development" of a catchment.

As indicated earlier, this dissertation aims to determine the impact of development on seasonal wetlands on the Cape Flats. Globally, urban land-use stands alone as the land-use that impacts most significantly on the hydrology of wetland ecosystems. The so-called "hardening" of catchments result from impermeable roofing, paths, tarred roads and other paved surfaces reducing the capacity of urban environments to absorb water (Wiseman, 1990; Davies *et al.*, 1993). Consequently, rain falling in the catchment reaches the river more quickly than it did before, raising flood levels above their natural level (Wiseman, 1990; Goudie and Viles, 1997). Goudie and Viles (1997) also point out that as progressively larger areas become urbanised, the interval between flood events become progressively shorter and the amplitude of floods become raised. The following diagram (OECD, 1986; cited in Goudie and Viles, 1997) illustrates the hydrological changes that occurred in Ontario, Canada, as a result of urbanisation.

Figure 2.1: Diagrammatic representation of the effects of urbanisation on hydrology



Old-school engineers viewed rivers merely as conduits of water. Rivers were canalised and straightened in order to make them more effective in transporting water away from residential areas. A further inescapable aspect of urban areas is the need for Wastewater Treatment Works (WWTWs). In the Western Cape WWTWs discharge mega litres (Mλ) of treated effluent into river systems every day, which has over time resulted in non-perennial rivers being transformed into perennial ones. In the Cape Flats the inevitable result of urbanisation was to increase streamflow in rivers and thereby transform seasonal wetlands into permanent ones (Mike Luger, Ninham Shand, Pers. comm.).

2.2.3 The effect of land-use on nutrient input into wetland ecosystems

As with inflow, nutrient loading of wetland ecosystems can be traced back to the different types of land-use within a catchment area. There are two major land-use types that contribute excessive amounts of nutrients to wetlands; the urban and agricultural land-use. John (1994) states that cultivated lands contribute more phosphates than land with indigenous vegetation while the high surface runoff from urban areas contributes significant amounts of nitrates and phosphates throughout the year. He adds that even the use of fertilisers in residential gardens can raise the nutrient input into a drainage system. WWTWs are also responsible for suffusing wetlands with nutrients (Maitland and Morgan, 1997), as is certainly the case with the Khayelitsha wetlands on the Cape Flats (Ninham Shand, 1999a).

The sustained high level of nutrient input into wetland ecosystems ultimately leads to eutrophication of the system. The term eutrophication refers to the excessive enrichment of water bodies by nutrients, usually nitrates and phosphates (Lewis *et al.*, 1984; Jeffries and

Mills, 1990). The increase of nutrients drives a significant increase in the productivity of a system, which often results in enhanced plant/ algae growth, reduced water clarity, reduced oxygen availability, and increased rates of sedimentation of particulate organic matter.

2.2.4 The effect of hydrological regime on vegetation

Hydrological regime refers to the natural variation (both in terms of volume and temporal variation) and quality of water in a river or wetland ecosystem. Riparian seasonal wetlands are highly dependent on the hydrological regime of their respective rivers as it is the river's hydrological regime that determines a wetland's physical and chemical properties, which includes amongst other things, the sediment input into the wetland; the morphology of the wetland; and the spatial heterogeneity of the wetland. Therefore, wetlands are vulnerable to accidental and intentional human interference of a river's hydrological regime. Relatively small interferences caused by e.g. drainage or engineering works may have magnified biological consequences (Etherington, 1983). So, in modifying and determining the chemical and physical properties of the wetland, the hydrological regime drives a specific biotic ecosystem response e.g. the composition of both plant and animal communities in the wetland ecosystem (Gosselink and Turner, 1978; Vymazal, 1995; Ehrenfeld, 2000). Thus, wetland plant communities are often extremely sensitive to changes in hydrology (Stone *et al.*, 1978; Etherington, 1983; Ehrenfeld, 2000). In this regard, Cronk and Fennessy (2001) note that when water levels in a wetland are stabilised, both plant species diversity and the diversity of vegetation types often result.

Apart from the chemistry of the water (e.g. oxygen saturation, nutrient concentration), the frequency and regularity of inundation as well as the depth of water influence the succession and typical zonation of plant communities around the wetland (Denny, 1985b; Vymazal, 1995; Warwick and Brock, 2003). This is especially true in dry regions like Australia and

South Africa where wetlands can become dry for long periods of time. Plant species in seasonal wetlands must be able to tolerate periods of desiccation as well as flooding (Warwick and Brock, 2003).

Denny (1985b) identifies four zones that occur around wetlands, each associated with specific types of vegetation:

- Terrestrial plant zone: this refers to the mostly dry land that abuts a wetland and is composed essentially of terrestrial plants that can tolerate a degree of flooding;
- Emergent plant zone: this refers to the shallow water zone at the edge of the wetland. Plants in this zone are anchored to the substrate and produce vegetative shoots that emerge through the water into the air;
- Euhydrophyte zone: this zone is deeper and is found between the emergent plant zone and the open-water zone. Light is still able to penetrate to the floor. The euhydrophyte zone may be characterised by the following sub-zones:
    - Floating-leaf and mixed-plant zone: plants completely submerged or anchored to substratum but with floating or both floating and submerged leaves;
    - Submerged-plant zone: plants rooted in or anchored to substratum with vegetative parts submerged below the water's surface at all times.
- Open-water zone: this zone is found in the deep areas of a wetland and can usually only support plants that float on water's surface.

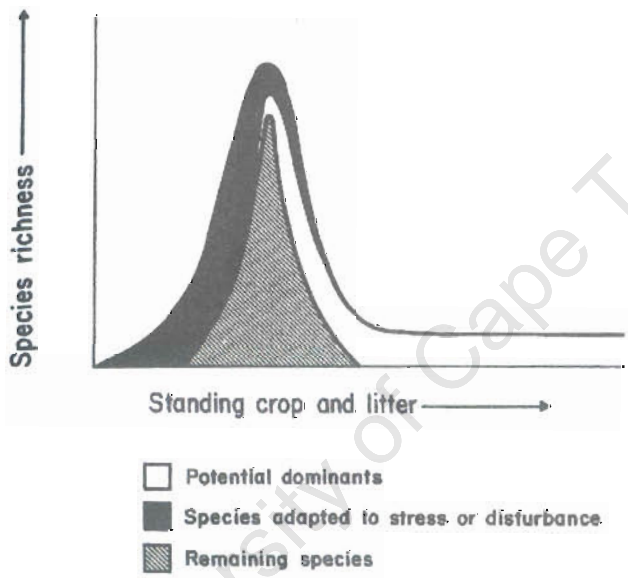
Among the ecosystem characteristics that are influenced by the hydrological regime are species composition and richness (biodiversity), primary productivity and nutrient cycling. The greater the spatial heterogeneity within an ecosystem, the greater the number of biotopes, which can support a greater number of species. One of the major factors affecting spatial heterogeneity is the hydrological regime (Denny, 1985a; Keddy and Fraser 2000; Warwick and Brock, 2003). For example, flood waters that act as a vehicle for movement of suspended sediment may cause uniform mixing and re-deposition of sediment, minimising spatial diversity. Accordingly, wetlands such as the marshes at the mouth of the Mississippi River which are subject to sheet flow by flooding waters, tend to be uniform and to have large areas of monospecific stands (Denny, 1985a). Conversely, by contributing to elevational and substrate differences, hydrological regime can also benefit species diversity, resulting in a plant zonation pattern, with different species occurring at different elevations. Thus, hydrological regime can lead to either uniformity or diversity depending on the regime pertaining to a particular wetland landscape. In the case of seasonal wetlands, seasonal inundation provides for successions of plant communities (increasing habitat diversity/ spatial heterogeneity) and for relatively high levels of substrate heterogeneity. Accordingly, as a general rule, seasonal wetlands support high levels of biodiversity (Keddy, 2000). Apart from encouraging plant diversity, seasonality also allows for a diversity of plant species to reproduce (Warwick and Brock, 2003). Once seasonality has been lost, and the streamflow into the system has been regulated, spatial heterogeneity (and, accordingly, biodiversity) often decreases (Day, 1987; Keddy, 2000; Cronk and Fennessy, 2001; Warwick and Brock, 2003). Hence, by definition, the ecological value of the seasonal wetland also decreases. In addition, the rate of deposition of particulate organic sediment (usually dead and decaying algae) increases. This results in the wetland becoming shallower, creating ideal conditions for the encroachment of emergent plants like *Typha capensis*, which is limited by water depth (Quick, 1987; Hall, 1993).

2.2.5 The effect of increased availability of nutrients on wetland vegetation

Nitrogen and phosphorus are the main macronutrients that impact on plants and, indeed, on the succession of plants, in wetlands (Keddy, 2000). Increasing the input of these nutrients to wetland ecosystems has been found to increase plant production and, should nutrient concentrations continue to increase, decrease species diversity (Jeffries and Mills, 1990; van Oorschot, 1994; Reddy and D'Angelo, 1994; Pereira *et al.*, 2002). The term eutrophication can refer to the natural nutrient enrichment of a water body, but is increasingly used in reference to a form of destructive pollution i.e. the pollution of a water body with excessive amounts of nitrates and phosphates (Jeffries and Mills, 1990). Waters that are referred to as eutrophic exhibit signs of excess nutrient loading with associated changes in the characteristics (such as species composition and biomass) of flora and fauna (Jeffries and Mills, 1990; Pereira *et al.*, 2002). As discussed in Section 2.2.3, wetlands that receive drainage water from urbanised catchments are particularly prone to nutrient pollution. One of the main reasons for this is the ease with which influent water quality can be chemically altered. Perhaps the most significant example of this is the addition of treated effluent-borne phosphate or fertiliser-derived nitrate, which causes eutrophication of wetland waters. Eutrophication may result in blooms of a few very productive species of algae and floating aquatics like the tropical water fern (*Salvinia molesta*) and the water hyacinth (*Eichhomia crassipes*). Such blooms may be followed by excessive oxygen demand as primary production increases. The floating aquatics and algae can rapidly deplete oxygen reserves in a wetland. Associated with the increase in photosynthesis is an increase in the water's pH caused by the release of CO_2 (a by-product of photosynthesis) which goes on to form $CaCO_3$. Fish death usually follows the oxygen depletion, the increase in pH and the release of toxins that is produced by algal decay (Etherington, 1983; Jeffries and Mills, 1990; Vymazal, 1995). According to Moore (1990) and van Oorschot (1994), increased productivity leads to a decrease in diversity. Keddy (2000), Cronk and Fennessy (2001) and

Pereira *et al.* (2002) support this assertion, saying that increased productivity often results in the dominance of a standing crop of strong competitors (e.g. *Typha capensis*) and a concomitant decrease in species richness. The relationship between species richness and a standing crop of strong competitors is illustrated by the following figure.

Figure 2.2: The relationship between species richness and a standing crop of strong competitors (from Wisheu *et al.* 1990; adapted from Keddy, 2000)

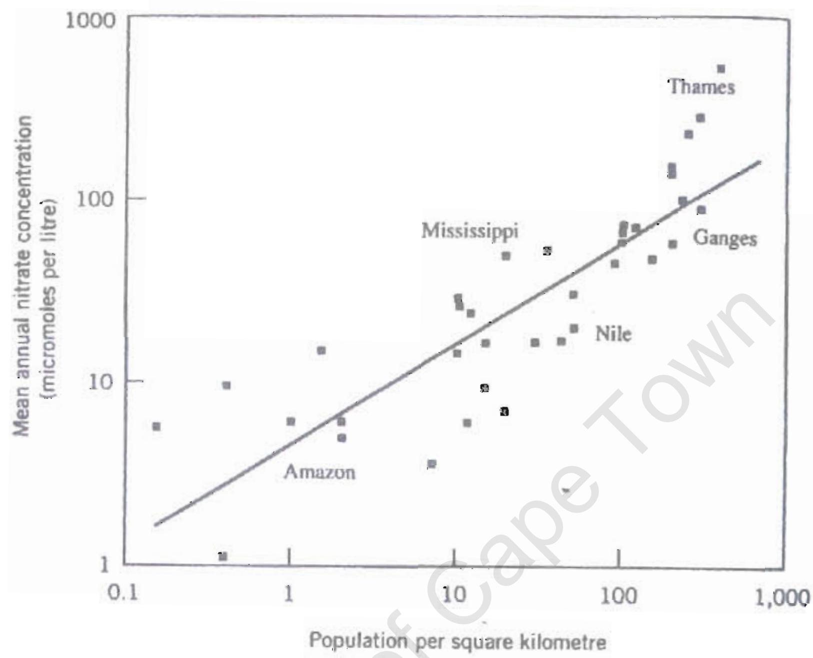


The cycling of nitrogen and phosphorus through wetland ecosystems are described below.

2.2.5.1 Nitrogen

Inorganic nitrogen in wetlands takes the form of nitrate (NO_3^-), nitrite (NO_2^-) and ammonium (NH4+) ions. In addition, nitrogen can also occur as part of organic molecules, either in the form of particulates or dissolved. One of the consequences of urbanisation is the increased nitrate concentration in rainwater and runoff (Keddy, 2000). The following diagram illustrates this, showing the nitrate concentration in water in 42 major rivers as a function of population density.

Figure 2.3: Nitrate concentration in rivers as a function of population density (from World Resources Institute, 1992; cited in Keddy, 2000)



Keddy (2000) also points out that much of the nitrogen used in agriculture is not obtained from natural sources but is extracted industrially from the atmosphere. Hence, the amount of biologically available nitrogen is increasing (Freedman, 1995, cited in Keddy, 2000). In fact, globally, the amount of industrially fixed nitrogen applied to cultivated land during the period 1980 to 1990 exceeded all the industrial fertiliser applied previously in human history (Vitousek *et al.*, cited in Keddy, 2000).

In a wetland system, particulate nitrogen may be deposited by sedimentation, although water movement may cause its re-suspension. Adsorption and diffusion processes are responsible for the direct exchange of ammonium (NH_4^+) and nitrate ions between sediment or pore water and the overlying water column (van Oorschot, 1994). This exchange process depends on the chemical conditions and relative concentrations of nitrate and ammonium in the pore and overlying water. Dissolved nitrogen moves by osmosis between pore water and overlying water. There are three ways in which nitrogen is taken up by plants, (1) direct uptake of ammonium and nitrate from the water; (2) nitrogen fixation; and (3) uptake of ammonium and nitrate from the sediment pore water by the roots of plants. Surface and groundwater flow are the major avenues of nitrogen output from wetland systems (Quick, 1987). Some nitrogen is also released atmospherically by plants.

Apart from stimulating plant growth, increased nutrients may also stimulate the mineralisation of organic matter (van Vuuren et al., 1992; cited in van Oorschot, 1994). Kadlec (1994) describes mineralisation as the process whereby organic nitrogen is broken up into ammonium and a hydrocarbon, depicted by the following chemical reaction: $C_xH_yN \longrightarrow NH_4^+ + HC$. An increase in nutrients drives an increase in plant productivity, which, in turn, causes the composition of plant communities to change. As plants die, the pool of organic matter in the wetland increases, and decomposition results in the release of ammonium. Once released into the water column, ammonium may (i) be taken up by plankton or vegetation; (ii) undergo nitrification to form nitrites and then nitrates under aerobic conditions; or (iii) be volatised to gaseous ammonia (NH_3) (Reddy and D'Angelo, 1994). Kemp *et al.* (1990; cited in Reddy and D'Angelo, 1994) show that the major mechanism regulating nitrogen cycling processes is the nitrification-denitrification process. Wetland vegetation, via nitrification-denitrification processes in the root zone, and by assimilation of nitrogen into plant tissue, plays a significant part in the nitrogen cycle. To summarise, levels of inorganic nitrogen in the water column are lowered by nitrification and denitrification, volatisation of ammonia, and uptake by plants.

2.2.5.2 Phosphorus

Southern Water (2000) state that phosphorus enters wetland systems via two major pathways:

- runoff and streamflow; and
- groundwater.

Because phosphorus cannot be lost from wetlands via metabolic processes (gaseous loss of phosphorus) (Reddy and D'Angelo, 1994), and phosphorus is often the limiting factor for plant growth in wetland ecosystems (Vymazal, 1995), most plants are adapted to store excess phosphorus (Jeffries and Mills, 1990). Stored phosphorus is returned to the water column when the plant dies and decomposes. Phosphorus also tends to get adsorbed (chemically or physically bound) on sediments in wetland soil (Kadlec, 1994). Therefore, phosphorus tends to accumulate in wetland systems. In wetlands, particulate phosphorus can be deposited in sediments and re-suspended via water movement. Phosphorus release from sediments depends on two mechanisms occurring simultaneously or within a short period of time. First, phosphorus needs to be released from sediments to the pool of dissolved phosphorus in the pore water, usually via desorption, dissolution, ligand exchange mechanisms, changes in redox status and enzymatic hydrolysis. Secondly, the processes of diffusion, wind-induced turbulence, bioturbation, current and/ or gas convection are required to transport the dissolved phosphorous from the pore water to the water column (Vymazal, 1995). There are two ways in which the nutrient is actively taken up by plants (1) uptake from the water by epiphytes; and (2) uptake from sediment pore water by the roots of plants (Quick, 1987). The main routes via which phosphorus is lost are by direct outflow and by export of nutrients by terrestrial grazers. For example, in KwaZulu Natal wetlands, cattle that graze on wetland vegetation ingest the phosphorus stored in plants and remove it from the wetland system when they move on. During fire events, phosphorus may be lost to the atmosphere.

Depending on its physical and chemical properties, wetland soil may act as a source or a sink for phosphorus in the water column (Reddy and D'Angelo, 1994). Generally, phosphorus is fixed in acid soils as aluminium and ferric phosphates (if the activities of these cations are high), while phosphorus fixation in alkaline soils is governed by the activities of calcium and magnesium (Reddy and D'Angelo, 1994). Further, phosphorus availability is generally highest in slightly acidic to neutral pH soils (Reddy and D'Angelo, 1994). At high phosphorus loadings, wetlands tend to retain phosphorus. Conversely, at low loadings, wetland systems tend not to retain phosphorus (Reddy and D'Angelo, 1994). This is pertinent considering the high phosphorus loadings of the selected wetlands.

2.2.5.3 The effects of eutrophication

The changes that occur to wetland vegetation as a result of eutrophication are uniform throughout the world. Jeffries and Mills (1990) elaborate on the general pattern that occurs as a result of eutrophication:

- changes in algae occur. Species composition and productivity alter, the latter often being greatly elevated. Blue-green "algae" (in reality they are not true algae but cyanobacteria) become increasingly dominant as eutrophication proceeds and can produce toxins. The increase in productivity (and seasonal die down of algal species) results in increased dead and decaying matter within the wetland, often leading to anoxic conditions.

- the rate of sedimentation, due to deposition of the dead and decaying organic matter, increases. Shallowing of the wetland results with concomitant changes in macrophyte communities. The shallows become stabilised as emergent vegetation proliferates.
- emergent vegetation further slows down the passage of water and traps sediment. Further shallowing occurs. Some of the more tolerant species flourish, assuming nuisance proportions. Sensitive species are lost and diversity is reduced;
- a general loss of animal diversity occurs as the animal species composition is altered. Losses are due mainly to changes in water chemistry and anoxia as well as to alterations in algae and macrophytes. The loss of a few animal species can lead to a breakdown in foodweb systems;
- the amenity and aesthetic value of the wetland is greatly reduced. Eutrophic waters assume a pea-soup colour and may produce noxious odours.

2.3 Typha capensis

Typha capensis (also called the bulrush or "papkuil" in South Africa and cattails in the USA) is a member of the family Typhaceae, which form the second most widespread aquatic emergent group in the world (Sculthorpe, 1967; cited in Hall, 1990). Of the eight to thirteen species of *Typha* that have been identified worldwide, only *Typha capensis* (formerly known as *Typha latifolia* var. *capensis*) is found in the Western Cape (Smith, 1987; cited in Hall, 1990). At present, the plant is found along all the major water courses of the Cape Flats (Hall, 1990).

Typha capensis grows to height of 1.5 to 2.5 m and consists of above-ground stems and leaves and below-ground rhizome and roots. Each stem bears up to 20 leaves with rounded leaf sheaths and linear blades (Hall, 1990). A large proportion of the plants biomass is in the form of the below-ground roots and rhizomes (Hall, 1993; Quick, 1987). As *Typha* plants grow, their rhizomes become tightly packed and expand on a wide front, known as a phalanx growth form, eventually excluding other plants from taking root in the soil (Hall, 1993). Although *T. capensis* does exhibit a pattern of seasonal development, winter die-back is limited mostly to older shoots and growth does indeed continue throughout the winter period (Hall, 1993).

Because many aquatic plants are more efficient at taking up and using nutrients than *Typha* is, it is only during periods of abundant nutrient availability that the plant can outcompete other plants (Quick, 1987). **Hence the proliferation of dense stands of Typha is an indication of the eutrophication of a waterbody**. In assessing the trophic state of Linhos Lake in Figueira da Foz, Portugal, Pereira *et al.* noted that *Typha latifolia* had morphological and physiological characteristics that gave it dominance in eutrophic systems. This is attributed to the fact that the macrophyte can actively pump nutrients from sediments, which are incorporated and preserved in its structure during the growing season (Bjork, 1994b; cited in Pereira *et al.*, 2002). *Typha* species have large internal air spaces that transport oxygen to the roots and rhizomes, and in addition, they can stimulate the decomposition of organic matter and the growth of nitrifying bacteria, which creates oxidised conditions in the often anoxic conditions associated with eutrophic waters (Brix and Schierup, 1989; cited in Pereira *et al.*, 2002). The United Stated Environmental Protection Agency (1995) adds that *Typha* species only needs trace amounts of sediment oxygen to germinate, which allows them to dominate nutrient-rich and oxygen depleted wetlands. Conversely, low concentrations of nutrients impact negatively on the population densities of *Typha* species (Moore, 1990). Therefore, in the Western Cape where increased surface runoff and treated sewage effluent have enriched wetlands with nutrients (Hall, 1990), *Typha capensis* has dominated, resulting in a reduction in habitat diversity and concomitantly biodiversity (Day, 1987).

The regular drying out of seasonal wetlands during the dry season is a further inhibitor to the spread of *Typha capensis*. This is because drying out inhibits growth of the plant (Day, 1987; Hall, 1993). Sojda and Solberg (1993, p. 5) state that seasonality actually shifts the "competitive ecological edge" to other species. Furthermore, evaporative drying of wetlands is usually associated with increasing water salinity, which is detrimental to the growth of *Typha* species (Sojda and Solberg, 1993). Because summer growth is usually limited by water supply along the landward margins of wetlands, if the water supply is stabilised, marginal growth is enhanced and *Typha capensis* will spread landward (Hall, 1990). Furthermore, where water depth is reduced (in wetlands that become silted up with sediment or the biomass of dead and decaying algae) growth will occur along the waterward edge (Hall, 1990).

To summarise, the proliferation of stands of *Typha capensis* in seasonal wetlands is indicative of:

- the loss of seasonal wetting and drying, i.e. the seasonal wetland that has become a permanent water body (Day, 1987; Hall, 1990; Hall, 1993; Sojda and Solber, 1993; Cronk and Fennessy, 2001); and
- nutrient-enrichment of the wetland (Apfelbaum, no date; Day, 1987; Quick, 1987; Hall, 1990; Moore, 1990; Hall, 1993; Pereira *et al.*, 2002).

Sections 2.2.2 and 2.2.3 show that such changes to hydrology and water quality (*viz.* nutrient enrichment) can be attributed to urbanisation and intensive agricultural development. Hence, because changes to hydrology and nutrient enrichment favour the growth of *Typha* species, a strong link can be made between the spread of *Typha* in wetlands and development of the catchments within which those wetlands occur.

As discussed in Section 2.2.4 and Section 2.2.5, changes to the hydrological regime and eutrophication (as a result of development) also have significant impacts on spatial heterogeneity and species richness respectively. The proliferation of *Typha capensis*, a vigorous competitor, is often at the "expense of other species and habitat diversity" (Hall, 1990, p. 13; Hall, 1993). Apfelbaum (no date) supports this argument and states that dense monocultures of *Typha* species reduces habitat heterogeneity and eliminates other plants. Figure 2.2 confirms this, showing that species richness decreases as the standing crop of a strong competitor (like *Typha capensis*) increases. Because ecological value is strongly associated with habitat diversity and biodiversity, it is argued that *Typha capensis* can be used as an indicator of the ecological value of seasonal wetlands.

Apart from its relationship to development, hydrology and nutrient enrichment, there are also several other reasons why *Typha capensis* is suitable as an indicator species of ecological value (EPA, 1995):

- Immobility – *Typha capensis* reflects site conditions and are practical for use in *in situ* assessments;
- Interpretability of gross patterns of spatial distribution – patterns can be determined from a distance without requiring permission for access to private property (e.g., through interpretation of aerial imagery);
- Sensitivity to a wide variety of stressors – Sensitivity to changes in hydrology and nutrient input is well known and documented; and

- Taxonomy is known better than for any non-animal assemblage and identification to genera is mostly straightforward.

2.4 Conclusion

This chapter, in exploring the various interrelationships between vegetation, hydrology, nutrients, land-use and ecological value, has shown how changes to wetland communities of *Typha capensis* can be used as an indicator of changes to the ecological value of a wetland.

This literature review indicates that the proliferation of *Typha capensis* is an indication of a decline in habitat diversity and biodiversity (species richness). Biodiversity, itself, is a useful tool in assessing the ecological value of an ecosystem. Furthermore, *Typha capensis* has been shown to be influenced by streamflow and nutrient input (the plant thrives in shallow areas, permanently inundated with nutrient-rich waters). Therefore, changes to the total area occupied by *Typha capensis* can be used to illustrate how development has affected the hydrology, habitat diversity, biodiversity and ecological value of seasonal wetlands.

CHAPTER THREE

3 METHODS

3.1 Introduction

The purpose of this research is to determine how development and related land-use changes have impacted on seasonal wetlands on the Cape Flats. In this dissertation it is hypothesised that the increased inflow of water and nutrient loading as a result of development within catchments has, to all intents and purposes, severely altered the ecological value of seasonal wetlands in the Cape Flats. Various methods have been applied to achieve the objectives of the study:

3.2 Methods

Objective 1: Propose a means of estimating ecological value over time

Both local and international literature on *Typha* species (including their ecology, their response to changes in nutrient availability and their response to changes in the hydrological regime) were used to argue the case that *Typha capensis* can be used as a reliable indicator of the ecological value of seasonal wetlands over time (Section 2.3).

Objective 2: Determine current ecological value

An assessment of the current ecological value of the selected wetlands was inferred using the Present Ecological Status (PES) procedure for wetlands (Duthie, 1999; Harding, 1999;

Southern Waters 2000). This methodology is the DWAF-approved method of assessing the present ecological status of wetlands. It uses a scoresheet and the expert judgement of specialists familiar with the wetland systems in question to determine the present ecological status of wetlands. In keeping with the definition of "ecological value", the scoresheet (using several criteria) assesses the PES in relation to a Pristine State or agreed upon Reference Condition. The Reference Condition is determined by eliciting local knowledge and referring to early aerial photography. Therefore, the accuracy of the PES assessment relies on the known history or natural condition of a wetland as well as the knowledge and experience of the specialists. This represents the main weakness of the methodology i.e. it can't be applied with a high degree of confidence to less well-known systems. In addition, results may differ depending on which specialists undertake the assessment. The strength of the methodology lies in its flexibility and robustness; scores for different criteria can be debated until a consensus is reached.

Although it does not directly assess habitat or biodiversity, the scoresheet does assess criteria that have direct relevance to habitat and biodiversity, including changes to inflow and inundation, changes to water quality, removal of indigenous vegetation and encroachment of alien plants and animals. All these criteria affect the habitat diversity and species richness of a wetland. Hence, current ecological value can be inferred from an assessment of the Present Ecological Status.

The PES methodology comprises the following tasks:

- Literature review (related to amongst others, types of development and land use in the catchment, hydrology, water quality, and exotic species);
- Aerial photographic assessment to determine changes that have occurred over time;

- Site visits and drawing on local knowledge to assess the functioning of the selected wetlands and impacts on them;
- Assessment of criteria and generation of preliminary PES scores (using the PES table presented in Appendix A); and
- Reporting on the results of the assessment.

Based on the information collected, the scoresheet is completed and a mean PES score and associated Confidence Level attained. This PES score is then interpreted using the table provided to determine the PES Category. The PES of a wetland can range from Category A (Unmodified, or approximate natural condition) to Category F (critically modified with an almost complete loss of natural habitat).

For the Zeekoevlei/ Rondevlei system, Southern Waters had already undertaken the procedure and produced an assessment of PES for both wetlands in 2000. A second assessment was undertaken to produce a more up-to-date assessment and to evaluate the results in comparison to Southern Water's initial assessment. Environmental Scientist, Mike Luger (who has a long history of study in Kuils River system), provided valuable input during the determination of the PES for Khayelitsha wetland for this dissertation. Please refer to Appendix A for a detailed explanation of the PES Methodology, including scoresheets for Zeekoevlei, Rondevlei and Khayelitsha and the table for the interpretation of scores.

Objective 3: Identify changes to inflow and nutrient input

Changes to hydrology were ascertained from past studies (e.g. Southern Waters (2000) and Ninham Shand (1999a)) as well as from changes observed on sequential aerial photos (e.g. increase in the size of the wetland). Historical water quality data was acquired from the

Scientific Services department of the City of Cape Town. This data is a record of nitrate, nitrite and total phosphorus concentration (mg/λ) measured at the inflows to Zeekoevlei/ Rondevlei and the Khayelitsha wetlands from 1981 to 2003. Data was collected anywhere from three times a year (e.g.1982) to 21 times a year (e.g. 1986). To determine seasonal variations, only data recorded in June (mid-winter) and December (mid-summer) for each year (or nearest month, if this isn't possible) are used in this dissertation.

Objective 4: Illustrate changes to land-use over time

Land-use maps (1:70 175 for the Kuils River catchment and 1:50 000 for the Lotus River Catchment), that also accurately delineated the boundaries of the selected catchments, were obtained from the Spatial Planning Department of the City of Cape Town. The catchment boundaries were then transferred to 1:50 000 maps obtained from the Department of Land Affairs: Land Surveys and Mapping. These 1:50 000 maps (dated 1942, 1979 and 1983 for the Lotus River catchment, and 1942, 1978/9 and 1981/3 for the Kuils River catchment) as well as the 1999 land-use maps from the City of Cape Town were used to identify the changing land-uses within the catchment over time. Three types of land-use were identified: open space, agricultural and urban land-use.

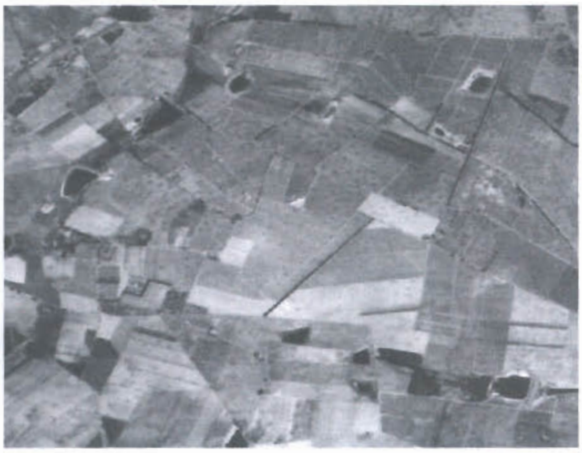
Thereafter, the areas of three land-uses were calculated using a grid of 1 cm X 1 cm squares. Identification of the types of land-uses on the maps were made using the legend provided on both the City of Cape Town maps and the 1:50 000 maps. The grid was then superimposed on the 1:50 000 maps and City of Cape Town land use maps and counted. For the 1:50 000 maps each square represented 0.25 km^2 while on the 1:70 175 City of Cape Town map each square represented 0.49 km^2. Thus, by counting the number of squares, an approximation of the total area occupied by each land use for a particular year could be calculated.

In addition to the total area of each land use, the pattern of land use development was also determined. According to Costa *et al.* (1996, cited in DEAT, 1997) and Marnewecke and Kotze (1999), aerial photos are considered to be the most accurate form of remotely sensed data to identify, delineate and map wetlands. Black and white aerial photographs from 1953 (month unknown) (1:36 000), March and April 1977 (1:50 000), August 1988 (1:50 000) and November 2000 (1:50 000) of the catchments from were obtained from the Department of Land Affairs: Land Surveys and Mapping and each land use outlined and digitised. The following examples illustrate how the different types of land-use were identified from the aerial photography.

Urban

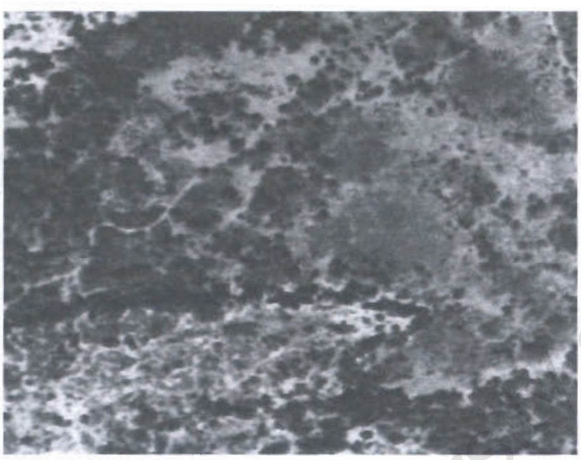
Urban land-use is characterised by a conglomeration of buildings, roads and railways. Sometimes a pattern of development can be identified e.g. roads and buildings in a circular or even hexagonal shape. Even informal settlements exhibit a similar pattern of buildings and associated road network.

Agricultural



Agricultural land-use is characterised by plots of cultivated land of various light shades of grey. Each plot generally has a rectangular, trapezoidal or similar shape. Buildings and roads are absent in any great number or density.

Open space



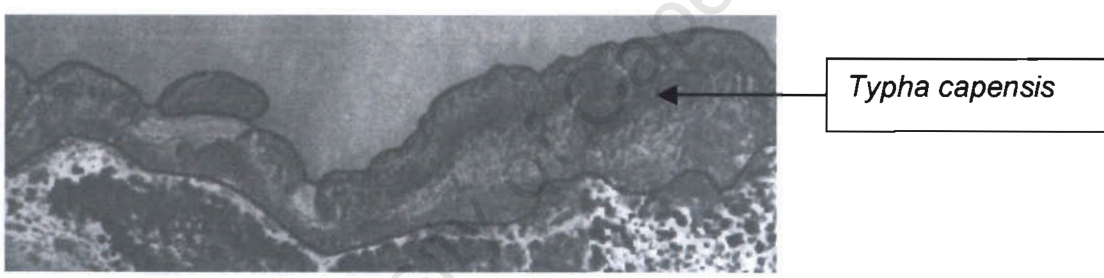
Open space is wholly different from the agricultural or urban land-uses. The ground is much more "patchy" and usually ranges from a very light to very dark (almost black) colour, depending on the vegetation type. Acacias are denoted by dark patches of colour, while indigenous vegetation and grasses are much lighter. Dunes are very light, almost white in colour. Geometric shapes are completely absent.

Although urban areas do have grass verges and lawns, unless they showed up distinctly on the aerial photographs (as in the case of parks or racecourses within urban areas) they were not incorporated into the open space land-use.

For each year, the selected wetlands, the catchment area and the identified land-uses were outlined on the aerial photographs using different coloured felt-tip pens. The photographs were then given to a graphics specialist who digitised the markings using Corel Draw and produced colour A4 sized maps illustrating the pattern of land-use change.

Objective 5: Map changes to Typha capensis over time

Again the research procedure is based on the interpretation of black and white aerial photos, this time enlarged to between 1: 4 000 and 1: 6 000. For Zeekoevlei/ Rondevlei, aerial photographs from 1944 (month unknown), October 1958, April 1968, August 1988 and November 2000 were obtained from the Department of Land Affairs: Land Surveys and Mapping. For the Khayelitsha wetlands aerial photographs from 1944 (month unknown), 1953 (month unknown), April 1968, August 1988 and November 2000 were obtained. The wetlands and areas of *Typha capensis* were outlined on the photographs using a felt-tip pen. *Typha capensis* was identified on the aerial photographs by its distinctive rough texture. The following image from one of the aerial photographs indicates this.



The photographs were then given to the same graphics specialist to digitise and produce colour, A4 sized maps that indicated the areas occupied by *Typha capensis* over time.

Objective 6: Illustrate the impact of development on ecological value

The grid overlay method, described above, was used to calculate the area of open water and *Typha capensis* from the same aerial photographs of Zeekoevlei, Rondevlei and the Khayelitsha wetlands that was used earlier.

CHAPTER FOUR

4 INTRODUCTION TO THE CASE STUDIES

The Zeekoevlei/ Rondevlei wetland and the Khayelitsha wetlands (Figure 4.1) were selected as case studies. The reason for their selection lies in the large amount of baseline data that already exists for both systems. This information was crucial in constructing the history of the wetlands. Zeekoevlei/ Rondevlei and the Khayelitsha wetlands fall in the same category described by Cowan (1995), i.e. they both occur on a western coastal slope and have a mediterranean climate. In addition, both wetlands are found in the lower reaches of their respective drainage systems. Importantly, and highly pertinent to this study, together they have been affected by a significant range of impacts generated by different manifestations of development including Wastewater Treatment Works, high-income residential areas, catchment hardening, manipulation of drainage patterns, informal settlement, informal grazing, agricultural runoff and horticultural market gardens. The result of these developments, though, is similar – an increased streamflow and nutrient input into the wetlands (Ninham Shand, 1999a; Southern Waters, 2000; City of Cape Town, 2001).

The natural drainage patterns prior to urbanisation on the Cape Flats consisted primarily of seasonal wetlands (Griffin and Grobicki, 2000). Most of these seasonal wetlands have been lost or ecologically compromised (Griffin and Grobicki, 2000) due to (1) alteration of their hydrological regime, (2) alteration in the quality of influent water, and (3) obliteration of the entire system (usually by infilling) (Day, 1987). Zeekoevlei, Rondevlei and the Khayelitsha wetlands are a few of the wetlands that remain from the numerous seasonal wetlands that once dotted the Cape Flats. Most of the wetlands on the Cape Flats usually formed after the winter rains. The sandy nature of the ground meant that water readily infiltrated the ground. The result was that these wetlands dried on a seasonal basis. Historically, the Khayelitsha wetlands (and associated Kuils River) formed such a system. Another type of wetland that existed was the surface expressions of groundwater that occurred as a result of the water table being very close to the surface of the ground. These wetlands formed rapidly at the onset of the rainy season and usually took much longer to completely dry out than the other seasonal wetlands on the Cape Flats. Zeekoevlei was one such wetland. Stephens (1929) and Southern Waters (2000) indicate that Zeekoevlei often underwent two or three year cycles of filling and drying out.

4.1 Zeekoevlei/ Rondevlei

Zeekoevlei and Rondevlei were originally seasonal wetlands on the False Bay coast (Figure 4.1). Currently, they are fed by groundwater as well as by the Big and Little Lotus Rivers (actually constructed canals for most of their reach), and are no longer seasonal. Though linked by groundwater, both wetlands, or vleis as they are also known in South Africa, were managed separately for many years for the purposes of recreation (Zeekoevlei) and nature conservation (Rondevlei). Recently Zeekoevlei has also been declared a nature reserve by the City of Cape Town.

For at least a century both vleis have been the recipients of human-induced nutrient-rich inflows, which have resulted in sustained blooms of blue-greens and the accelerated accumulation of organically-rich sediment (Southern Waters, 2000). The proliferation of emergent plants and algae can be attributed to the large amounts of phosphorus entering the system (Southern Waters, 2000). In addition, Harding (1996) states that the high degree of wind-induced resuspension of sediments in Zeekoevlei causes the release of phosphorus from sediments.

Figure 4.1: Map showing the location of Zeekoevlei/ Rondevlei and the Khayelitsha wetlands

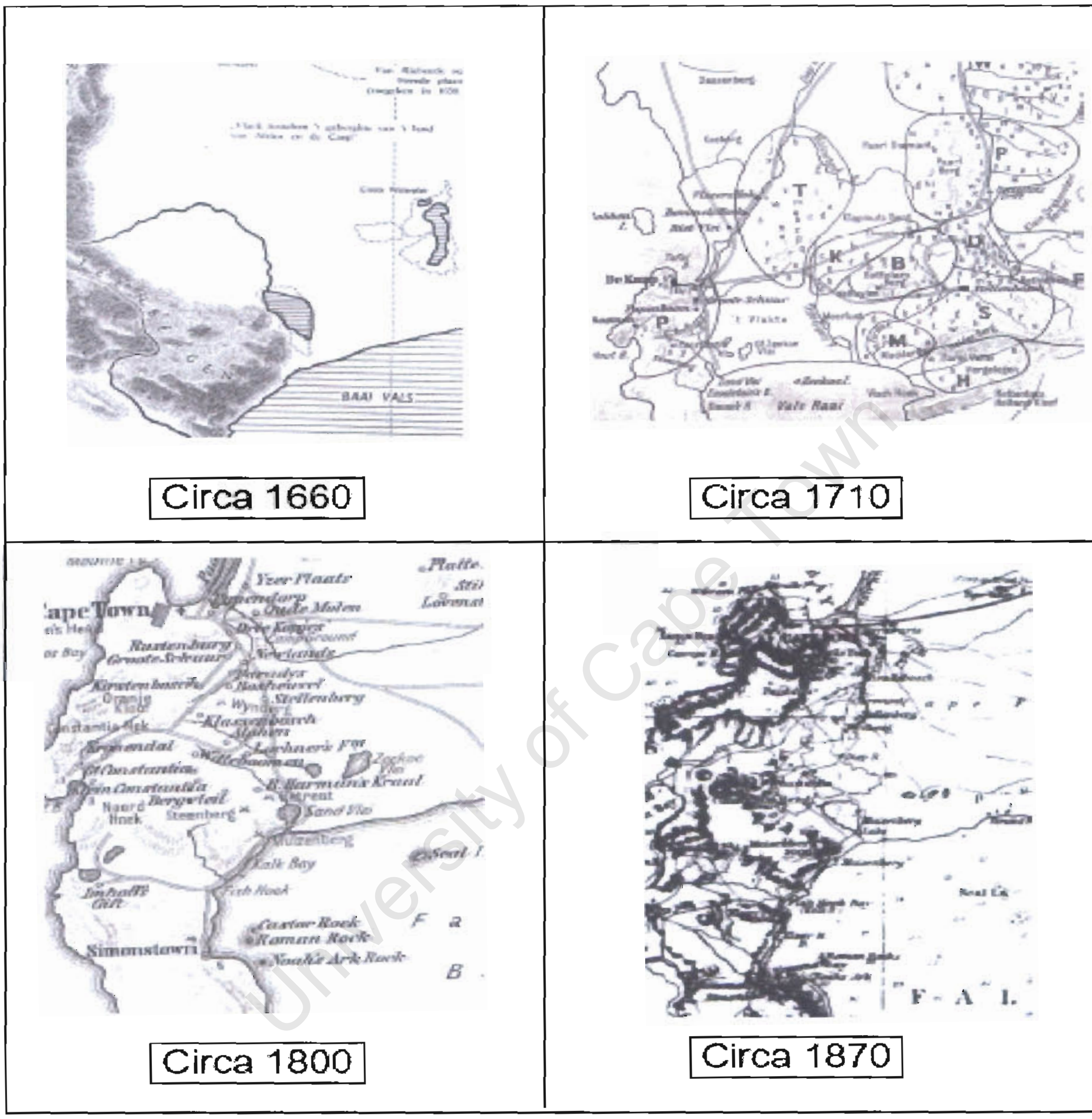
4.1.1 Zeekoevlei

Plate 4.1: Zeekoevlei in the mid-1990s, looking south towards False Bay (from Southern Waters, 2000)

With a surface area of 2.56 km^2 and perimeter of 12.6 km, Zeekoevlei is one of the largest remaining waterbodies on the Cape Flats (Southern Waters, 2000). Zeekoevlei is fed by the Big and Little Lotus Rivers, which drain approximately 80 km^2 of catchment. These "rivers" were initially ephemeral drainage channels that appeared only during wet periods. However, in order to initially pave the way for agriculture and thereafter to transport urban runoff, these channels were made permanent and sections were canalised. Prior to the modification of the hydrological regime, the wetland was inundated only during the winter rainy season. Water levels in the wetland fluctuated greatly in concert with the seasons, with Zeekoevlei almost completely drying up during summer (Stephens, 1929).

The following figure illustrates how the wetland changed in shape and location from the 1600s to the 1800s.

Figure 4.2: Maps from the Cape Archives showing the varying location and shape of Zeekoevlei from the 1600s to the 1800s (from Southern Waters, 2000).



In the mid 1700s the vlei was known to be home to several hippopotamuses. According to Southern Waters (2000) and Harding (1996), Zeekoevlei did not drain into the sea. However, the CSIR (1982) states that a natural outlet did indeed exist, but closed up during the first quarter of the 20th century. Thereafter, the adjacent dune field simply absorbed any water flowing from Zeekoevlei. As was characteristic of wetlands in the Cape Flats both Zeekoevlei and Rondevlei were inundated in the wet season, forming several connected vleis or ponds that gradually dried out. Prior to the construction of the Wynberg Disposal Works in the 1920s, the vlei was still relatively pristine and a haven for birds. In the following years, water quality in Zeekoevlei became compromised when some of the treated effluent from the Wynberg Disposal Works, which was discharged into the adjacent dunes, found its way into the wetland (Harding 1996; Southern Waters, 2000).

The next major modification of the wetland ecosystem came about in the mid 1940s when attempts were made to regulate the water level in the vlei (to enable year-round sailing). In due course, a 51 m long weir, with a crest height of 5.19 m above sea level, was built, and during the same period, the Zeekoe canal was extended right to the False Bay shoreline (Southern Waters, 2000). The weir achieved its aim of water level regulation, but it also prevented the vlei from being flushed during the winter wet season. The loss of this flushing action meant that algal populations and nutrients were confined within the wetland. But even so, the vlei (post-1945) was reported to be in good condition as far as water quality and clarity was concerned. At this time, sago pondweed (*Potamogeton pectinatus*) covered most of Zeekoevlei. The yachting community, wanting to eliminate the pondweed that fouled the centreboards and rudders of their sailing craft, made several complaints to the City of Cape Town. In 1951, their complaints led to the use of sodium arsenite (a salt of arsenic) on the pondweed. Within three weeks the pondweed had turned brown and sunk to the bottom of the vlei, with reportedly no adverse effects on fish, bird life or littoral vegetation (Cape Town City Engineers records; cited in Southern Waters, 2000). The following spring, however, the decaying plant material at the bottom of the vlei combined with catchment-derived nutrients resulted in a large bloom of algae (Southern Waters, 2000).

Studies (e.g. Harding, 1996 and Harding, 1991) have indicated that there is usually a cycle of growth and decline of algal populations within waterbodies. The die-off of algal populations is generally followed by the growth of other species. In Zeekoevlei, there had been a cyclic alternation between summer algal blooms and winter pondweed (Stephens, 1929). Harrison (1962), too, describes an alternating dominance by macrophytes (pondweed) and microphytes (algae) based on seasonal wet and dry periods. Since *ca* 1953, the lake has been continuously dominated by cyanobacterial phytoplankton (*Microcyctis aeruginosa* forma *flos-aquae*) (Southern Waters, 2000). This was due to the eradication of pondweed and the disruption of the natural hydrological cycle following water level regulation in 1948.

Anecdotal evidence (cited in Southern Waters, 2000) suggests that *Typha capensis* was introduced to Zeekoevlei along the exposed shoreline east of the present yacht club and the end of the peninsula in the 1950s. Due to the now constantly eutrophic state of the wetland, *Typha* was able to outcompete *Scirpus* (now *Schoenoplectus*) *nodosus*, which once delineated the dry-season high water level of the vlei. A small stand of *Schoenoplectus* can still be found in the deep-water belt of the wetland, but for all intents and purposes, *Typha capensis* is the dominant macrophyte in Zeekoevlei.

By the 1960s, an increase in urbanisation and industrialisation in the catchment resulted in an increase in pollutants entering the vlei. Nutrients were entering the system via the Big and Little Lotus Rivers as well as via seepage from the sewage works. Harding (1996) identifies farming and horticultural activities as major sources of phosphorus loading to Zeekoevlei. In 1963, plans were formulated to upgrade the existing Wynberg Sewage Disposal Works as it could no longer process the volume of wastewater entering it. Consequently, oxidation ponds to circulate and help treat effluent were constructed on the dune field south-east of Zeekoevlei. The present Strandfontein Wastewater Treatment Works (WWTW) was constructed in the 1970s. The maturation ponds of the WWTW and Zeekoevlei were connected by groundwater, and Zeekoevlei was often the recipient of nutrient-rich effluent. This seepage connection between the WWTW and the vlei was reported to be closed off during the mid 1980s (Southern Waters, 2000). There were rumours (always denied by the Cape Town City Council) that there were actually pipes discharging treated effluent from the WWTW into Zeekoevlei as well (Day, J.A., Zoology Department, University of Cape Town, pers comm.).

Approximately 20% of the vlei's volume is made up of silt. The large quantity of silt in the vlei, composed mainly of dead algae, contributes a significant quantity of nutrients as the algae decompose and release nutrients (nitrates and phosphorus) into the water (Southern Waters, 2000). This, coupled with increasing levels of sedimentation and input of nutrient from outside sources, has facilitated the advance of the reed beds into the lake. In 1995, the weir structure was modified to allow winter “drawdowns” of the lake. According to Southern Waters (2000), the primary purpose of the drawdowns was to allow physical access to allow reed and litter clearing. The drawdowns have a secondary, beneficial effect in that algae and nutrient-rich water are routinely flushed out of the lake.

4.1.2 Rondevlei

Plate 4.2: Rondevlei in the mid-1990s, looking east towards Zeekoevlei (from Southern Water, 2000)

Rondevlei has a surface area of approximately 0.45 km^2 and a perimeter of approximately 3 km. It has an average depth of 1.0 – 1.5 m in winter and 0.3 m in summer. The vlei was once physically connected to Zeekoevlei, but was probably isolated after a windblown sandbar became stabilised with vegetation (Middlemiss, 1975; cited in Southern Waters, 2000). An alternative theory is that the construction of the road to the Zeekoevlei peninsula physically separated Rondevlei from Zeekoevlei (Day, J.A., Zoology Department, University of Cape Town, pers comm.).

In the 1940s an outlet canal from Rondevlei was constructed to drain southwards into the adjacent dune fields. Rondevlei was declared a wild bird sanctuary in July 1950, and the Rondevlei Nature Reserve was established in 1952. 1954 saw the construction of a permanent weir to regulate the water level and prevent flooding of the nearby residential area. In the late 1950s or early 1960s the water level was lowered, and this, coupled with influx of nutrients from storm water channels and uncontrolled entry of silt into the system, allowed extensive beds of *Scirpus littoralis* and *Typha* to proliferate on the edges of the vlei (Langley, Cape Peninsula National Parks, pers comm.; cited in Southern Waters 2000). Around the same time, the grass *Paspalum vaginatum*, formed dense mats of waist-high grass that covered the entire shoreline and shallow water margins (Southern Waters, 2000). Until the early 1970s, the vlei was clear, but since then the vlei has been becoming shallower as siltation increases, and water clarity has been deteriorating.

Four hippopotamuses were introduced in 1981 to Rondevlei (the first in 300 years) to help control the encroachment of *Paspalum* into and around the vlei. Rondevlei up to 1996 had aquatic vegetation that alternated between algae and pondweed (similar to the cyclical pattern at Zeekoevlei). In recent years, however, eutrophication of the vlei has led to an increasing tendency for the formation of dense aggregations of blue-green algae during the winter months (Southern Waters, 2000). Furthermore, as with Zeekoevlei, Rondevlei's water has become very turbid, probably as a direct result of the blue-green bloom, of carp stirring sediment at the bottom of the vlei and of wind perturbation.

The main source of pollution of the vlei is urban runoff washed into the vlei via the Perth Road canal, the Italian Road culvert and the Cafda Village culvert. When Zeekoevlei is in flood the problem can be exacerbated when (1) discharge from Rondevlei to the Zeekoe canal is backed up; or (2) polluted waters from the Zeekoe canal backs up the Rondevlei canal, over the weir and into Rondevlei (Gibb Africa, 1997; cited in Southern Waters, 2000).

At present both vleis are permanent features, both are hypertrophic (Rudnick, 1986), and both have clearly endured drastic changes to the structure and distribution of their plant communities.

4.2 Khayelitsha wetlands

Plate 4.3: View of the Khayelitsha wetlands (2001), looking south east away from Khayelitsha (source: Ninham Shand photo library)

Under present conditions, the Khayelitsha wetlands comprise a system of connected wetlands, bordered by the N2 national road to the north, the Khayelitsha informal settlement to the south and west, and Baden Powell Drive to the east. Types of land-use in the Kuils

River catchment include high- and low-cost residential suburbs, WWTWs, commercial areas, agricultural lands, pockets of natural vegetation and tracts of undeveloped and vacant land (Ninham Shand, 1994). Residents of the Khayelitsha informal settlement rely heavily on the wetlands for food, as fishing is often necessary to supplement their diets. In addition residents use the wetlands as a grazing ground for their cattle. This is not always ideal as the feathery seeds of *Typha capensis* irritate the cattles' eyes and may lead to blindness.

In its pristine state, much of the area used to be a series of unconnected wetlands that were waterlogged during the winter rainy season, and which gradually dried out during summer. Nutrient levels were probably low and the wetland was probably rich in planktonic fauna and grassy floodplain vegetation (Low, 1998; Southern Waters, 1998).

The Kuils River itself was originally ephemeral, flowing during the winter months and drying during summer. In the vicinity of the Khayelitsha wetlands, it probably had two main channels that varied in alignment over time. There was no *Typha capensis* of any significance along the route (Day, J.A., Zoology Department, University of Cape Town, pers comm.). Over the last four decades or so, the Kuils River system has been significantly disturbed and manipulated. One of the channels that previously flowed north of the N2 was subsequently, for unknown reasons, blocked, resulting in the single southward channel around the Ninth South African Infantry (9SAI) military base carrying all the flow except during large flood events. The three main impacts on the system have been due to effluent from wastewater treatment works, continued urbanisation of the catchments, and infilling of the Khayelitsha area to facilitate the construction of formal and informal settlements.

In 1953, the only disturbance to the site was an aerodrome and the roads and buildings associated with farming activities. Aerial photography from 1971 show the construction of the N2 freeway, Baden Powell Drive and the associated borrow pits. At this time the river and wetland was still predominantly seasonal (Ninham Shand, 1994). The development of the barracks of the SA Cape Corps on the aerodrome further impacted the hydrological regime of the Kuils River (Ninham Shand, 1994). A Ninham Shand report (1986) identifies several Wastewater Treatment Works (WWTWs) as sources of nutrients of the Kuils River upstream of the Khayelitsha wetland. During 1979, the Scottsdene WWTW discharged 500 m^3/ day of treated effluent into the Bottelary River (a tributary of the Kuils River). The first WWTW at Bellville was commissioned in 1969 and had a capacity of 9 000 m^3/ day. By 1979, the treated effluent discharge totalled approximately 21 000 m^3/ day and a second works with a capacity of 23 000 m^3/ day was being commissioned. In addition, a total of approximately 2 900 m^3/ day was discharged from the Kuilsrivier, Mfuleni and South African Cape Corps WWTWs during the same time period. By 1999, The Scottsdene WWTW was discharging 4 Mℓ of treated effluent per day and Bellville WWTW was discharging 52 Mℓ/ day (Ninham Shand, 1999b). The discharge of treated effluent from the WWTWs turned the Kuils River into a permanent river and consequently the wetland system lost its seasonality as it was fed with a permanent stream of water. Associated with this was a significant decrease in habitat diversity, manifest in a decline in plant species and the proliferation of large, monospecific stands of *Typha capensis*. Streamflow was also augmented by runoff from irrigated agricultural land and from the hardened surfaces associated with urbanisation.

Over the period from 1971 to 1993, the parts of the wetland system were subject to considerable disturbance and infilling to create the Khayelitsha informal settlement (Ninham Shand, 1994). The lack of a sewage system to service the settlement has no doubt added to the faecal coliform and nutrient pollution of the wetland.

As a consequence of these impacts, the wetland has been transformed from a seasonal, nutrient-poor system to a permanent, nutrient-rich system. There has been a considerable impact on the indigenous flora and fauna and at present only remnants exist. The nutrient-rich water, coupled with the elevated water table, caused a loss of biodiversity (evidenced by the proliferation of *Typha capensis*). The encroachment of *Typha* led to a decrease of grassy pans and open water, the habitat for many invertebrates and birds. The greatest impact was probably on aquatic invertebrates in the wetlands, many of which are now extinct (Southern Waters, 1998 and Day, J.A., Zoology Department, University of Cape Town, pers comm.). The changes described above clearly had a negative impact on the ecological value of the Khayelitsha wetlands.

Currently, the open water bodies are used for fishing, swimming and recreation. A positive biophysical impact is that the open water provides a valuable habitat for various bird species to swim and feed in. *Typha capensis* also provides a suitable site for many bird species to nest in but it also poses a safety hazard. A study by Ninham Shand (1999a) reports that criminals sometimes hide within the dense vegetation in order to mug or assault passers by.

CHAPTER FIVE

5 RESULTS

5.1 Present Ecological Status

The summary scoresheet (Table 2) shows Southern Water's (2000) Present Ecological Status (PES) assessment of Zeekoevlei and Rondevlei as well as this dissertation's independent assessment of Zeekoevlei, Rondevlei and the Khayelitsha wetlands. The original scoresheet, which is a key component of the DWAF methodology to assess the PES of wetlands, is included in Appendix A. The scoring system used is as follows:

0 = critically modified

1 = seriously modified

2 = largely modified

3 = moderately modified

4 = largely natural

5 = natural or unmodified

For each score, a relative confidence in the assessment is also indicated, where:

1 = marginal/ low confidence

2 = moderate confidence

3 = high confidence, and

4 = very high confidence

For each assessment, the mean score is calculated and thereafter interpreted using the following table:

Table 1: Interpretation of scores for determining present ecological status

Interpretation of Mean of Scores for all Attributes: Rating of Present Ecological Status Category (PES Category)
WITHIN GENERALLY ACCEPTABLE RANGE
CATEGORY A >4; Unmodified, or approximates natural condition.
CATEGORY B >3 and <=4; Largely natural with few modifications, but with some loss of natural habitats.
CATEGORY C >2 and <=3; moderately modified, but with some loss of natural habitats.
CATEGORY D =2; largely modified. A large loss of natural habitats and basic ecosystem functions has occurred.
OUTSIDE GENERAL ACCEPTABLE RANGE
CATEGORY E >0 and <2; seriously modified. The losses of natural habitats and basic ecosystem functions are extensive.
CATEGORY F 0; critically modified. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat.

Table 2: Summary scoresheet of the PES assessments

Criteria and attributes	**Zeekoevlei 1**		**Zeekoevlei 2**		**Rondevlei 1**		**Rondevlei 2**		**Khayelitsha**	
Hydrologic	Score	Confidence	Score	Confidence	Score	Confidence	Score	Confidence	Score	Confidence
Flow modification	0	4	0	4	2	4	0	4	0	4
Permanent Inundation	1	4	0	4	2	4	1	3	5	4
Water Quality										
Water Quality Modification	0	4	1	4	2	4	1	3	0	4
Sediment load modification	0	4	1	4	3	4	2	3	2	3
Hydraulic/ Geomorphic										
Canalisation	0	4	0	4	2	4	1	4	3	3
Topographic Alteration	0	4	1	3	2	4	3	2	2	3
Biota										
Terrestrial Encroachment	2	4	3	2	2	4	3	2	2	3
Indigenous Vegetation Removal	2	4	3	2	2	4	2	2	2	3
Invasive plant encroachment	1	4	2	3	2	4	4	3	1	3
Alien fauna	2	4	2	2	2	4	4	3	3	3
Overutilisation of biota	2	4	3	3	4	4	5	3	2	3
TOTAL	**10**	**44**	**16**	**35**	**25**	**44**	**26**	**32**	**22**	**36**
MEAN	**0.9**	**4**	**1.5**	**3.2**	**2.3**	**4**	**2.4**	**2.9**	**2**	**3.3**

Zeekoevlei 1 and Rondevlei 1 = Southern Waters' (2000) PES assessments.
Zeekoevlei 2, Rondevlei 2 and Khayelitsha = this dissertation's PES assessments.

According to Southern Waters (2000), the Present Ecological Status (PES) of Zeekoevlei is Category E. This means that the wetland is "seriously modified" and that "The loss of natural habitats and basic ecosystem functions are extensive". Southern Waters' (2000) PES assessment of Rondevlei showed it to be Category C. This means that the system is "moderately modified" and that there is a "large loss of natural habitats and basic ecosystem functions". These results were evaluated against this dissertation's independent assessment and were verified. Although the individual scores may have differed slightly the overall assessments were very similar.

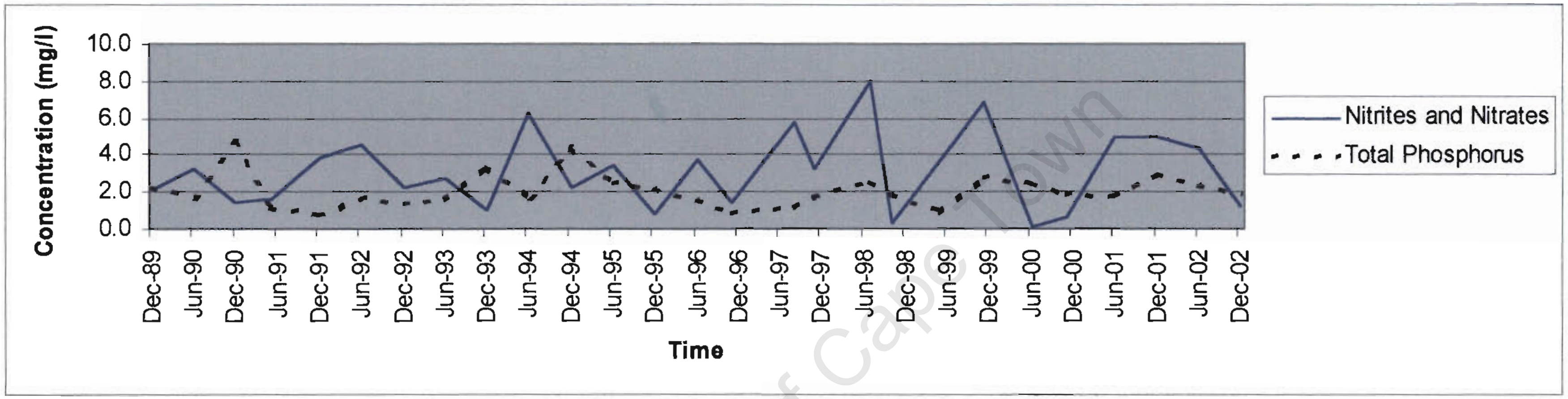
The PES assessment of Khayelitsha wetlands revealed it to be a Category D wetland. The system is "largely modified". This means that a "large loss of natural habitats and basic ecosystem functions has occurred".

These assessments of PES begin to paint a picture of ecosystems that have been significantly modified from their pristine states.

5.2 Water chemistry

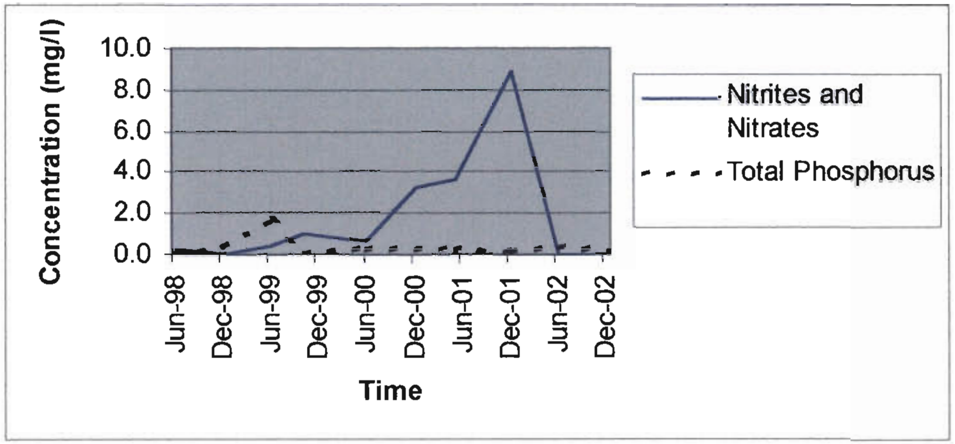
The figures below were synthesised from data (Appendix C) received from the City of Cape Town's Scientific Services department. They show the concentration of nutrients entering the selected wetlands over time.

Figure 5.1: Concentration of nutrients entering Zeekoevlei via Big Lotus River over time



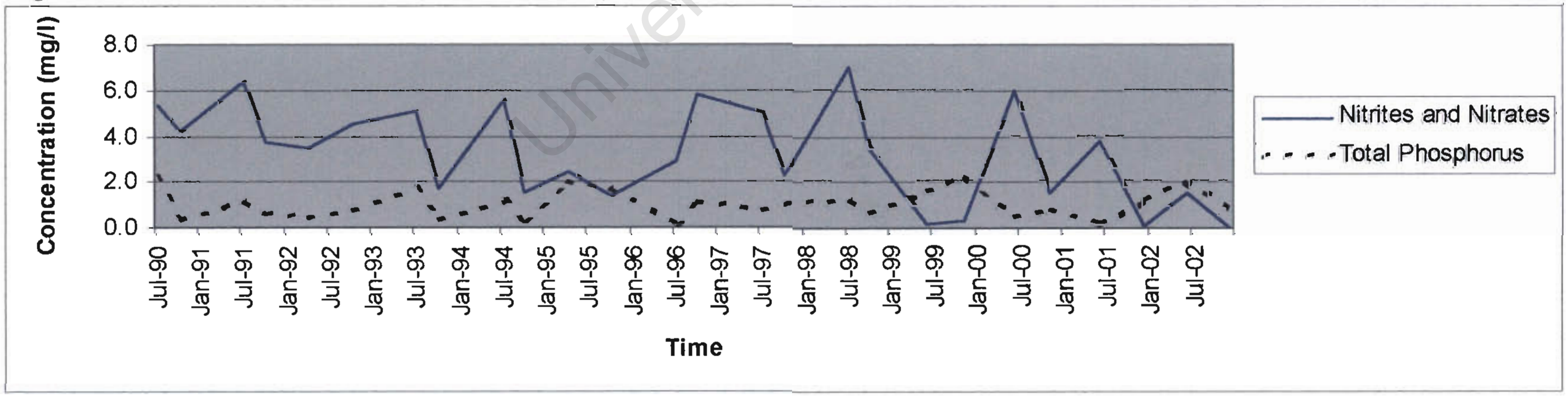
It is difficult to identify any significant trend from Figure 5.1. It is clear that the concentrations of nitrates and nitrites (NO_x) are almost always higher than those of the total phosphorus. From the DWAF (1996b) water quality guidelines it is apparent the total phosphorus and NO_x concentration levels lie within the eutrophic range, i.e. total phosphorus and NO_x entering Zeekoevlei is equal to or greater than 0.025 – 0.25 mg/λ and 2.5 – 10 mg/λ respectively. It appears that concentrations of phosphorus and NO_x exhibit seasonal cycles. Generally, concentrations increase during winter and decline during summer (January 1991 *vs* July 1991, January 1998 *vs* July 1998, January 2000 *vs* July 2000, etc.). After 1995, there appears to be an increase in the annual range in the concentration of NO_x.

Figure 5.2: Concentration of nutrients entering Rondevlei over time



It can be seen that NO_x concentrations entering Rondevlei since 1999 been greater than total phosphorus entering the wetland (Figure 5.2). The data from Scientific Services did not have a December 2002 value for NO_x, hence the zero value. Between June 2000 and December 2001 there was a large increase in the concentration of NO_x entering Rondevlei. According to the DWAF (1996b) guidelines for water quality, Rondevlei has been eutrophic with respect to NO_x since December 2000. Apart from the period between December 1998 and June 1999, relatively low concentrations of total phosphorus have been entering Rondevlei.

Figure 5.3: Concentration of nutrients entering Khayelitsha wetlands over time

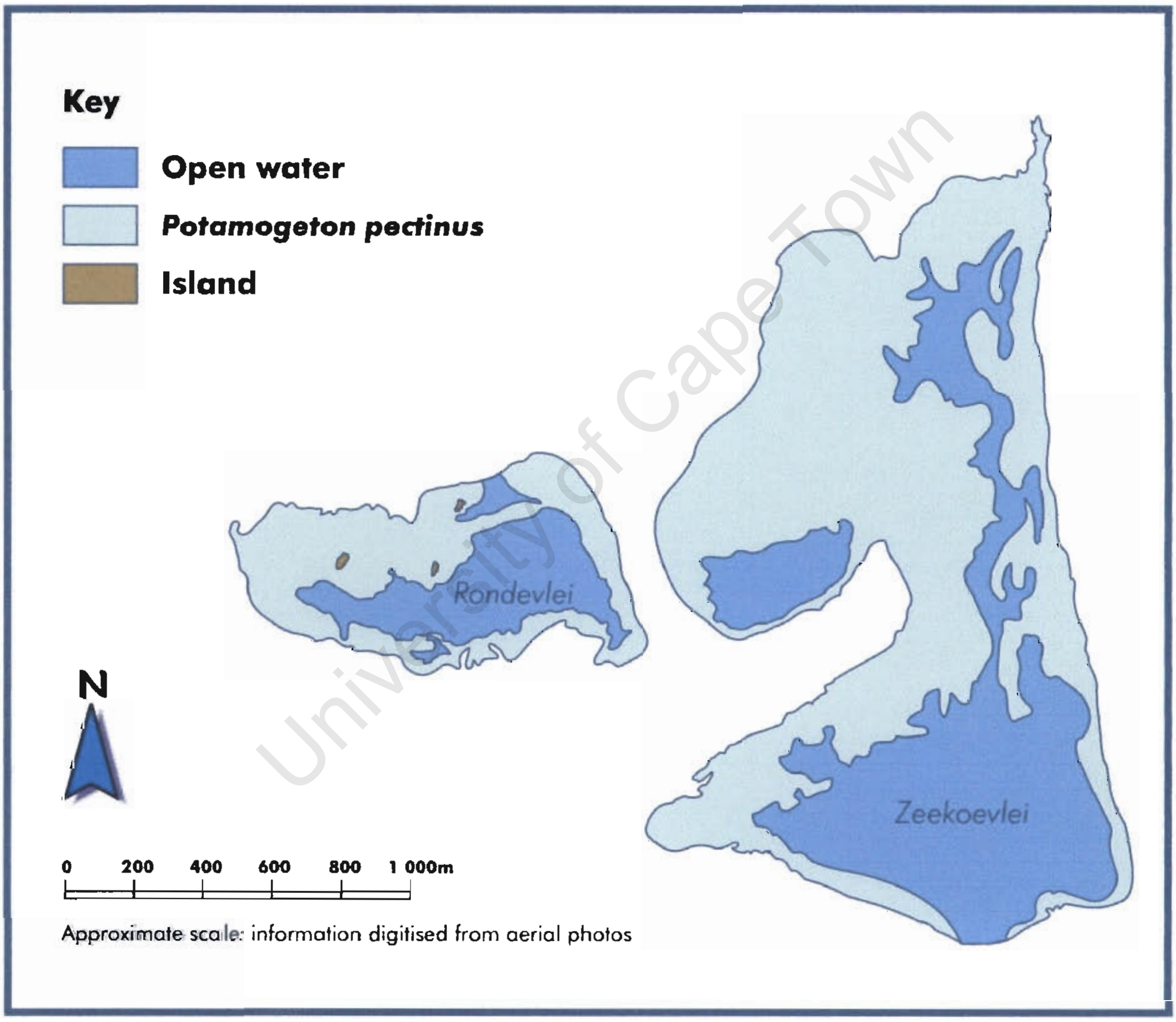


As with Zeekoevlei, the concentrations of nutrient entering the Khayelitsha wetlands lie well within the eutrophic range for aquatic ecosystems (DWAF, 1996b) (Figure 5.3). Also, similar to Zeekoevlei, the range of NO_x concentrations appears to have increased after 1996. Generally, the amount of phosphorus entering the Khayelitsha wetlands is higher than that entering Zeekoevlei or Rondevlei (for Khayelitsha, total phosphorus concentrations oscillate around the 2.0 mg/λ level while for Zeekoevlei and Rondevlei, total phosphorus is most often below the 2.0 mg/λ level).

5.3 Changes to the wetlands over time

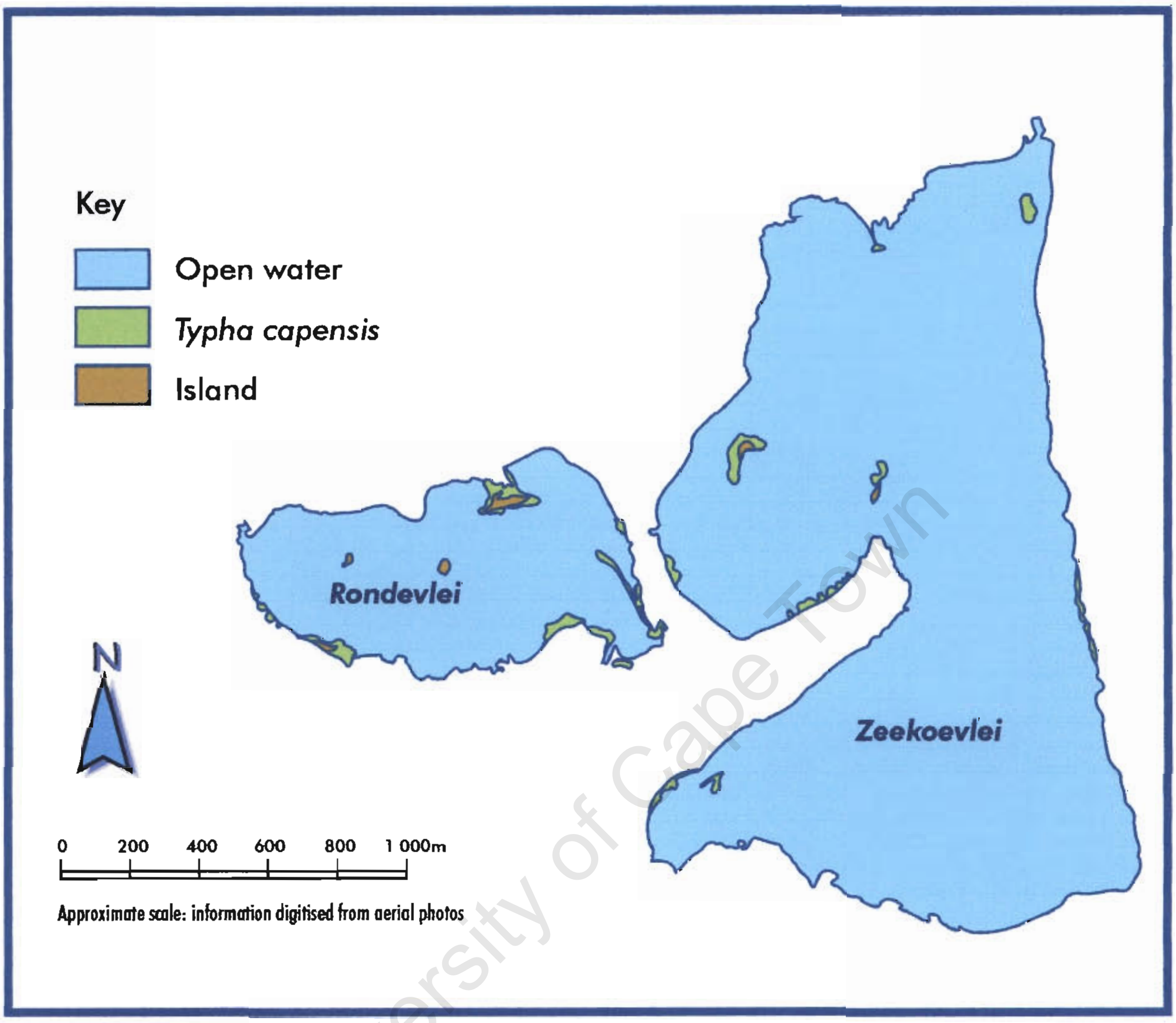
The following figures, based on the aerial photographs, illustrate the changing areas of *Typha capensis* within each of the wetlands.

Figure 5.4: Zeekoevlei and Rondevlei in 1944



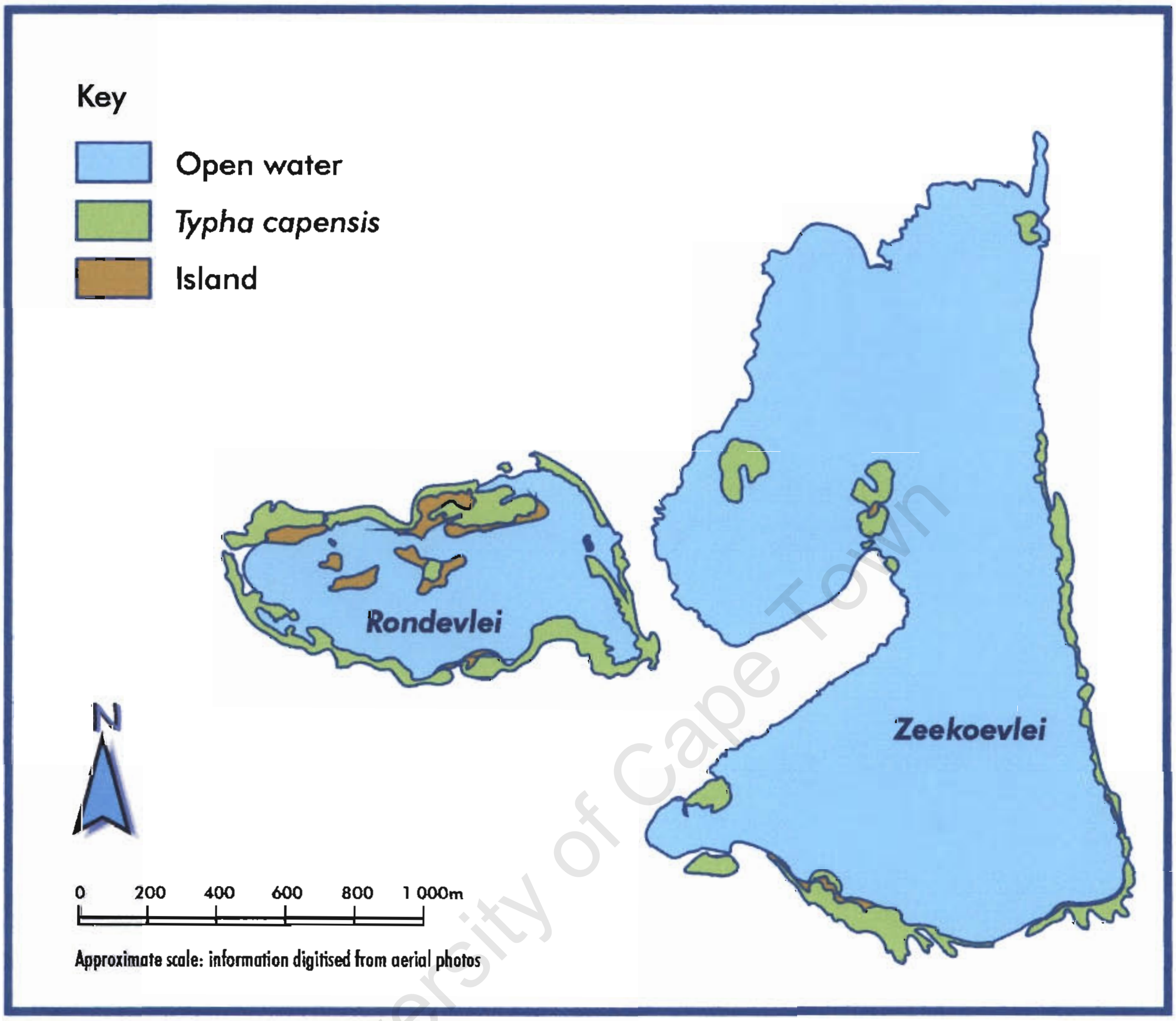
There was very little or no *Typha capensis* at all in Zeekoevlei or Rondevlei in 1994 (Figure 5.4). The wetlands were largely natural. Much of the shorelines of the vleis were vegetated with pondweed (*Potamogeton pectinatus*), which tended to expand toward the centre of the vleis.

Figure 5.5: Zeekoevlei and Rondevlei in October 1958



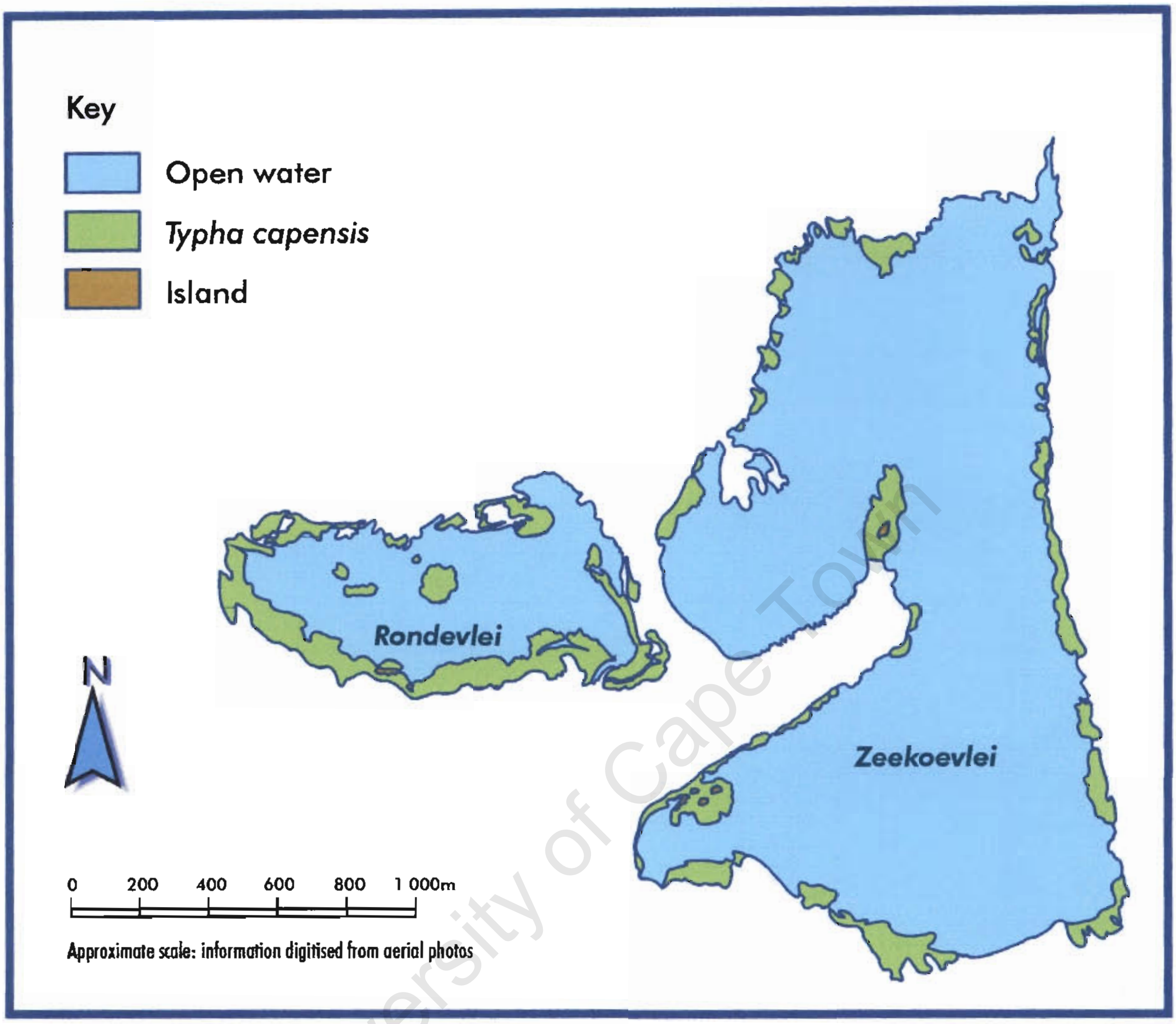
Small stands of *Typha capensis* occur in isolated areas within the wetlands. The pondweed that was dominant can no longer be seen (Figure 5.5).

Figure 5.6: Zeekoevlei and Rondevlei in April 1968



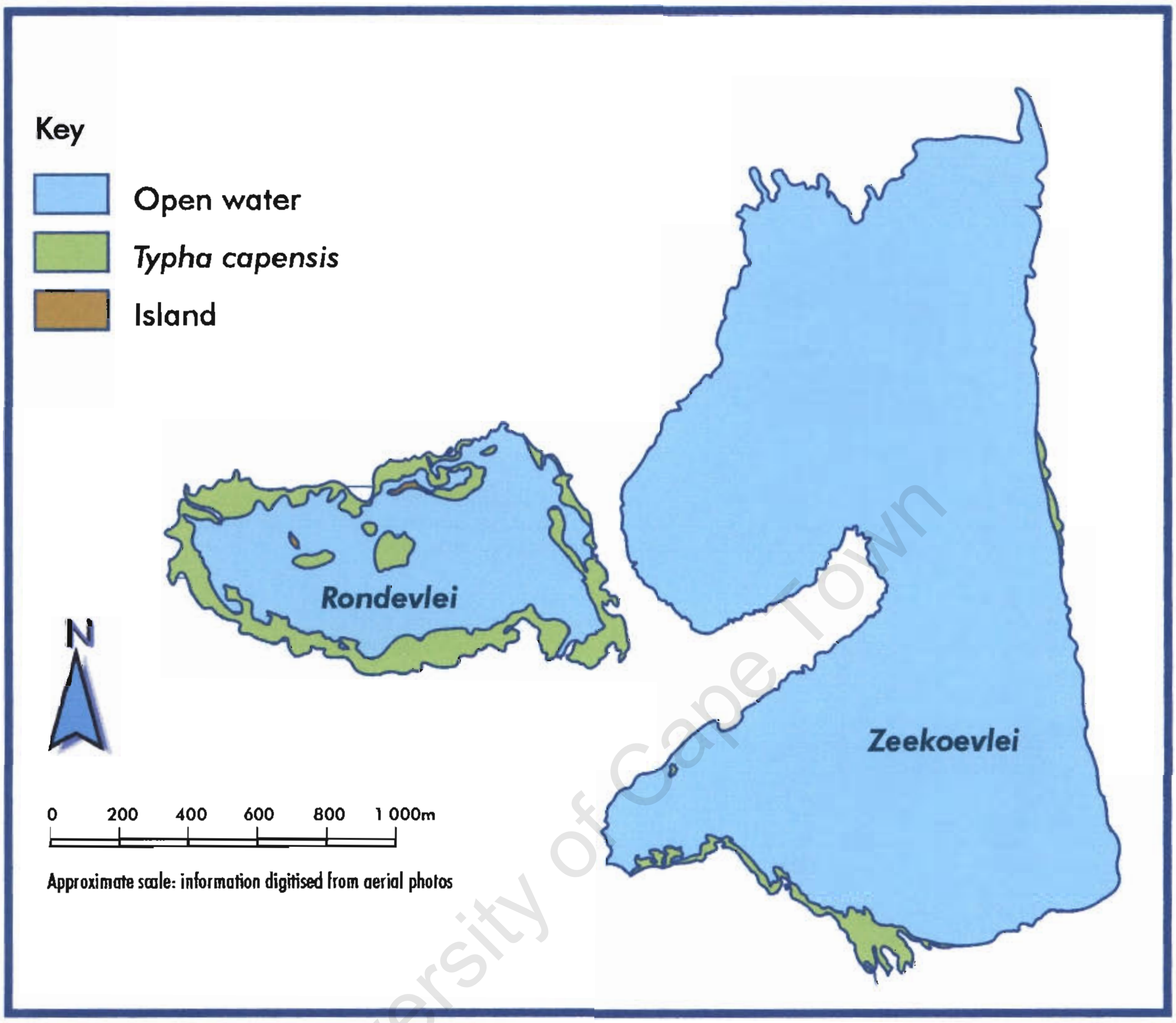
By 1968, *Typha capensis* has spread dramatically, covering all of Rondevlei's shoreline and about half of Zeekoevlei's. In addition, the plant has begun extending into the open water of both wetlands (Figure 5.6).

Figure 5.7: Zeekoevlei and Rondevlei in August 1988



Typha capensis has proliferated and cover most of the shoreline of both wetlands (Figure 5.7). The stands that had invaded the north eastern part of Zeekoevlei (*cf* Figure 5.6) were probably removed to facilitate boating.

Figure 5.8: Zeekoevlei and Rondevlei in November 2000



From Figure 5.8 it can be seen that Zeekoevlei has undergone an intensive *Typha* clearing operation. Except for a few isolated spots on the southern and eastern shores, *Typha capensis* has been eradicated. The physical clearing of *Typha* coupled with the winter drawdowns have had a decimating effect on the *Typha* in Zeekoevlei. There does not appear to have been a significant reduction of *Typha capensis* in Rondevlei.

Figure 5.9: Khayelitsha wetlands in 1944

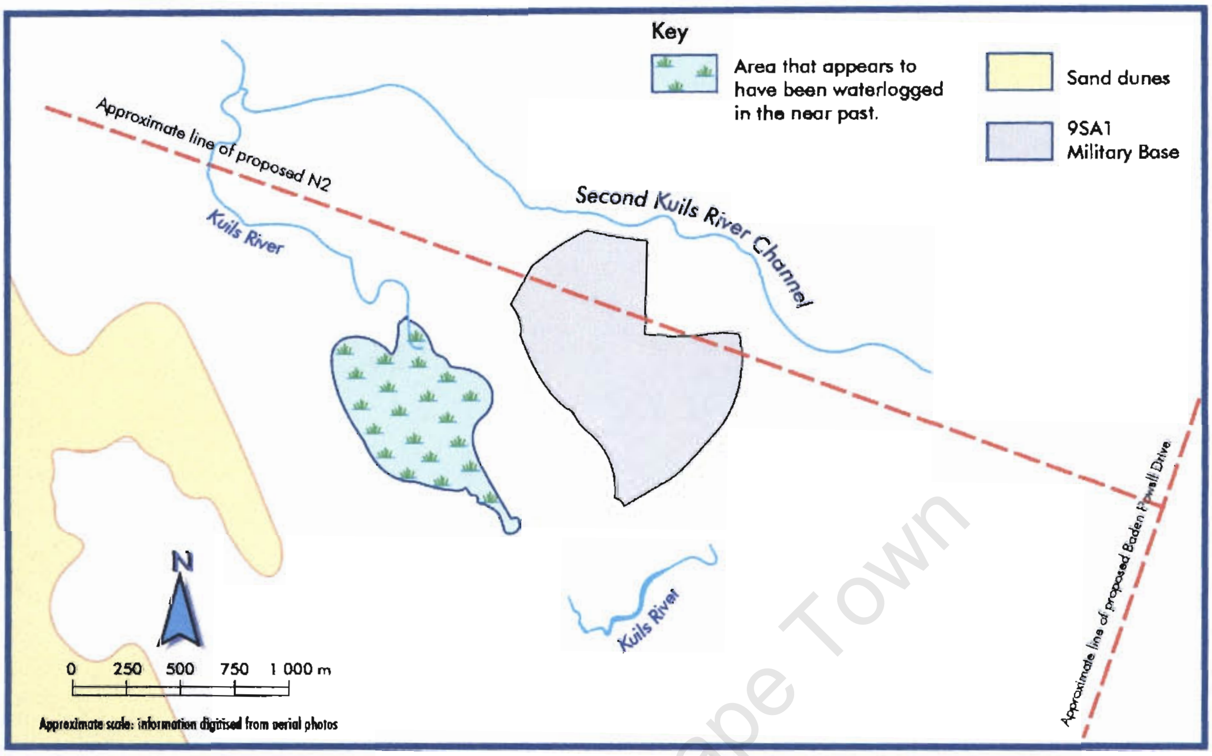


Figure 5.9 shows a largely natural area. The Kuils River is still seasonal and is not confined to a single channel. The N2, Baden Powell Drive and the military base have not been built yet. The figure shows an area that has been waterlogged recently, evident from a vegetation type that is distinct from the terrestrial vegetation around it. This "wetland" area is probably a result of recent winter rains (the date of this figure is unknown). The edge of a dune field can be seen to the east.

Figure 5.10: Khayelitsha wetlands in 1953

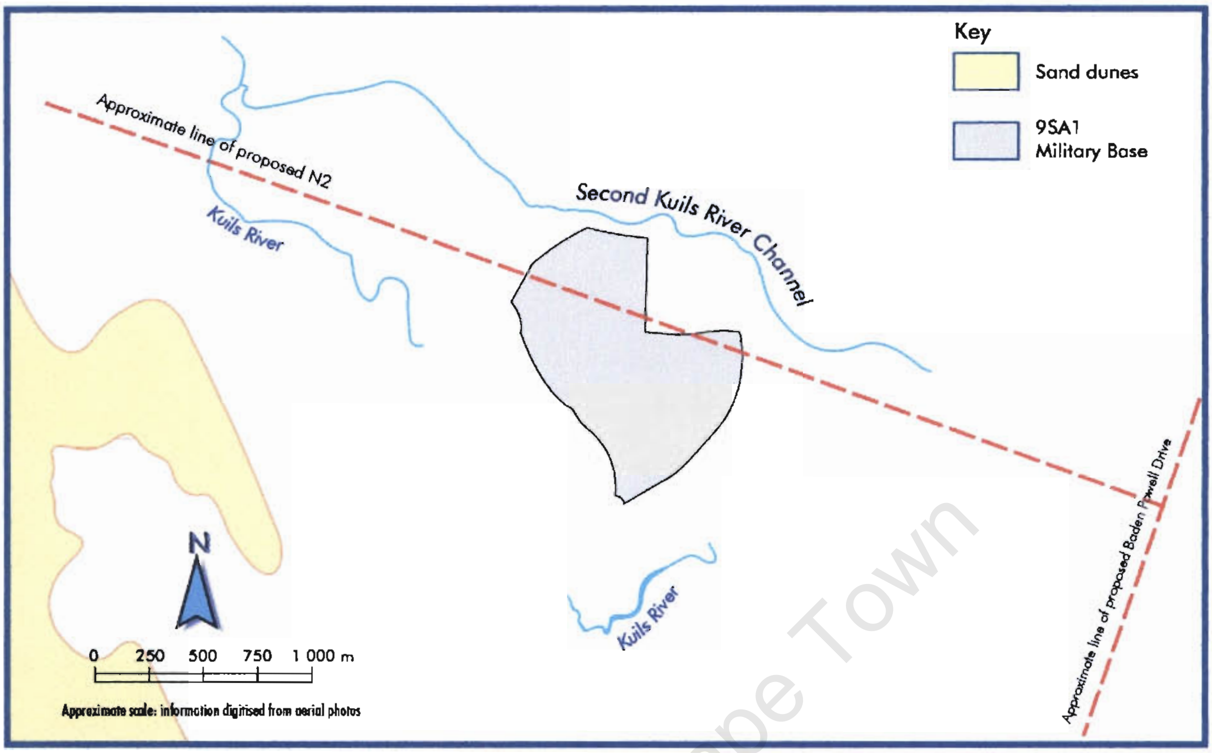
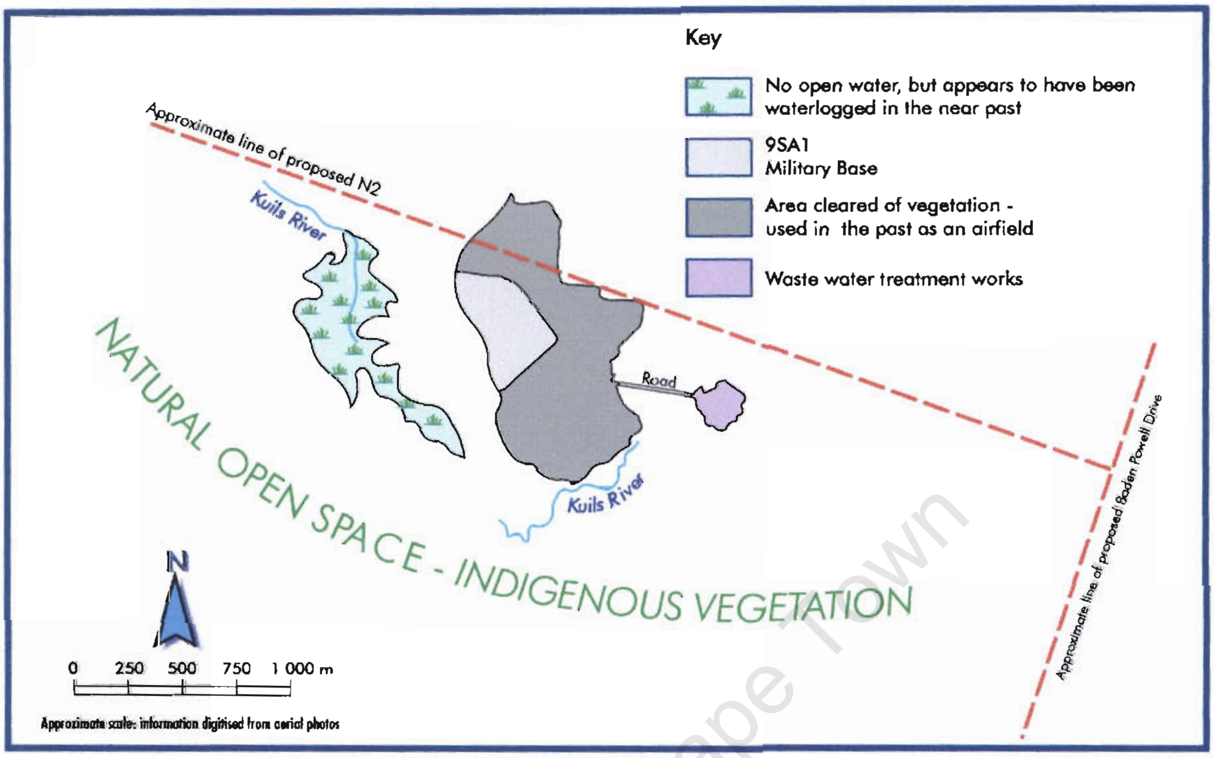


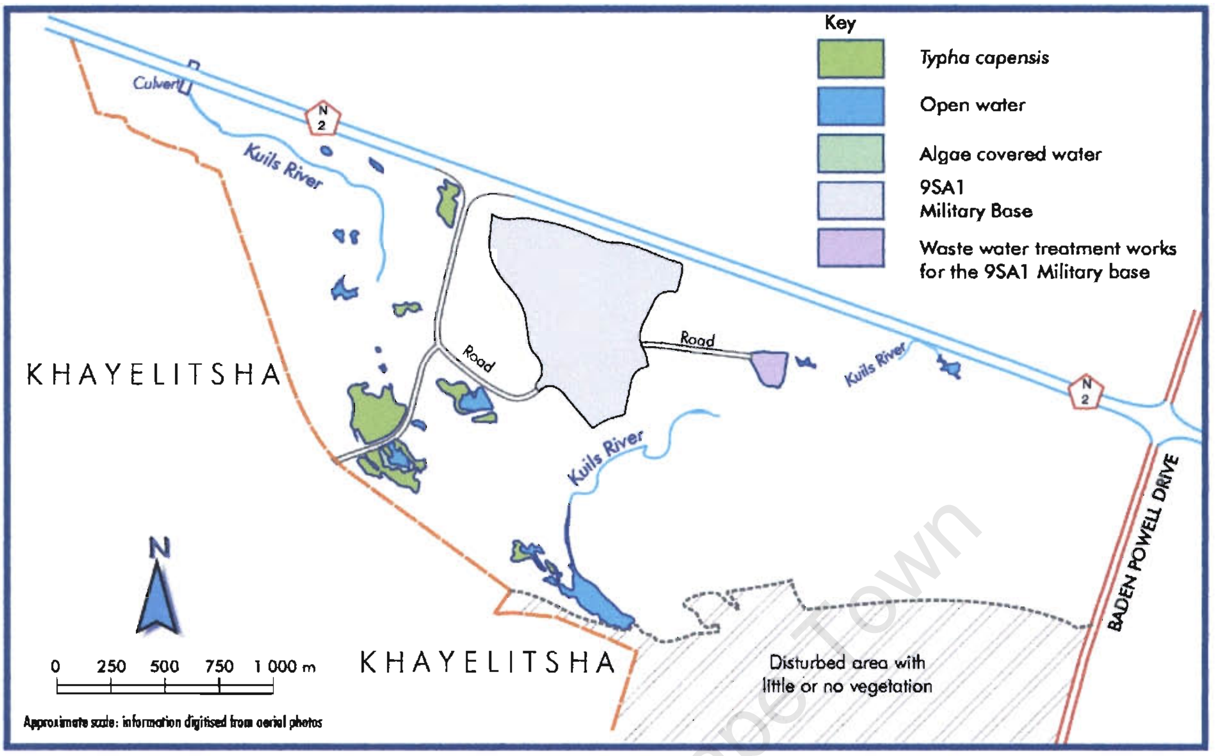
Figure 5.10 paints a very similar picture to Figure 5.9. The only difference is that now the "wetland" area can't be seen. This is probably because the aerial photograph was taken in summer, the dry season. As with Figure 5.9, the date is unknown.

Figure 5.11: Khayelitsha wetlands in April 1968



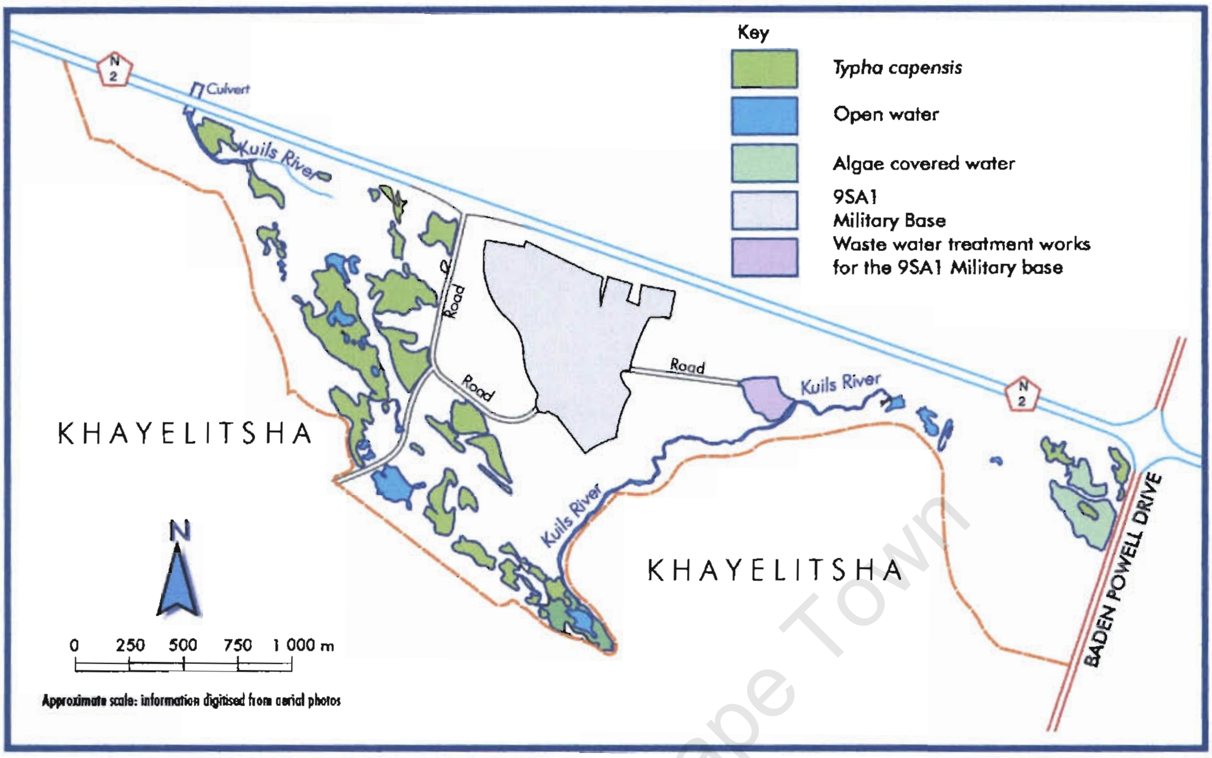
The aerial photograph on which Figure 5.11 is based was taken in the wet winter season. Predictably, the "wetland" area has returned. The dune field can no longer be seen and the first incarnation of the military base has been built. Much of the area still comprises natural open space.

Figure 5.12: Khayelitsha wetlands in August 1988



The above figure indicates that by 1988, the N2, Baden Powell Drive and the present-day military base have been built. Another major change is that the Khayelitsha informal settlement has developed to the south east. The Kuils River has been harnessed into a single channel and now flows through a culvert under the N2. Distinct water bodies can be seen, as well as *Typha capensis*. Much of the natural open space that occurred south of the N2 has been disturbed.

Figure 5.13: Khayelitsha wetlands in November 2000

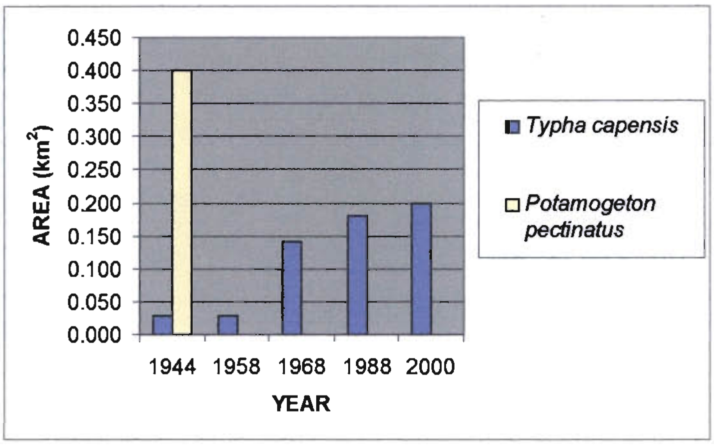


Even though well into summer, plenty of water can still be seen. Furthermore, *Typha capensis* has proliferated, occupying large areas of the wetlands (Figure 5.13). The informal settlement has also proliferated. It has extended northwards and eastwards, reducing the extent of the wetlands. The system of wetlands is now a permanent.

It is observed that in all cases (except for Zeekoevlei and Rondevlei in 2000) the area occupied by *T capensis* has been increasing steadily over time.

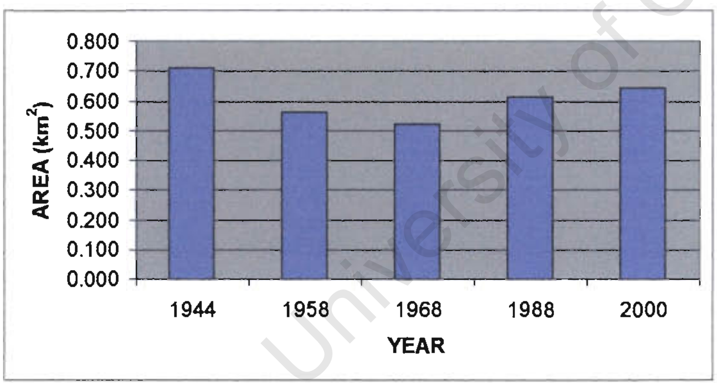
The following graphs quantify the changes illustrated by Figures 5.4 to 5.13.

Figure 5.14: Histogram showing the changes to Rondevlei over time



The *Potamogeton pectinatus* (pondweed) that dominated the vlei in 1944 was totally eradicated by 1958. After 1958, the area covered by *Typha capensis* rose steadily.

Figure 5.15: Histogram showing changes to the area of open water at Rondevlei over time



The vlei generally ranges from 0.5 to 0.6 km^2 in area. There isn't a discernible seasonal variation and the summer (November) 2000 area is higher than the winter (April) 1968 area.

Figure 5.16: Area occupied by *Typha* as a percentage of the area of Rondevlei over time

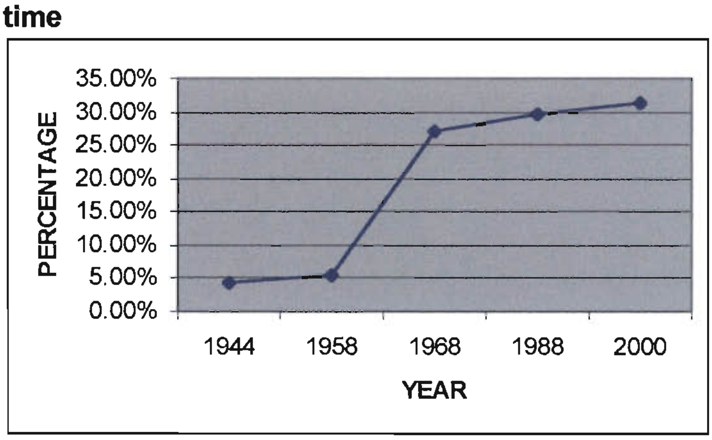


Figure 5.16 emphasises the dramatic increase in *Typha capensis* in Rondevlei from approximately 5% in 1958 to

approximately 27% in 1968. In 2000 *Typha* represents approximately 31% of the entire area of Rondevlei.

Figure 5.17: Histogram showing the changes to Zeekoevlei over time

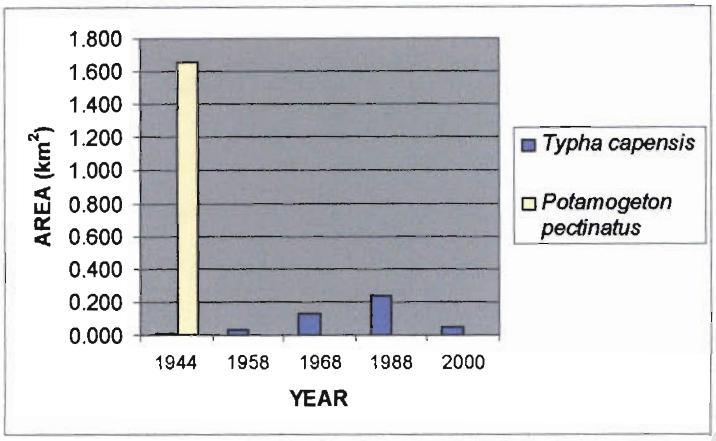
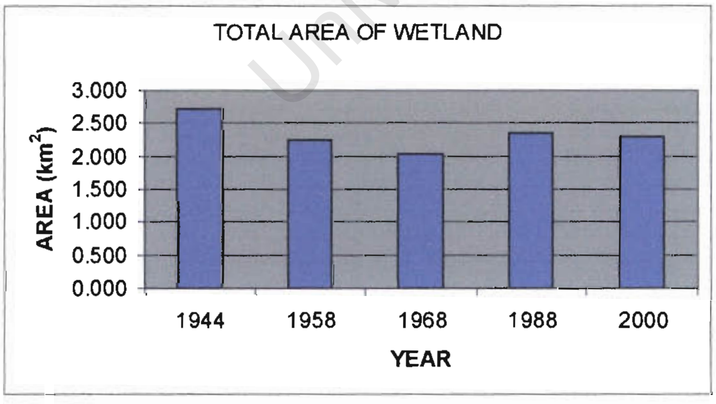


Figure 5.17 is similar to Figure 5.14 in that between 1944 and 1958, the pondweed had completely disappeared from Zeekoevlei. *Typha capensis* increased steadily until 1988. In 2000, the area occupied by *Typha* decreased drastically due to physical clearing and the effects of the winter drawdowns.

Figure 5.18: Histogram showing changes to the area of open water at Zeekoevlei over time



As with Figure 5.15, Figure 5.18 shows no discernible seasonal variation in the overall area of Zeekoevlei. Winter (April) 1968 appears to have been relatively dry, while summer (November) 2000 appears to have been relatively wetter.

Figure 5.19: Area occupied by *Typha* as a percentage of the area of Zeekoevlei over time

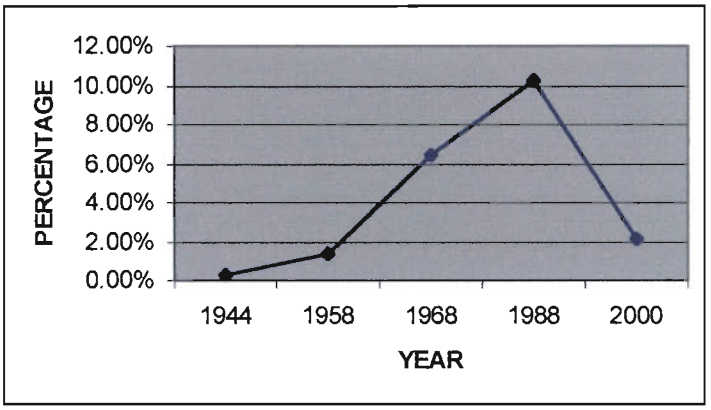
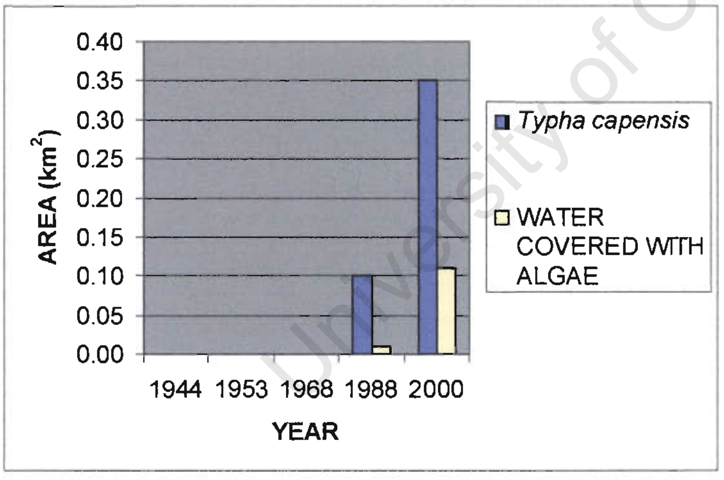


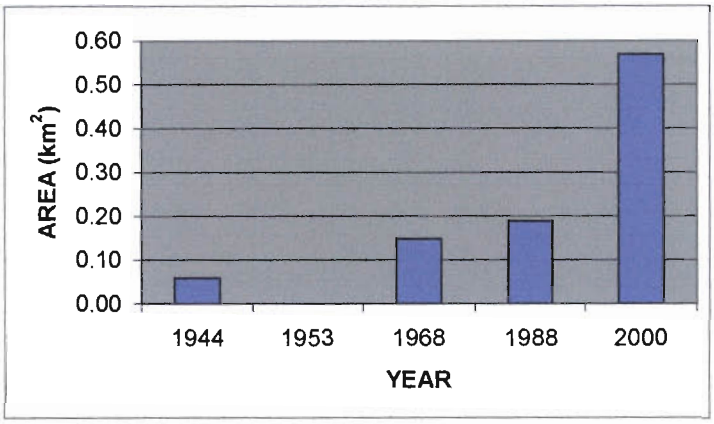
Figure 5.17 can be misleading due to the vertical scale of the graph and may lead one to believe that *Typha capensis* did not increase drastically. Figure 5.19 dispels this notion by emphasising that the area of Zeekeovlei occupied by *Typha capensis* increased from approximately 0.5% in 1944 to approximately 10% in 1988.

Figure 5.20: Histogram showing the changes to the Khayelitsha wetlands over time



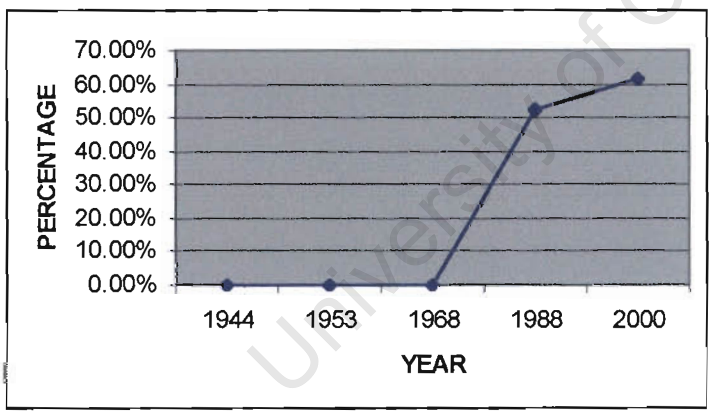
Up until 1968, there was little or no *Typha capensis* in the Khayelitsha wetlands at all (Figure 5.20). After 1988 the area occupied by *Typha* increases significantly. Moreover, the amount of algae in the water bodies increases from approximately 0.01 km^2 in 1988 to just over 0.1 km^2 in 2000. No algae were present prior to 1988.

Figure 5.21: Histogram showing changes to the area of open water in the Khayelitsha wetlands over time



The increase in area of the wetlands from 1988 to 2000 is illustrated. The 1944 and 1968 areas represent, not water bodies, but land that appears to have been waterlogged in the past (*cf.* Figures 5.9 and 5.11).

Figure 5.22: Area occupied by *Typha capensis* as a percentage of the Khayelitsha wetlands

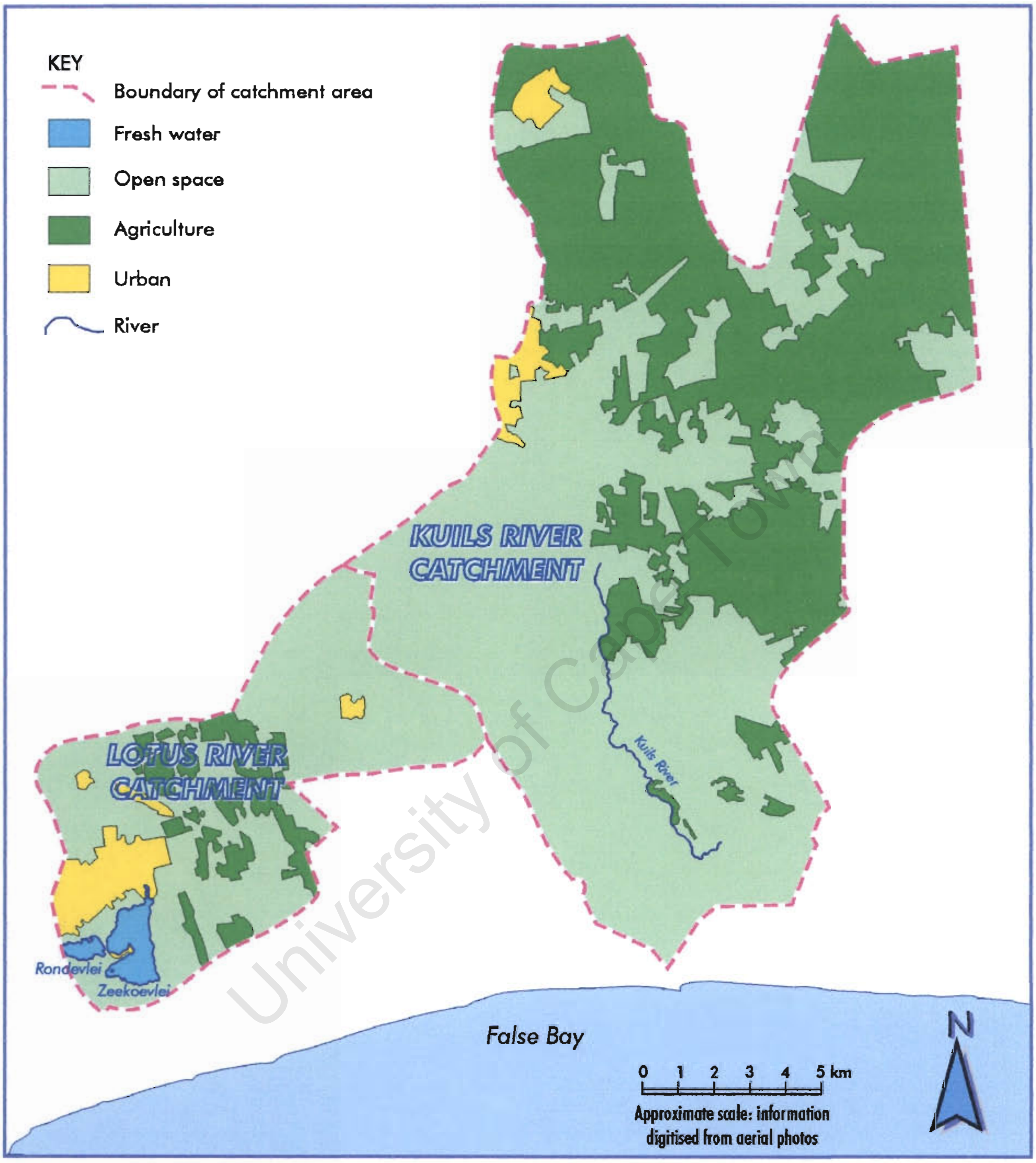


This figure emphasises the drastic increase in *Typha* from 1968 to 2000. No *Typha capensis* was noted from 1944 to 1968.

5.4 Pattern of land-use development within the selected catchments

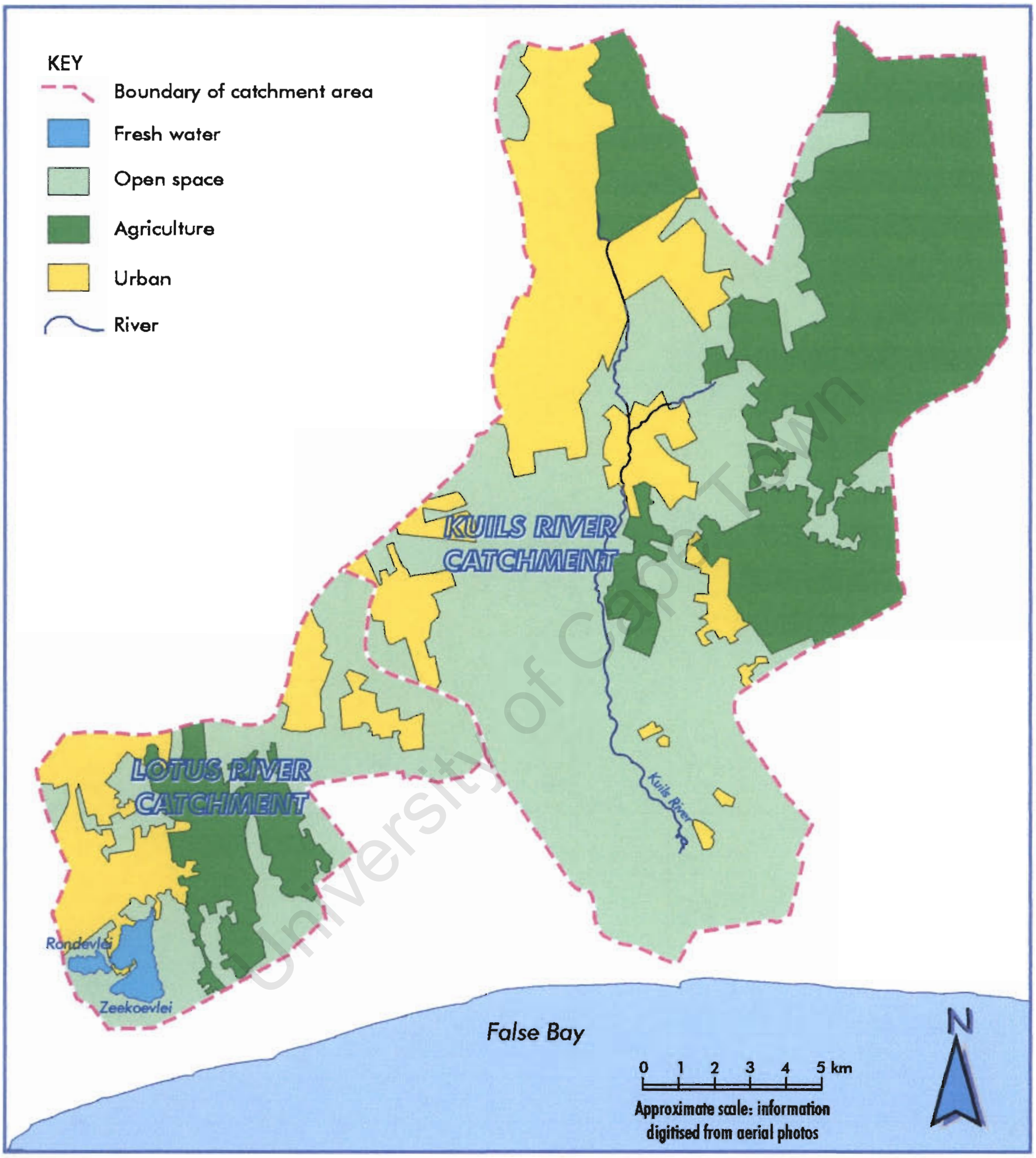
The following figures illustrate the pattern of land-use development within the selected catchments.

Figure 5.23: Lotus River and Kuils River catchments in 1953



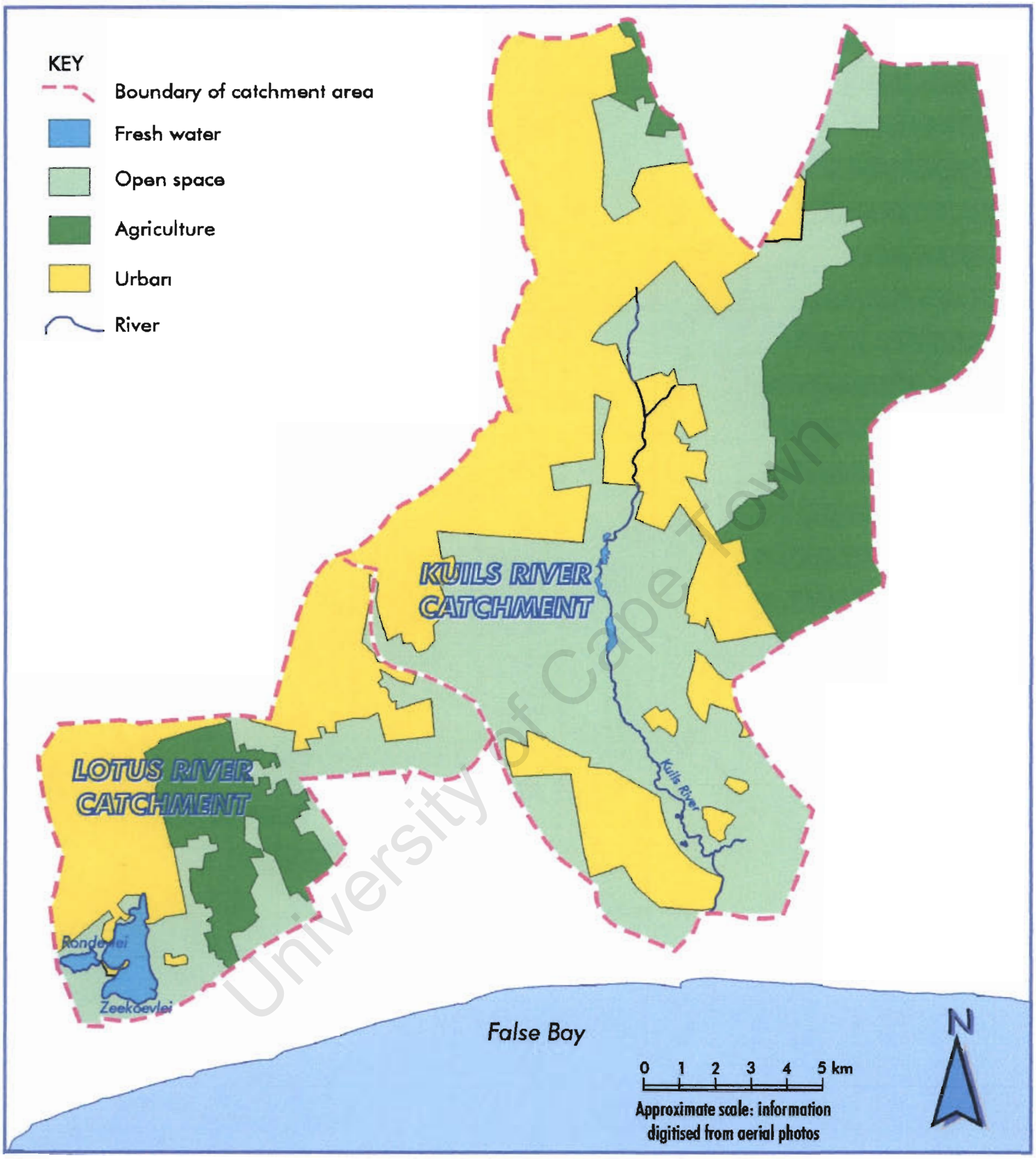
In 1953 both the Lotus River and the Kuils River catchment were dominated by large areas of open space (comprising a mix of indigenous and alien vegetation). Agriculture, in addition to open space, dominated the Kuils River catchment, but was sparsely dispersed within the Lotus River catchment (Figure 5.23). Urban areas were isolated and concentrated around a few key nodes.

Figure 5.24: Lotus River and Kuils River catchments in 1977



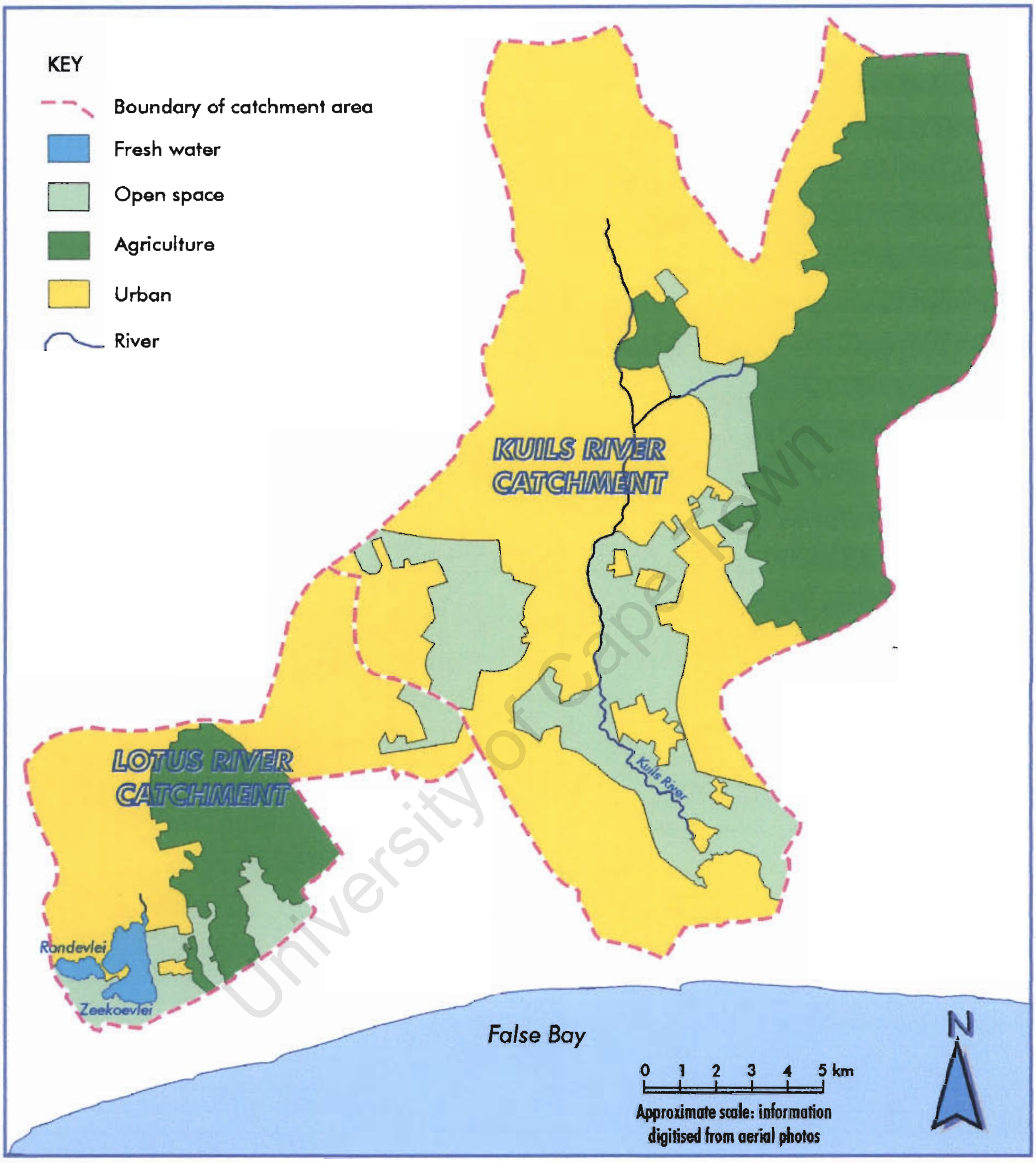
By 1977, the urban areas had begun to grow (Figure 5.24). Agriculture in the Kuils River catchment occupied much of its original area but became more consolidated. In the Lotus River catchment agriculture appears to have increased in area and become more consolidated (the Philippi horticultural area).

Figure 5.25: Lotus River and Kuils River catchments in 1988



Urbanisation had begun invading much of the open space by 1988 (Figure 5.25). Agriculture in the Kuils River catchment has also lost ground to urbanisation. In the Lotus River catchment also, urbanisation has increased but not into the Philippi horticultural area (the only real agriculture occurring within the catchment).

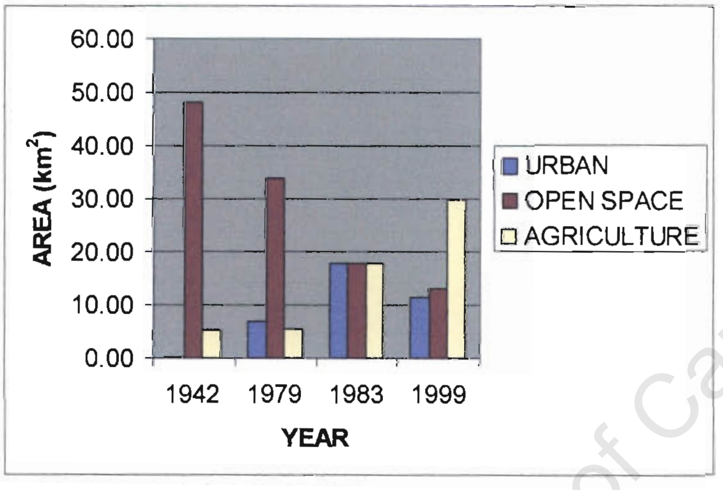
Figure 5.26: Lotus River and Kuils River catchments in 2000



The figure above shows that by 2000 almost all the open space in the Lotus River catchment had been lost. Most of the catchment has been urbanised and a large portion of the remaining land is used for agricultural purposes. The Kuils River catchment displays a similar pattern. Open space has been relegated to a few isolated areas while urban areas dominate. The agricultural area occupies approximately the same area as in Figure 5.25.

The following diagrams quantify the changes illustrated by Figures 5.23 to 5.26.

Figure 5.27: Histogram showing the changing land-uses in the Lotus River catchment over time



Open space has been decreasing steadily as progressively more land is appropriated for urban and agricultural land-use. The fact that urban land use decreases in 1999 is misleading and is due to the fact that the 1999 land use maps obtained from the City of Cape Town, grouped informal settlements and rural development into the "agricultural" land-use. If informal settlements and rural development were grouped with the "urban" land-use, the 1999 urban area would be higher than the 1983 area.

Figure 5.28: Histogram showing the changing land-uses in the Kuils River catchment over time

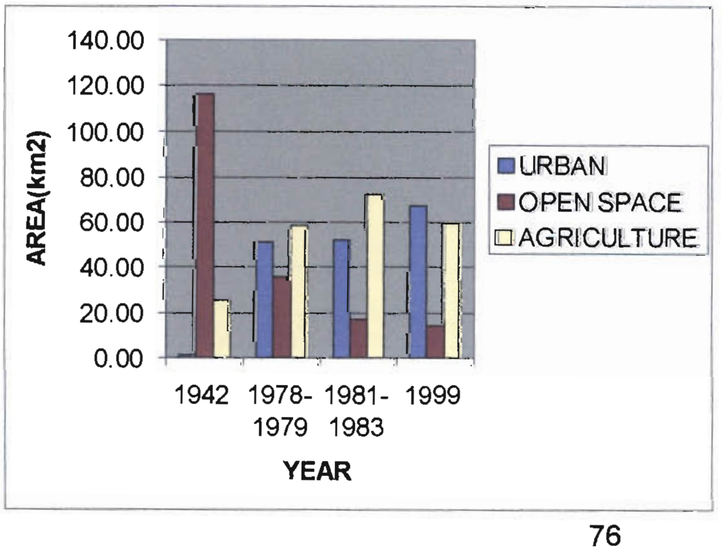


Figure 5.15 shows the same trend as Figure 5.14 above. Open space has decreased drastically while urban and agricultural land-uses have increased proportionately.

CHAPTER SIX

6 DISCUSSION

6.1 Changing land-uses within the catchments

For both catchments (Figure 5.27 and 5.28), the 1999 data were synthesised from existing land-use maps that the City of Cape Town had commissioned. As indicated in Chapter 4, land-use in the catchments prior to 1999 were derived from standard 1:50 000 topographical maps. The 1999 land-use maps differ from the 1:50 000 maps in the definition of "urban" and "agricultural" land-use. The 1999 City of Cape Town maps do not include established informal settlements in the "urban" category. Instead they are included in an "agriculture and rural" category. This explains why the agriculture and urban land-uses in Figures 5.27 and 5.28 do not follow the trends established prior to 1999. The reason why the City of Cape Town's maps were used was because of their accurate representation of the catchment boundaries and the land-uses within. These maps enabled the catchment boundaries to be relatively accurately transferred to the 1:50 000 maps.

Therefore, in Figure 5.27 the 1999 urban land-use value would to be higher than in 1983. Although the 1999 agriculture land-use value would decrease proportionately, it would also remain higher than that of 1983. Generally speaking, Figure 5.27 shows that open space in the Lotus River Catchment has decreased steadily over time, while urban and agricultural land-uses have increased steadily. The relationship is inversely proportional.

Figure 5.28 shows a similar trend, whereby open space decreases over time with concomitant increases in urban land-use. Taking the differences between the City of Cape Town's maps and the 1:50 000 maps into consideration, the agricultural land-use covers a much smaller area in 1999 than in previous years. This is easy to explain when one examines the 1:50 000 maps. Up to 1983, agriculture was sparsely spread over large tracts of land. However as demand for urban land-use increased, urban areas began to spread, with the result that the area of agricultural land-use began to shrink. Progressively smaller tracts of land where now being more intensively cultivated, employing more sophisticated farming methods.

Figures 5.23 to 5.26 illustrate the pattern of development within the catchments. In the Lotus River Catchment, urban residential land-use and agricultural land-use in the form of the Philippi horticultural area have both increased over time to occupy almost equally large areas of land, at the expense of the natural open space. The large residential areas contribute significant amounts of runoff due to catchment hardening and canalisation (see below). The Philippi horticultural area contributes significant amounts of nitrates from fertilisers into the Lotus River. The high range of NO_x concentration illustrated after 1995 in Figure 5.1 can be attributed to the channelling of surface runoff from the horticultural area to a single point on the Lotus River (Southern Waters, 2000).

The Kuils River catchment is much larger than the Lotus Catchment and has developed differently in that urban areas grew to dominate other land-uses. The resultant increased surface runoff and treated effluent from the Wastewater Treatment Works (WWTWs) has had a great impact on the Khayelitsha wetlands. WWTWs discharge huge volumes (refer to Section 4.2) of nutrient-enriched effluent into the Kuils River, drastically altering the hydrology and water chemistry.

The development of these catchments represents a global trend. Ehrenfeld (2000) states that the growth of urban areas has been a dominant demographic characteristic of the 20th century. Global population during this time has increased tenfold and Platt (1994; cited in Ehrenfeld, 2000) notes that the proportion of the human population living in urban areas has risen from 14% in the early 1900s to over 50% at the end of the century. This has had devastating effects for urban and peri-urban wetlands. The need for space for the growing population, the need for increasing agricultural land to provide food for the population, the need for "clean" water, and the negative perception of wetlands as wastelands or breeding grounds for disease have led to the modification and sometimes complete eradication of wetlands.

The loss of open space and concurrent development of the catchment has resulted in a number of changes to the hydrology of these catchments. Originally, the Lotus and Kuils River catchments did not have a permanent connection to the sea. These seasonal rivers flowed only during the winter rainy months. During the rainy season, the Cape Flats saw the development of waterlogged soils, marshy areas, and depressions filled with water. In fact, the Kuils River takes its name from the ponds that developed in the river course – "kuil" meaning "pond" in Afrikaans. The Lotus Rivers drained into the depression now known as Zeekoevlei and Rondevlei. During the dry summer season, most of the standing water in the catchments, as well as the rivers themselves, would have dried up.

After World War II urbanisation of the Lotus catchment, saw the rivers changing from seasonal to perennial systems. Abbott Grobicki (2001, p. 158) call the Lotus River (in its current permanent state) a "totally unnatural phenomenon" that was "engineered solely for the purpose of stormwater removal" from the growing urban area. Zeekoevlei and Rondevlei as well would have filled and dried in concert with the seasons and notes by Edith

Stephens (1943) indicate that a dry period from 1925 to 1935 saw both Zeekoevlei and Rondevlei dry up.

Urbanisation in the Kuils River catchment (specifically the development of several WWTWs and associated effluent) saw the Kuils River becoming perennial and the various wetlands drained and/ or channelled into consolidated bodies of water in the remaining areas of open space (Figure 5.13).

Urbanisation, in changing the hydrology of the catchments, has had a tremendous impact on the (once) seasonal wetlands. Some of the effects of urbanisation are listed below:

- Some rivers have been formalised into concrete canals, increasing runoff;
- Catchment surfaces have been made impervious resulting in increased runoff into rivers. For example, Abbott Grobicki (2001) indicates that from 1983 to 1996 the impervious area of the Lotus River catchment increased from 17% to 34% of the entire catchment area;
- Large volumes of treated effluent from sewage treatment plants are being discharged into rivers. For example, the Bellville WWTW in the Kuils River catchment increased its treated effluent discharge into the Kuils River from 21 Mλ/ day in 1979 to 52 Mλ/ day in 1999;
- Eutrophication of rivers and water bodies from treated effluent discharge, agricultural runoff and urban runoff, has resulted. Harding (1992) cited in Southern Waters (2000) approximates the total phosphorus load to Zeekoevlei from the Big Lotus River to be 11 000 kg/ year.

There are two key issues that are highlighted by the above points: (1) development has led to substantially increased volumes of water entering river systems; and (2) development has resulted in eutrophication of water bodies. These two factors have had a severe detrimental impact on the seasonal wetlands that were once common on the Cape Flats. Development have threatened to destroy, or at the very least, compromise the ecological integrity of both permanent and seasonal wetlands here in South Africa (e.g. the Khayelitsha wetlands (Ninham Shand, 1999a) and Moddervlei (Gibbs, 2003)) and abroad e.g. in the United States of America (e.g. the wet prairies, bogs and swamps of the American Midwest (Prince, 1997)), in New Zealand (e.g. the Tongariro Delta (Chagué-Goff *et al.*, 1999)), and in Australia (e.g. the Lower Murray Valley Wetlands (Jensen, 2002)).

From Figures 5.1, 5.2 and 5.3, it is difficult to quantify the actual amounts of nitrates, nitrites and phosphates entering the wetlands because they are measured as concentrations. Unless the volumes are also known, one cannot actually plot the total amount of nutrients entering the wetlands. Hence, from the water chemistry data alone, one cannot say categorically that "the amount of nutrients entering the selected wetlands is clearly increasing over time" and prove it by way of a graph. For, even though the concentration of nitrates, nitrites and phosphates seem not to increase significantly, this is does not necessarily mean that the absolute amounts of these nutrients are not increasing significantly. The increasing amounts of nutrients are "disguised" by the increasing volumes of water. Therefore, nutrient input into the system was inferred from the changes to the area occupied by *Typha capensis* over time. Moreover, the high nutrient levels in the rivers leading to Zeekoevlei and within the wetland itself, are reflected in the high mean annual levels of phytoplankton biomass (Southern Waters, 2000).

6.2 Changes to Rondevlei and Zeekoevlei over time

Figures 5.14, 5.15, 5.17 and 5.18 show the changes to Rondevlei and Zeekoevlei over time. The most marked change is the complete disappearance of the pondweed (*Potamogeton pectinatus*), after 1944 (Figures 5.14 and 5.17). Southern Waters (2000) reports that in 1951, Zeekoevlei was sprayed with a dose of sodium arsenite (a salt of arsenic) to control the pondweed and facilitate boating on the vlei. Rondevlei contained pondweed until the early 1970s (Southern Waters, 2000). No sign of pondweed was observed from the 1958 or 1968 aerial photos. This is possibly because the photographs were taken in early spring (October 1958) and winter (April 1968). Pondweed dies down almost completely in winter (Day, pers. comm., Stephens, 1947).

Figures 5.4 to 5.8 show that the area occupied by *Typha capensis* has increased steadily over time. Figures 5.14, 5.16, 5.17 and 5.19 quantify these observed changes. In Rondevlei, the area occupied by the reed increases significantly from approximately 4% in 1944, to approximately 31% in 2000. Figure 5.15 shows the fluctuation in the total area of the wetland from 1944 to 2000. Rondevlei was reduced from about 0.77 km^2 in 1944 to about 0.50 km^2 in 1968. Thereafter, its area increased to about 0.64 km^2 in 2000. There is no discernible pattern to this fluctuation. The lack of a complete year-to-year photographic history coupled with the physical manipulation of Rondevlei's water level (in the form of construction of the weir and winter drawdowns) means that a clear seasonal pattern cannot be distinguished.

In Zeekoevlei, *Typha capensis* increases sharply from approximately 0.3% in 1944 to approximately 10% in 1988. Thereafter, however, there is a very steep drop down to approximately 2% in 2000. Figure 5.18 shows the fluctuating area of Zeekoevlei. In 2000, Zeekoevlei occupies a smaller area than in 1944 (about 2.28 km^2 compared to about 2.71 km^2). Again, the lack of a consistent photographic history and physical manipulation of the water level makes finding a seasonal pattern almost impossible.

Figure 5.27 indicates that the urbanised area of the Lotus River catchment increased by a factor of 28 between 1942 and 1979. A cautious estimate would place the urban footprint in the catchment during the late 60s/ early 70s at about 3 km^2. This is still more than an order of magnitude greater than the 1942 urban area (approximately 0.25 km^2 of the catchment). The increase in urbanisation led to increased runoff, increased nutrient input into the system via stormwater channels, and the need to "regulate" the water level in the wetland in order to prevent flooding of adjacent residential properties. The construction of a permanent outlet weir from Rondevlei in 1954 resulted in a lowering of the water level, creating shallow conditions on the fringes of the wetland. Rondevlei suffered further shallowing due to the uncontrolled entry of silt into the system (Day, King and Harding, unpublished; cited in Southern Waters, 2000). Siltation of the vlei was likely to be due to an increased, and faster, surface runoff (associated with urbanisation and catchment hardening). The more "energetic" runoff is likely to have increased the transport of silt into Rondevlei. Siltation of wetlands as a consequence of catchment hardening has been noted by Bohn and Kershner (2002) and Tong and Chen (2002). Figure 5.27 also indicates the rapidly increasing agricultural footprint in the Lotus River catchment. Surface runoff from the Philippi horticultural area, which is rich in phosphates and nitrates/ nitrites, drains into the Zeekoevlei/ Rondevlei system, causing eutrophication of the wetlands (Southern Waters, 2000). Fertilisers from the horticultural area also contaminate groundwater and groundwater discharge into Zeekoevlei and Rondevlei raises nutrient levels in these wetlands. Moreover, the City of Cape Town (2001) emphasises that seepage from the adjacent Strandfontein sewage maturation ponds contributes approximately 36% of the total annual phosphorus load to Zeekoevlei.

As with Rondevlei, the late 1940s/ early 1950s saw the construction of a weir in Zeekoevlei to stabilise the water level, in order to facilitate year-round sailing. As indicated in Section 4.1.1, sodium arsenite was used to eliminate pondweed from the wetland. The resulting decomposing mass of tonnes of plant material contributed to the nutrient enrichment of Zeekoevlei. Southern Waters (2000) estimates that this "internal loading" contributes approximately 8 500 kg of phosphorus per year to Zeekoevlei. The other major avenues of nutrient input were from urbanisation/ industrialisation via the Lotus Rivers, from seepage from the sewage works, and from agricultural runoff from the Philippi horticultural area. Catchment hardening and algal blooms (which eventually die off and sink) resulted in the increased sedimentation of Zeekoevlei, making it increasingly shallow.

The increase in *Typha capensis* is indicative of the changes to the hydrology of the wetland. According to Hall (1993), Keddy (2000), Cronk and Fennessy (2001) and Pereira *et al.* (2002), artificial stabilisation of water levels and shallow water levels promote the encroachment of *Typha* species. Quick (1987), Moore (1990) and Keddy and Fraser (2000) add that, once water bodies become nutrient enriched, *Typha* proliferates. Thus the proliferation of *Typha* in Rondevlei (Figure 5.16) and Zeekoevlei (Figure 5.19) can be seen as an indicator of the shallow and nutrient enriched status of the wetland, which can directly be attributed to the increasing development of the catchment. Pereira *et al.* (2002) describe a similar phenomenon in Linhos Lake in Portugal, where *Typha latifolia* has proliferated as a result of eutrophication. As a result of eutrophication of the lake zooplankton species diversity was reduced (Pereira *et al.*, 2002).

The sharp decline of *Typha*, illustrated in Figure 5.19, is indicative of the management measures taken to control the encroachment of this plant in Zeekoevlei. Since 1995, Zeekoevlei has been subjected to winter "drawdowns" in order to flush the system and reduce the impacts of eutrophication (refer to Section 4.1.1). The receding water levels isolated the reed beds and in the absence of deep water refugia, promoted fish predation by piscivorous birds (Southern Waters, 2000). Consequently there was less predation by fish on the organism that feed on algae and algal blooms were reduced. The receding water level also facilitated physical access for clearing of *Typha capensis*.

The winter drawdowns were implemented in an attempt to simulate the natural seasonal hydrology that would have prevailed before the development of the catchment and manipulation of its hydrology. Zeekoevlei/ Rondevlei were originally seasonal wetlands that occasionally dried up completely in summer. Development of the catchment and the channelling of surface runoff and nutrients into the wetlands resulted in the loss of that seasonality; Zeekoevlei and Rondevlei are now permanent features. Unfortunately a photographic record of this historic seasonality does not exist. However, Southern Waters (2000) cites early maps from Jan van Riebeek's time (the mid 1600s) to the 1800s that illustrate the widely fluctuating seasonal water levels. In addition, Edith Stephens' (1943; 1947) various notes and correspondence collaborate with this evidence, indicating that the two vleis were indeed seasonal features.

The loss of seasonality and concomitant eutrophication of the water bodies have completely transformed the natural state of these systems. Natural habitat diversity was reduced as the wetlands became permanent features (refer to Section 2.2.4, which discusses the effect of seasonality on substrate/ habitat diversity and biodiversity). The regulation of water levels and spread of large stands of *Typha* have severely reduced the mudflat and shallow water's edge habitats. A loss of the natural biodiversity has resulted, severely impacting on the ecological value of the wetlands. Southern Waters (2000) and this dissertation (Appendix A) have determined the "Present Ecological Status" of Zeekoevlei and Rondevlei to be a Category E and Category C respectively. Zeekoevlei lies outside the "Generally Acceptable

Range" and is classified as being "seriously modified" i.e. indicating extensive losses of natural habitats and basic ecosystem functions. Rondevlei, being a protected reserve for a longer period, fares better. It is classified as being only "moderately modified" with some loss of natural habitats. As outlined in the literature review, the loss of habitat invariably results in loss of biodiversity, and thereafter, a decrease in ecological value. Jensen (2002) has shown that introducing seasonality to the Gurra Gurra wetlands in the Lower Murray River Valley, Australia, has begun to ameliorate the habitat diversity (which manifests as an increased diversity of wetland plants and macroinvertebrate community) of these once-seasonal wetlands.

The results indicate that the ecological values of Zeekoevlei and Rondevlei have been severely degraded. The literature review establishes a clear relationship between development of a catchment's surface and increased surface runoff and nutrient input into rivers or other water bodies. The literature also identifies the link between eutrophication and the proliferation of *Typha*. The relationship between increased and channelled surface runoff and the loss of seasonality in rivers and wetlands is a fairly straightforward one. This dissertation has illustrated the increasing development in the Zeekoevlei/ Rondevlei catchment. In addition, it has illustrated the proliferation of *Typha capensis* in Zeekoevlei and Rondevlei, which links development to changes to the wetlands. Therefore, one can draw the conclusion that development of the catchment has degraded the ecological value of Zeekoevlei to the point that it is severely impaired and bears little resemblance to its original condition. Rondevlei has been impacted upon to a lesser extent, and therefore, being closer to its natural state has a higher ecological value. This is because Rondevlei has been relatively more sheltered from the impacts of urbanisation that Zeekoevlei. It has a smaller urbanised catchment and receives most of its water from Princess Vlei via a canal.

6.3 Changes to the Khayelitsha wetlands over time

Figure 5.28 displays the rapid decrease of open space in the Kuils River catchment from 1942 (approximately 116 km^2) to 1999 (approximately 13.96 km^2). This is due to the development of urban and agricultural areas within the catchment. In 1942 the area occupied by urban/ agricultural areas was negligible. By 1999 urban and agricultural areas occupied 127.12 km^2 (more than 80%) of the catchment.

As usual, development resulted in hardening of the catchment. In order to facilitate urbanisation and agriculture, urban runoff (and the various seasonal ponds associated with the non-perennial Kuils River) were channelled into a formalised river to drain into the sea. A significant additional impact was the commissioning of the WWTW at Bellville in 1969 to help service the needs of the growing population on the Cape Flats. Treated effluent from the sewage works was discharged into the Kuils River, to be transported to the sea. Bellville WWTW initially had a capacity of 9 Mℓ/ day, but rapid urbanisation in the catchment led to the sewage works being upgraded. By the late 1990s the Bellville Wastewater Treatment Works was discharging approximately 52 Mℓ of treated effluent into the Kuils River each day (Ninham Shand, 1999b). The Scottsdene Wastewater Treatment Works, by 1999, was discharging 4 Mℓ/ day into the Bottelary River, a tributary of the Kuils (Ninham Shand, 1999). Thus, the seasonal Kuils River and Khayelitsha wetlands became perennial features. A second, equally significant, impact of treated effluent discharge on the Kuils River was the infusion of high concentrations of nitrates and phosphorus into the river system. This, together with sewer discharge and diffuse urban runoff, resulted in the eutrophication of the Khayelitsha wetlands.

Figures 5.9 – 5.13, 5.20 and 5.21 are very interesting because they illustrate the change in the Khayelitsha wetlands from a seasonal to a perennial system. Figures 5.9 – 5.11 and 5.20 indicate that there was no open water up to 1968. This is slightly misleading as the amount of open water seen would, during that period, depend on the season in which the aerial photograph was taken. Back then, the wetland system was seasonal and dried out in summer. Hence, if the photographs were taken in summer, this would account for the lack of open water. There is no way of knowing the season, as the months in which the 1944 and 1953 aerial photographs were taken were not recorded. A clearer explanation can be derived from Figures 5.9 – 5.11 and 5.21. The 1944 and 1968 values indicate, not open water, but the area that appeared to have been waterlogged in the near past. The vegetation is also indicative of waterlogged soil. In 1953, there is no sign of areas that appear to have been recently inundated at all. The wetlands had completely dried out. 1968 is a very significant year as it illustrates the wetland system just before the Bellville Works was commissioned *viz.* largely natural, with no permanent body of standing water. It is only in 1988 that open water is visible. This is a direct result of development in the catchment and the operation of the Wastewater Treatment Works.

Figure 5.21 can be interpreted to mean that up to at least 1968 the Khayelitsha wetland system was in a relatively natural state. It flooded during the wet winter months and dried, sometimes completely, during the summer months. However, development of the catchment (Figures 5.23 – 5.26 and 5.28) completely transformed the system. The total area of wetland increased from approximately 0.2 km^2 in 1988 to approximately 0.6 km^2 in 2000 (Figure 5.21). This is due directly to the increased inflow from the sewage treatment works, and from urban stormwater runoff.

Figure 5.3 illustrates the concentration of nutrients entering the Khayelitsha wetlands via the Kuils River. As explained earlier it is difficult to quantify the actual amounts of nitrates, nitrites and phosphates entering the wetlands without knowing the volume of inflow. It is likely that nutrients are, in fact, increasing over time but has been "disguised" by the increasing volumes of water. Therefore, nutrient input into the system was inferred from the changes to the area occupied by *Typha capensis* over time.

As explained in the literature review (Quick, 1987; Hall, 1990; Hall, 1993; Chagué-Goff *et al.*, 1999; Keddy, 2000; Keddy and Fraser, 2000), the encroachment and proliferation of *Typha capensis* is indicative of the excessive eutrophication of wetlands. Figures 5.20 and 5.22 illustrate the substantial impact that the nutrient rich treated effluent has had on the Khayelitsha wetlands. *Typha* was absent in the wetlands in 1968, but by 1988 occupied a massive 52% of the wetland. By 2000 this had increased further to approximately 61%. This value may well have been higher if it were not for the *Typha* clearing and dredging operations undertaken by the City of Cape Town in recent years. Dredging maintains relatively high water levels and is a significant control to the spread of *Typha*. However, while dredging and clearing can control *Typha*, the high nutrient levels of the water promotes the growth of other "nuisance" aquatic plants like the water hyacinth as well as the growth of algal scums and blue green algae (Ninham Shand, 1999). Figure 5.20 shows that algae-covered water increasing from about 0.01 km^2 in 1988 to about 0.11 km^2 in 2000. Up to 1968, no algae-covered water can be discerned from the aerial photographs. Studies from Portugal, England and Kenya indicate that the proliferation of *Typha* species and algal blooms as the result of eutrophication is a widespread phenomenon (Pereira *et al.*, 2002; Gitonga, 1992; Maitland and Morgan, 1997).

The proliferation of *Typha* stands as well as the loss of seasonality has considerably reduced the natural habitat diversity of the Khayelitsha wetlands. The shallow water communities cannot compete with *Typha capensis*, especially in nutrient-enriched waters (refer to Section 2.2.5). Eutrophication has also enabled the invasive *Eichhornia crassipes* (water hyacinth) and algal blooms to invade the open water. The results of the PES assessment undertaken for the Khayelitsha wetlands indicate that the wetlands can be classified as Category D: "largely modified" i.e. having experienced large losses of natural habitats and basic ecosystem functions. The result is an inevitable reduction in biodiversity. As inevitable, is the conclusion that development of the catchment has relentlessly degraded the ecological value of the Khayelitsha wetlands.

It can be seen that development of the Kuils and Lotus River catchments has severely degraded the ecological value of the Khayelitsha and Zeekoevlei/ Rondevlei wetlands respectively.

This trend, exemplified by the case studies, is not confined to the Lotus River or Kuils River catchments. Development of catchments all over the Cape Flats (and indeed in countries around the world) has had similar impacts on the seasonal wetlands that, at least on the Cape Flats, were once quite ubiquitous. In order to facilitate urban and agricultural growth, wetlands were drained and infilled; standing water was seen as an anathema to development and was diverted into concrete canals wherever possible, to be transported away from urban areas as quickly as possible; and wherever possible, treated effluent flows from the rapidly increasing number of wastewater treatment works were discharged into rivers, for cost-effective transport to the sea (Ehrenfeld, 2000; Griffin and Grobicki, 2000; Jensen, 2002; Tong and Chen, 2002; Luger and Brown, 2003). Consequently, seasonal rivers became perennial, some seasonal wetlands were eliminated, others became permanent features, and nutrient enrichment of rivers and wetlands from urban runoff, agricultural runoff and treated effluent became the norm.

The effects of development on the seasonal wetlands in the Cape Flats have been well documented and numerous examples of changing species composition, loss of seasonality, hypertrophication, loss of habitat diversity, proliferation of alien aquatic plants/ algal scums/ indigenous weeds can be found in the various studies undertaken e.g. Harding (1996), Ninham Shand (1986, 1994, 1999a), Southern Waters (2000) and Abbott Grobicki (2001). The findings of this study support the conclusions drawn in these reports.

Complete rehabilitation of Zeekoevlei/ Rondevlei and the Khayelitsha wetlands is unlikely. Rather the focus should be on effective management to meet realistic objectives. The few remaining seasonal wetlands on the Cape Flats (e.g. the Wetton-Ottery marsh, some wetlands within Varkensvlei Forest Reserve and the Hanover Park wetland) need to be maintained in order to preserve the many indigenous bird and frog species that depend on them. It is essential to preserve a range of seasonal wetlands as they all dry out at different times and different species habitat them in turn as shallow water turns to mud habitats and *vice versa*.

6.4 Discussion of the objectives of this study

In Chapter One, this study set out to achieve certain objectives and to a large degree, these objectives have been met. Section 2.3 argues that *Typha capensis* can be used as an indicator of the changing ecological value of seasonal wetlands over time. Using *Typha capensis* is useful because it can be relatively easily identified on aerial photography and its changing area can be measured over time from one photograph to the next. The value of this method lies in its ability to determine the relative ecological value within a selected seasonal wetland over time e.g. one can compare the ecological value of a seasonal wetland in 2000 to the ecological value it had in 1990. Thus, one can determine whether ecological value has been deteriorating or improving. However, it must be noted that this method is a coarse measure and does not allow the ecological value of a seasonal wetland at a single point in time to be determined and nor does it allow a comparison between different seasonal wetlands to be made.

With respect to Objective 2, an estimate of the current ecological value of the selected wetlands was inferred from the Department of Water Affairs and Forestry's (DWAF's) Present Ecological Status (PES) methodology described in Section 3.2. The DWAF PES methodology was used because, as indicated above, measuring *Typha capensis* cannot be used to determine ecological value at a given point in time. Although the PES methodology does not directly assess habitat or biodiversity (which are key attributes of ecological value) it does assess criteria that have direct relevance for habitat and biodiversity, and hence the PES could be used to infer ecological value.

Changes to inflow and nutrient input over time (Objective 3) was determined from past studies, observations from the aerial photographs and from water chemistry data from the Scientific Services Department of the City of Cape Town. This dissertation did not attempt to monitor inflow and nutrient changes, but it did show, by citing information from various studies (e.g. Ninham Shand, 1999a; Southern Water, 2000), that the natural hydrological regime has been altered and that once-seasonal river and wetland systems have become permanent systems. The proliferation of *Typha capensis* (identified and measured in this dissertation) indicated that nutrient input into the selected wetlands has been increasing. Although the source of these nutrients has not been specifically identified, studies indicate that the WWTWs and internal nutrient loading (from decomposing organic matter) are two of the major sources of nutrients.

The changes to land-use over time (Objective 4) have been described and illustrated by means of figures based on sequential aerial photography (Figures 5.23 to 5.26). The pattern of land-use development within the Lotus and Kuils River catchments from 1953 to 2000 is clearly illustrated, albeit at a coarse scale.

Figures 5.4 to 5.13 map the area occupied by *Typha capensis* as an indicator of the effects of development (Objective 5). However, the accuracy of the areas measured depended on the quality of the photograph. In some cases, e.g. the aerial photograph on which Figure 5.13 is based, the lighting was inadequate and parts of the aerial photograph were too dark to reliably identify *Typha capensis.* Consequently, the area of *Typha capensis* identified is probably an underestimation.

With respect to Objective 6, this dissertation, and particularly Chapter Six, has shown that development, in increasing inflow and nutrient input, has resulted in a decline in the ecological value of the selected wetlands. Again, due to the nature of the method employed, comparisons between the selected wetlands with respect to the changes to their ecological value over time cannot be made. However, the PES method does enable a direct comparison to be made Section 5.1). This method, if used at annual intervals, would enable the Ecological Status of each wetland to be tracked over time. The PES of different wetlands, within the same catchments or in different catchments, could be compared and the possible causes of impacts identified.

CHAPTER SEVEN

7 RECOMMENDATIONS AND MANAGEMENT ISSUES

The findings have implications for the management of catchments in South Africa and abroad. It is clear that effective management and rehabilitation of seasonal wetlands depend on a comprehensive understanding of how observed site-level problems can be related to the larger scale process occurring within the catchment (Bohn and Kershner, 2002). Although the rivers and wetlands are in a degraded state, they are not beyond rehabilitation in terms of specific management criteria. One needs to be pragmatic for, as the following table from Ehrenfeld (2000) shows, urban environments place a number of constraints on rehabilitation of wetlands.

Table 3: Wetlands in natural and urban environments (from Ehrenfeld, 2000)

Natural environments	Urban Environments
Ecological characteristics and functions are readily identified	Ecological functions may be less important than human values
Natural disturbance regimes are critical	Natural disturbance regimes may be impossible to restore
Nutrient limitations are the norm	Nutrients are often present in abundance or over-abundance and cannot be reduced
Hydrology is a function of regional climate, geology and physiography	Hydrology is usually highly altered in terms of total volumes, sources and flow rates

This chapter provides broad guidelines for the management of the case studies and it is hoped that proven management options, like the drawdowns in Zeekoevlei and Rondevlei, can be adopted for other vleis on the Cape Flats as well. Studies of methods to control *Typha* (e.g. Quick, 1987; Hall, 1990; Hall, 1993) have produced various feasible management options that can be implemented. Knowledge of the sources of nutrient pollution enables catchment managers to implement measures to mitigate against this impact (e.g. more stringent controls on the quality of treated effluent discharged into rivers). This study highlights the value of open space as it allows water to filter through, and in the process has a cleansing effect on the water, improving its quality. Chagué-Goff *et al.* (1999) has shown how reed beds (e.g. *Typha capensis*) at the inlet to wetlands would have an equally important role in purifying the water that enters the wetland. It is clear is that a piece-meal management of the catchment is ineffective. There needs to be a shift towards a holistic, integrated management of the catchment, in which natural resources of the wetland are managed in a sustainable manner. As Wang (2001) points out land-use planning departments should co-operate with water/ catchment management departments and view catchments as the natural spatial unit for land-use planning and sustainable water resource management.

Integral to management initiatives, is strong community-driven natural resource use, especially in cases like the Khayelitsha wetlands, where the wetland is used every day by the local Khayelitsha community as (1) a source of food (fish), (2) a source of fodder for their cattle, (3) a recreational site, as well as (4) a dumping ground and toilet. The social needs of the local community are linked to the management of the wetland resource. As Getzner (2002) notes, the protection of wetlands is more than just an ecological issue and involves a number of crucial aspects of social and political decision making processes. Where there is the social and political will, wetlands can be managed in a sustainable manner.

7.1 Management of the Zeekoevlei/ Rondevlei system

As alluded to above, rehabilitation is directly related to a management goal. One has to ask, "What is the wetland being managed for?" and only thereafter can a rehabilitation and management plan be developed to meet the management goals. In the case of Rondevlei, the goal is to manage the wetland as a conservation and educational area while Zeekoevlei is being managed as a recreational as well as a conservation area.

In light of their dual roles it is unlikely that the wetlands could be rehabilitated to their original conditions. In addition, the drastic changes to the hydrology of the Lotus River mean that it would be extremely difficult to do this in any case. For conservation and education purposes, the Rondevlei management plan would have focus on maintaining as much habitat diversity as possible in order to support as many viable biotic populations as possible. The following steps are by no means a comprehensive management plan, but aim to identify certain management options arising out of this study that could be undertaken to maximise habitat diversity and encourage a return to a more natural species composition and diversity.

- Maintain some form of seasonality within the system. The winter drawdowns described earlier benefits the system greatly facilitating the flushing of sediment and algae from Rondevlei. As illustrated by Jensen (2002) re-introducing seasonality to the Gurra Gurra wetlands in the Lower Murray River Valley in Australia has had remarkable benefits for biodiversity.

- The water body should not be allowed to become uniformly shallow. Varying depths should be maintained and to this effect, dredging may become necessary from time to time. The reason for this is that different depths support different types of wetland vegetation and provide more habitats.

- *Typha capensis* should not be allowed to proliferate. If necessary, mechanical clearing of the *Typha* should be implemented. Hall (1993) describes several methods of controlling the spread of *Typha*.

- A mix of mud flats, reed beds and open water is desirable as they attract a variety of birds. Open water is preferred by ducks and geese, waders prefer the mud flats and shallow water, while the reeds are attractive from a nesting and hiding perspective (Gibbs, D, Rondevlei Nature Reserve, *Pers. Comm.*)

All the points above are relevant to Zeekoevlei as well, as they serve to further the aims of conservation In addition the following steps could be taken to manage Zeekoevlei as a recreational area.

- For recreational use, water quality (in terms of clarity, toxicity, odour etc) is of paramount importance. In this regard the South African Water Quality Guidelines for recreational use (DWAF, 1996a) should be adhered to.

- A reed bed should be maintained at the Big and Little Lotus River inlets into Zeekoevlei. Chagué-Goff *et al.* (1999) have shown that where reed beds are found at a wetland's inlet, they assimilate much of the nutrients and improve the quality of water passing through the beds. In addition they would act as a litter trap, preventing litter from entering the wetland. Naturally, routine clearing of the reed beds would be necessary.

- To ensure a sufficient water depth to facilitate boating, it may become necessary to dredge the wetland occasionally. Decreasing water depth is a result of sludge build-up on the wetland floor when algal blooms die and sink to the bottom (Keddy, 2000; Keddy and Fraser, 2000; Southern Waters, 2000). The sludge is also a source of continuing nutrient input into the wetland (Day, 1987; Southern Waters, 2000)

- Winter drawdowns, in flushing water from the wetland, would help to flush algae from the wetland and prevent sludge build-up.

It must be noted that the localised, or site-specific management plans described here do not address the source of many of the problems. In order for these management plans to be of maximum benefit, they need to be integrated into a larger, more holistic Catchment Management Plan. Catchment Management would seek to address the needs of the local community while protecting natural resources at the same time. The broader issues related to stormwater management, urban planning, protection from flooding, protection of ecological integrity, legislative controls etc. would be addressed in an Integrated Catchment Management Plan.

7.2 Management of the Khayelitsha wetlands

The Khayelitsha wetlands are distinct from Zeekoevlei and Rondevlei in that they are utilised by the local community to meet basic needs for water and food (Wright *et al.*, 1993). Whereas Zeekoevlei/ Rondevlei are associated with the more affluent use as recreational areas (boating and bird-watching), the Khayelitsha wetlands are very much a feature of everyday life for the local community of Khayelitsha. The wetlands are used as a source of water, food and grazing for livestock and as such, the management plan would need to have a strong social emphasis.

- Because people are often in contact with the water, water quality needs to be addressed. *Typha* reed beds at the Kuils River inlet into the wetland would help to improve the quality of water entering the system. However, should the quality fall short of the South African Water Quality Guidelines for recreational use (DWAF, 1996a), the local community should be warned and signs erected.

- The dense *Typha* stands in other areas of the wetlands have the potential to substantially elevate flood levels (Ninham Shand, 1999a) and pose a threat to the safety of the local community. The *Typha* also results in water lying stagnant for long periods of time, increasing health risks. These stands should be controlled on a regular basis, preferable by mechanical means, in order to provide employment to local residents. Removing *Typha* will also be beneficial as nutrients would be removed from the system.

- Dredging is necessary to control the *Typha* and to clear channels.

- Environmental education (run by the local community for the local community) would help to make people aware of the impacts of littering and the hazards associated with water contaminated with faecal material. The benefits to the local community of a "healthy" wetland should be stressed. For example, better water quality (in terms of faecal coliforms at least) would reduce the chances of people who come into direct contact with the water of falling ill and fish deaths as a result of anoxic conditions created by water hyacinth or algal proliferation would be reduced.

- A fire timetable may need to be developed and implemented. Fires, in addition to helping control the spread of *Typha* and promoting habitat diversity, would also promote new growth within the wetland, which is nutritionally speaking, better fodder for livestock than mature plants.

- Cattle should not be allowed to overgraze as overgrazing may lead to a decrease in habitat diversity (Kotze, 1997). However, less intensive grazing would help increase biodiversity by clearing areas of monospecific stands of *Typha capensis*.

As for Zeekoevlei and Rondevlei, the management of the Khayelitsha wetlands should form part of an Integrated Catchment Management Plan. This would include the provision of basic sanitation in Khayelitsha, stricter control of the quality of effluent entering the Kuils River from the WWTWs and environmental education with respects to the economic, agricultural and ecological benefits of maintaining the wetlands in a healthy condition.

7.3 Conclusion

The greatest defence against the continued loss of seasonal wetlands on the Cape Flats, in South Africa, or indeed in the world, is knowledge and dissemination of this knowledge to civil society. Society needs to learn the importance of seasonal wetlands, the functions they provide for the ecosystem (which includes humans), as well as how society's activities directly and indirectly impact on seasonal wetlands. It is hoped that this dissertation, in adding to the existing body of wetland knowledge, will aid in the effective conservation and management of seasonal wetlands.

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APPENDIX A

DWAF PES Methodology

APPENDIX W4: IER (FLOODPLAIN WETLANDS) PRESENT ECOLOGICAL STATUS (PES) METHOD

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APPENDIX W4: IER (Floodplain wetlands): Present Ecological Status (PES) Method

(Version 1.0 adapted from Kleynhans 1996 and Kleynhans 1999)

W4. 1 Introduction

The aim of this document is to provide a method for determining, at an Intermediate level of determination, the present ecological status of palustrine wetlands according to a modified Habitat Integrity approach developed by Kleynhans (1996, 1999).

W4. 2 Overview of the PES methodology

Table W4-1 details criteria for assessing the habitat integrity of floodplain wetlands and provides footnotes for allocating a score to attributes and rating the confidence level associated with each score . The criteria were selected on the assumption that anthropogenic modification of the criteria and attributes listed under each criterion can generally be regarded as the primary causes of degradation of the ecological integrity of a wetland. On Table W4-1:

- Score each attribute according to the guidelines provided in the footnote.
- Calculate a mean score for Table W4-1 using the individual scores for all attributes.
- Provide a confidence rating for each score according to the guidelines provided in the footnote to indicate the areas of uncertainty in the determination.

Table W4-2 provides guidelines for the determination of the Present Ecological Status Class (PESC), based on the mean score determined for Table W4-1. If any of the attributes scores < 2 (i.e., it is considered to be seriously or critically modified) this score and not the mean should be taken into consideration. This approach is based on the assumption that extensive degradation of any of the wetland attributes may determine the Present Ecological Status Category (PESC). In any case, the mean on which the assessment of the PESC is based should be regarded as a guideline and should also be tested against the opinion of local experts.

Biological integrity is not directly estimated through this approach though in some systems or parts of systems, information on biological integrity is available. In such cases, the information on biological integrity can be used as a check of the PES Category determination. The mean is used to relate the ecological state of the wetland to a particular PES Category (Table W4-2).

W4. 3 Tasks in the PES methodology

The PES methodology comprises the following tasks:

W4.3.1 Literature review

A review of the literature and maps is an essential first step to the determination of the intermediate PES of a wetland. Extensive reliance is placed during the assessment on a comprehensive information base of the wetland and its past and present characteristics. If available, reference must be made to reports compiled for developments in the catchments such as reconnaissance phase and pre-feasibility reports for dam and other developments, catchment/basin studies, impact studies and management plans. The following aspects need to be addressed specifically which relate to the assessment criteria:

(a) Types of development and land use

Documentation on the types of development and land use in the catchment in question provides very valuable information for indicating the nature of problems in the catchment. These can guide the assessor with addressing the pertinent components which need to be given specific attention in the remainder of the literature search. For example extensive sugar cane farming in a catchment can give an indication of the extent of irrigation return flows and industry and pertinent associated water quality variables, the extent of impoundments and water abstraction, the nature of associated industry and development, the extent of removal of riparian vegetation and exotic encroachment.

(b) Hydrology

The point of gathering hydrological data is to establish the degree to which those aspects of the flow regime critical to the wetland in question have been modified by various forms of development, agriculture, silviculture and any other anthropogenic influences. This information will be used to assess the flow modification criterion of the procedure. Every effort must be made to establish the degree to which the virgin flow regime has been altered. The standard way in this is measured is by estimating the percentage of the virgin mean annual run-off (MAR) that presently remains at different points on the main stream and at the confluence of major tributaries. For floodplains the changes to the nature of floodpeaks will be critical.

Hydrological data is often available in the catchment and feasibility reports and studies. However, any observed hydrological data, which is available from gauge stations, will be of great value. WR90 simulated monthly data will also be useful. In the absence of sufficient hydrological data, professional judgement will need to be applied which is reliant on the experience of the assessor. On this basis the assessment of flow modification is inferred from the extent of different land use types in the catchment which have known impacts on flow modification such as forestry and some forms of agriculture.

(c) Water quality

The assessment of the water quality criterion is based on the water quality information which is documented in catchment study reports and from water quality databases such as that of DWAF or large industries in the catchment which are reliant on water from local rivers or for the discharge of water into local rivers . However, the problem is that such data are largely confined to the macro-constituents which may not necessarily indicate the problems which impact on the in-stream biota. However, if this is the only data available the best use must be made of it in the assessment.

The key water quality elements, which need to be assessed for ecological reasons, depend on the nature of developments in the catchment. For example, for a catchment which is extensively impacted by agriculture it will be necessary to investigate total dissolved solids (TDS), nitrogen in various forms, orthophosphates, total suspended solids (TSS) and to consider the distance from the known sources. For a catchment impacted by mining it would be necessary to rather concentrate on pH and total dissolved solids (TDS) and the distance from known sources. Water quality aspects need to be compared with available water quality guidelines.. This will give an indication of conditions and the nature of water quality problems which may exist.

(d) Erosion and sedimentation

Investigation into erosion and sedimentation will address the bank erosion and bed modification criteria of the assessment. Catchment studies frequently have information on erosion and the linkage to the nature and extent of sedimentation in the main stream and larger tributaries. Such information may also be available from feasibility studies for weirs and dams in the catchment. It is often the case that specific tributaries are more impacted than others due to different land-use practices. It is therefore pertinent to investigate sedimentation at different points in the main stream as well as on the major tributaries.

(e) Exotic species (flora and fauna)

A description of the nature and extent of exotic plant species in catchments is commonly found in catchment and basin studies. With recent DWAF and RDP initiatives it is also possible that specific programs have been launched for the eradication and control of exotic species. Such programs will have investigated the major problem areas in the catchment and thereby provide a sound basis for assessing the exotic encroachment criterion. Regional and local nature conservation reports may also detail the encroachment of exotic species as well as exotic aquatic fauna of the rivers. Further information on aquatic fauna and specifically exotic fauna may also be available from local fishing club newsletters and circulars.

W4.3.2 Aerial photographic assessment

Aerial photograph interpretation is one of the few ways in which an overall impression of habitat integrity can be obtained. Depending on the scale of the photographs and whether stereoscopic pairs are available, a wide variety of data can be collected for a wetland which can aid with the assessment. However the assessor must always bear the age of the photographs in mind. Substantial changes in vegetation, land use practices and other physical characteristics can take place in a short space of time, particularly in areas where rural densification is taking place and where agriculture and forestry are common. The value of obtainable information can vary depending on the experience of the person scrutinizing the photographs. For example an experienced person will be able to differentiate between indigenous and exotic tree species, or identify extensive bank erosion whereas the untrained eye might miss this level of detail.

If photography is recent and of an appropriate scale, this interpretation could form the larger part of the assessment, particularly in terms of physical characteristics such as: the nature and extent of different type of land use; extent of vegetation removal and exotic encroachments, extent of erosion and sedimentation, changes in flow regime and inundation.

W4.3.3 Site visit and use of local knowledge

The site visit is also an essential part of the intermediate status procedure as it is a primary source of first hand information which can be included in the assessment. However, extreme caution must be exercised in letting observations from easily accessible points dominate the assessment. Access points often provide a false perception of the integrity of a wetland due to the fact that these areas are normally highly disturbed. They are commonly characterised by extensive vegetation removal; exotic plant encroachments; inundation; bank erosion and sedimentation; impacts of local people, cattle and goats; and solid waste disposal. If possible, elevated views of the river should be used in preference since these give a far less disturbed view of the wetland.

It is highly recommended to contact local people. local authorities, nature conservation staff, local ecologists and other reliable contacts, telephonically if necessary, to provide adequate insight into the characteristics of the wetland. These people can give valuable insights into changes to the wetland that have occurred.

It is essential that the maximum benefit must be made of the site visit. Each of the assessment criteria should be systematically considered for each of the (wetland) zones and notes captured on appropriate maps of the area. This will ensure that the eventual assessments of the criteria remain consistent and objective throughout.

W4.3.4 Assessment of criteria and generation of preliminary PES scores

The assessment of the present status criteria (Table W4-1) must be undertaken at this point and must be done with the assistance of all of the information collected. Make all assessments according to the guidelines provided in Tables W4-1 and W4-2.

W4.3.5 Reporting

The final report should be as concise as possible. Assessment scores should be tabulated for the components and an explanation provided for the reasons for assigning specific scores to each criterion. Confidence ratings must be provided in the tables to indicate the areas of uncertainty in the assessment.

Table W4-1: Scoresheet with criteria for assessing Habitat Integrity of Palustrine Wetlands (adapted from Kleynhans 1996)

Criteria and attributes	Relevance	Score	Confidence
Hydrologic			
Flow modification	Consequence of abstraction, regulation by impoundments or increased runoff from human settlements or agricultural land. Changes in flow regime (timing, duration, frequency), volumes, velocity which affect inundation of wetland habitats resulting in floristic changes or incorrect cues to biota. Abstraction of groundwater flows to the wetland.		
Permanent Inundation	Consequence of impoundment resulting in destruction of natural wetland habitat and cues for wetland biota.		
Water Quality			
Water Quality Modification	From point or diffuse sources. Measure directly by laboratory analysis or assessed indirectly from upstream agricultural activities, human settlements and industrial activities. Aggravated by volumetric decrease in flow delivered to the wetland		
Sediment load modification	Consequence of reduction due to entrapment by impoundments or increase due to land use practices such as overgrazing. Cause of unnatural rates of erosion, accretion or infilling of wetlands and change in habitats.		
Hydraulic/Geomorphic			
Canalisation	Results in desiccation or changes to inundation patterns of wetland and thus changes in habitats. River diversions or drainage.		
Topographic Alteration	Consequence of infilling, ploughing, dykes, trampling, bridges, roads, railwaylines and other substrate disruptive activities which reduces or changes wetland habitat directly or through changes in inundation patterns.		
Biota			
Terrestrial Encroachment	Consequence of desiccation of wetland and encroachment of terrestrial plant speciesdue to changes in hydrology or geomorphology. Change from wetland to terrestrial habitat and loss of wetland functions.		
Indigenous Vegetation Removal	Direct destruction of habitat through farming activities, grazing or firewood collection affecting wildlife habitat and flow attenuation functions, organic matter inputs and increases potential for erosion.		
Invasive plant encroachment	Affect habitat characteristics through changes in community structure and water quality changes (oxygen reduction and shading).		
Alien fauna	Presence of alien fauna affecting faunal community structure.		
Overutilisation of biota	Overgrazing, Over-fishing, etc		
TOTAL MEAN			

Scoring guidelines per attribute:
natural, unmodified = 5; Largely natural = 4, Moderately modified = 3; largely modified = 2; seriously modified = 1; Critically modified = 0.
Relative confidence of score:
Very high confidence = 4; High confidence = 3; Moderate confidence = 2; Marginal/low confidence = 1.

Table W4-2: Interpretation of scores for determining present ecological status (Kleynhans 1999)

Interpretation of Mean* of Scores for all Attributes: Rating of Present Ecological Status Category (PES Category)
WITHIN GENERALLY ACCEPTABLE RANGE
CATEGORY A >4; Unmodified, or approximates natural condition.
CATEGORY B >3 and <=4; Largely natural with few modifications, but with some loss of natural habitats.
CATEGORY C >2 and <=3; moderately modified, but with some loss of natural habitats.
CATEGORY D =2; largely modified. A large loss of natural habitats and basic ecosystem functions has occurred.
OUTSIDE GENERAL ACCEPTABLE RANGE
CATEGORY E >0 and <2; seriously modified. The losses of natural habitats and basic ecosystem functions are extensive.
CATEGORY F 0; critically modified. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat.

*: If any of the attributes are rated <2, then the lowest rating for the attribute should be taken as indicative of the PES category and not the mean.

W4.4 References

C.J. Kleynhans 1999. A procedure for the determination of the ecological reserve for the purposes of the national water balance model for South African River. Institute of Water Quality Studies, Department of Water Affairs & Forestry, Pretoria.

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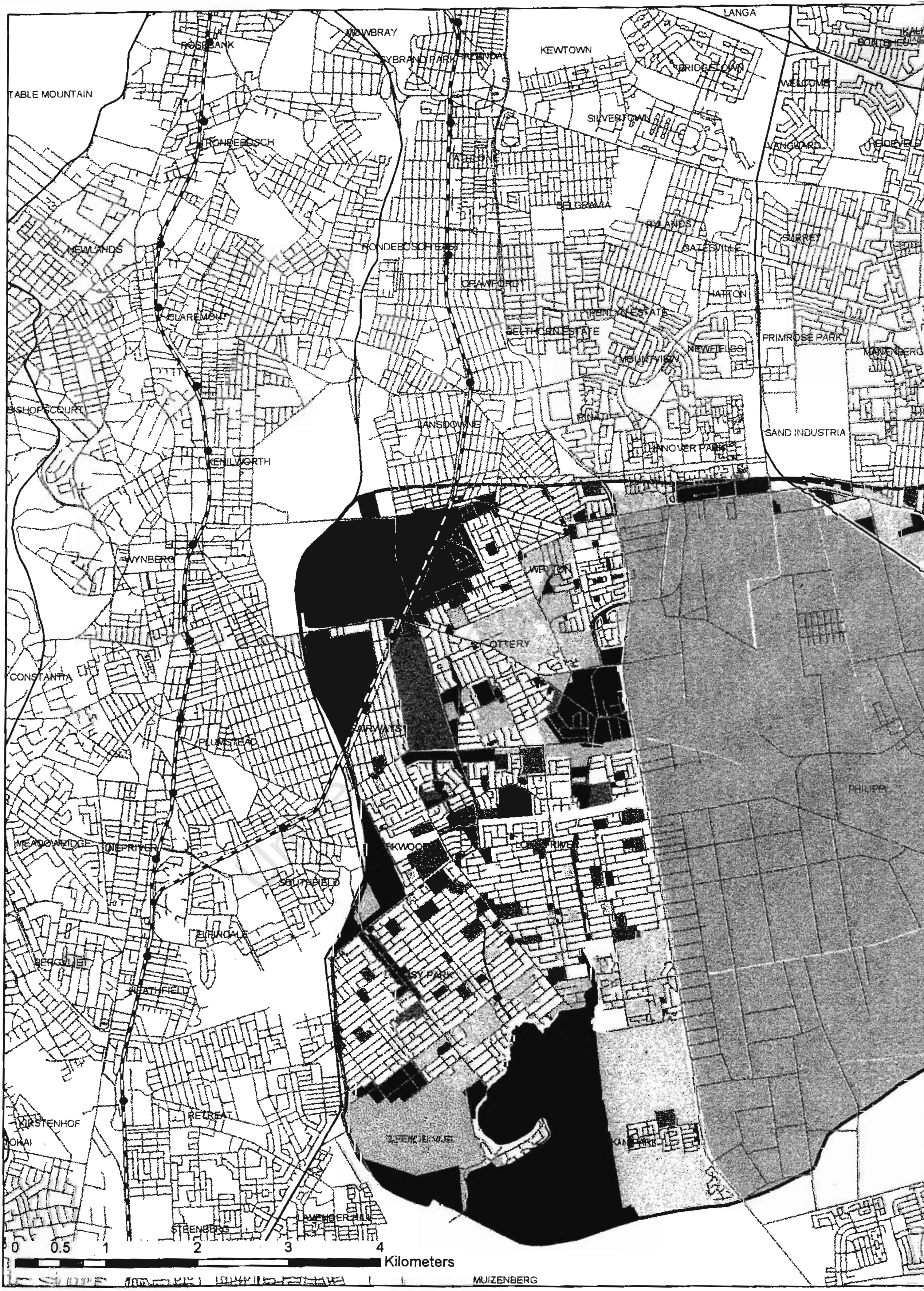
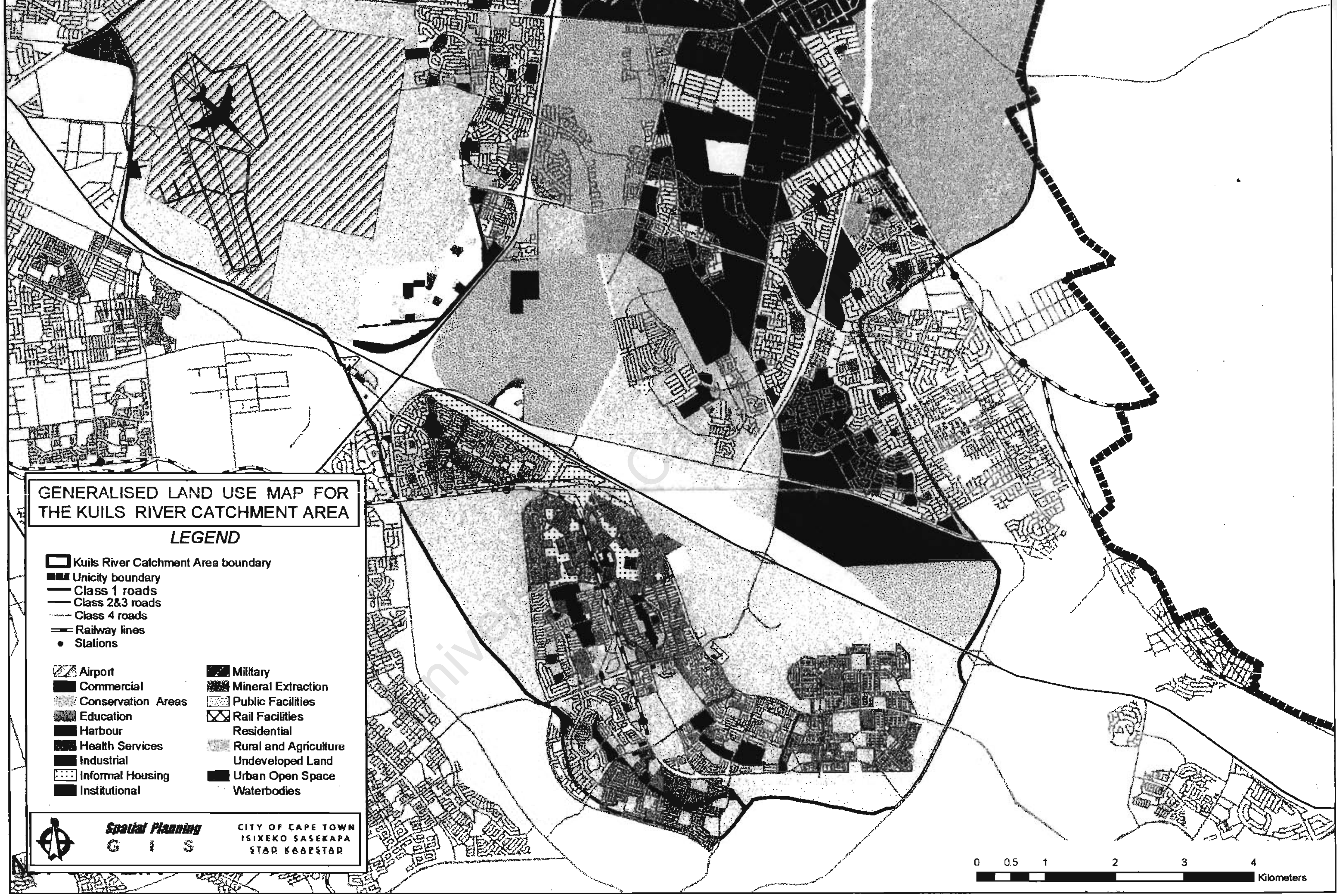
APPENDIX B

1999 land-use maps from City of Cape Town


LANGA
MOWBRAY
ROSEBANK
TABLE MOUNTAIN
KEWTOWN
BRIDGETOWN
WELCOME
SILVERTOWN
RONDEBOSCH
ATHLONE
VANGUARD
BELGRAVIA
RYLANDS
NEWLANDS
GATESVILLE
SURREY
CRAWFORD
HATTON
CLAREMONT
PRIMROSE PARK
MANENBERG
NEWFIELDS
MOUNTVIEW
BISHOPSCOURT
LANSDOWNE
SAND INDUSTRIA
HANOVER PARK
KENILWORTH
WYNBERG
OTTERY
CONSTANTIA
FAIRWAYS
PLUMSTEAD
PHILIPPI
MEADOWRIDGE
DIEPRIVER
SOUTHFIELD
ELFINDALE
BERGVLIET
HEATHFIELD
RETREAT
KIRSTENHOF
STEENBERG
MUIZENBERG
0 0.5 1 2 3 4
Kilometers



GENERALISED LAND USE MAP FOR THE KUILS RIVER CATCHMENT AREA
LEGEND
Kuils River Catchment Area boundary
Unicity boundary
Class 1 roads
Class 2&3 roads
Class 4 roads
Railway lines
Stations
Airport
Commercial
Conservation Areas
Education
Harbour
Health Services
Industrial
Informal Housing
Institutional
Military
Mineral Extraction
Public Facilities
Rail Facilities
Residential
Rural and Agriculture
Undeveloped Land
Urban Open Space
Waterbodies
Spatial Planning
G I S
CITY OF CAPE TOWN
ISIXEKO SASEKAPA
STAD KAAPSTAD
0
0.5
1
2
3
4
Kilometers

APPENDIX C

Water chemistry data from the Scientific Services Department

Chemistry of water entering Zeekoevlei via Big Lotus River (Source: Scientific Services Department)

Date	Ammonia (NH_3)	Nitrates and Nitrites (N_{ox})	Total Phosphorus	Orthophosphates
19/07/90	0.8	5.3	2.2	m
18/10/90	<0.10	4.2	0.3	m
20/07/91	1.3	6.4	1.1	m
29/10/91	0.3	3.7	0.6	m
24/04/92	3.1	3.5	0.4	m
08/10/92	<0.10	4.5	0.7	m
29/07/93	0.8	5.1	1.7	m
22/10/93	1.1	1.7	0.3	m
26/07/94	0.6	5.6	1.1	m
21/10/94	1.0	1.5	0.2	m
13/04/95	3.0	2.4	2.0	m
19/10/95	8.7	1.4	1.7	m
26/07/96	2.2	2.9	0.2	m
03/10/96	1.9	5.8	1.1	m
31/07/97	2.3	5.0	0.7	m
28/10/97	2.4	2.3	1.0	m
22/07/98	0.8	7.0	1.1	m
15/10/98	0.6	3.5	0.6	m
09/06/99	9.6	0.2	1.5	0.9
04/11/99	11.0	0.3	2.2	2.0
21/06/00	3.7	6.0	0.4	0.3
23/11/00	0.9	1.5	0.7	0.4
14/06/01	0.1	3.8	0.1	0.0
19/12/01	0.8	0.1	1.1	0.9
06/06/02	1.8	1.5	2.0	0.3
03/12/02	0.1	0.0	0.8	0.6

m = not analysed   0.0 = below detection limit

Chemistry of water entering Rondevlei (Source: Scientific Services Department)

Date	Ammonia (NH_3)	Nitrates and Nitrites (N_{ox})	Total Phosphorus	Orthophosphates
03/06/98	0.1	0.2	0.0	m
17/12/98	0.5	0.0	0.3	m
10/06/99	0.2	0.4	1.6	m
05/10/99	0.4	1.0	0.0	m
20/06/00	0.3	0.6	0.2	m
20/12/00	1.1	3.2	0.2	0.1
10/05/01	0.3	3.6	0.2	0.1
12/12/01	0.5	8.9	0.1	0.0
06/06/02	0.1	0.0	0.3	0.2
11/12/02	0.5	m	0.1	0.0

m = not analysed 0.0 = below detection limit

Chemistry of water entering Khayelitsha wetlands (source: Scientific Service Department)

Date	Ammonia (NH_3)	Nitrates and Nitrites (N_{ox})	Total Phosphorus	Orthophosphates
08/12/89	0.1	2.1	2.2	0.0
01/06/90	0.1	3.2	1.7	0.0
13/12/90	<0.1	1.4	4.6	0.0
23/05/91	<0.1	1.6	1.1	0.0
06/12/91	<0.1	3.8	0.7	0.0
11/06/92	<0.1	4.5	1.6	0.0
04/12/92	<0.1	2.2	1.3	0.0
04/06/93	<0.1	2.7	1.6	0.0
02/12/93	<0.1	1.0	3.3	0.0
23/06/94	<0.1	6.3	1.7	0.0
01/12/94	<0.1	2.2	4.3	0.0
08/06/95	0.4	3.4	2.4	0.0
08/12/95	<0.1	0.8	2.1	0.0
13/06/96	0.8	3.7	1.5	0.0
14/11/96	0.3	1.4	0.8	0.0
28/08/97	2.6	5.8	1.1	0.0
20/11/97	5.4	3.2	1.7	0.0
23/07/98	1.1	8.0	2.5	0.0
21/10/98	0.8	0.3	1.8	0.0
26/05/99	2.9	3.7	0.9	0.8
16/11/99	1.6	6.9	2.7	2.4
06/06/00	12.2	0.1	2.4	2.3
16/11/00	7.2	0.6	1.8	1.5
07/06/01	2.4	5.0	1.7	1.5
06/12/01	11.4	5.0	2.9	2.7
20/06/02	1.3	4.3	2.3	1.7
12/12/02	5.8	1.2	1.8	1.9

0.0 = below detection limit