Wetland Health and Importance Research Programme

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Wetland Valuation Volume II
Wetland Valuation Case Studies

Volume Editor: J Turpie
Series Editor: H Malan

WATER RESEARCH COMMISSION

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WETLAND HEALTH AND IMPORTANCE RESEARCH PROGRAMME

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WETLAND VALUATION. VOL II

WETLAND VALUATION CASE STUDIES

Report to the
Water Research Commission

by

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Series Editor: H Malan[2]

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PREFACE

This report is one of the outputs of the Wetland Health and Importance (WHI) research programme which was funded by the Water Research Commission. The WHI represents Phase II of the National Wetlands Research Programme and was formerly known as "Wetland Health and *Integrity*". Phase I, under the leadership of Professor Ellery, resulted in the "WET-Management" series of publications. Phase II, the WHI programme, was broadly aimed at assessing wetland environmental condition and socio-economic importance.

The full list of reports from this research programme is given below. All the reports, except one, are published as WRC reports with H. Malan as series editor. The findings of the study on the effect of wetland environmental condition, rehabilitation and creation on disease vectors were published as a review article in the journal Water SA (see under "miscellaneous").

An Excel database was created to house the biological sampling data from the Western Cape and is recorded on a CD provided at the back of Day and Malan (2010). The data were collected from mainly pans and seep wetlands over the period of 2007 to the end of 2008. Descriptions of each of the wetland sites are provided, as well as water quality data, plant and invertebrate species lists where collected.

An overview of the series

Tools and metrics for assessment of wetland environmental condition and socio-economic importance: handbook to the WHI research programme by E. Day and H. Malan. 2010. (This includes "*A critique of currently-available SA wetland assessment tools and recommendations for their future development"* by H. Malan as an appendix to the document).

Assessing wetland environmental condition using biota

Aquatic invertebrates as indicators of human impacts in South African wetlands by M. Bird. 2010.

The assessment of temporary wetlands during dry conditions by J. Day, E. Day, V. Ross-Gillespie and A. Ketley. 2010.

Development of a tool for assessment of the environmental condition of wetlands using macrophytes by F. Corry. 2010.

Broad-scale assessment of impacts and ecosystem services

A method for assessing cumulative impacts on wetland functions at the catchment or landscape scale by W. Ellery, S. Grenfell, M. Grenfell, C. Jaganath, H. Malan and D. Kotze. 2010.

Socio-economic and sustainability studies

Wetland valuation. Vol I: Wetland ecosystem services and their valuation: a review of current understanding and practice by Turpie, K. Lannas, N. Scovronick and A. Louw. 2010.

Wetland valuation. Vol II: Wetland valuation case studies by J. Turpie (Editor). 2010.

Wetland valuation. Vol III: A tool for the assessment of the livelihood value of wetlands by J. Turpie. 2010.

Wetland valuation. Vol IV: A protocol for the quantification and valuation of wetland ecosystem services by J. Turpie and M. Kleynhans. 2010.

WET-SustainableUse: A system for assessing the sustainability of wetland use by D. Kotze. 2010.

Assessment of the environmental condition, ecosystem service provision and sustainability of use of two wetlands in the Kamiesberg uplands by D. Kotze, H. Malan, W. Ellery, I. Samuels and L. Saul. 2010.

Miscellaneous

Wetlands and invertebrate disease hosts: are we asking for trouble? By H. Malan, C. Appleton, J. Day and J. Dini (Published in Water SA 35: (5) 2009 pp 753-768).

EXECUTIVE SUMMARY

Introduction

This study forms part of the resource economics component of the Wetlands Health and Importance (WHI) research programme, and together with a review of best practice, informed the development of a protocol for the valuation of wetlands.

Case studies were selected to fill some important gaps in wetland valuation in South Africa, as well as to provide examples of studies carried out at different levels. The case studies presented here are summarised in Table E1. The case studies are presented as a series of stand-alone papers.

Table E1: Study sites, services considered, scale and level of rigour of the case studies presented in this report

Chapter	Study area	Service	Scale	Level
2	Letseng-la-Letsie, and Mfuleni	Provision of natural resources	Local	Comprehensive
3	Nylsvley	Flow regulation	Local	Intermediate
4	South-western Cape	Water quality amelioration	Regional	Intermediate to comprehensive
5	Nylsvley	Recreation	Local	Intermediate

Chapter 2: A comparative study of the value of provisioning services of a rural wetland in Lesotho and a peri-urban wetland in Cape Town, South Africa

Few studies have valued provisioning services of temperate southern African wetlands. Research was undertaken on provisioning services of a remote rural wetland, Letseng-la-Letsie, in Lesotho and a peri-urban wetland in Mfuleni, Cape Town. This aimed to quantify incomes from wetland resources, assess the relative dependency of communities on wetland provisioning services and estimate the total provisioning value of the wetlands. Data were collected from informal interviews and structured household surveys. Despite the different settings, both wetlands were mainly used for grazing livestock. The estimated total value added over the last year from grazing was US$180 078 for Letseng-la-Letsie and US$540 286 for Mfuleni. Letseng-la-Letsie and Mfuleni were also used for hunting, whilst Mfuleni was partially cultivated. A greater percentage of households used the wetlands in Letseng-la-Letsie than in Mfuleni (65% versus 13%), in spite of the greater proximity in Mfuleni. However households around Letseng-la-Letsie derived a lower proportion of their income from the wetlands (6% versus 82%). This reflects more specialised livelihood strategies in the urban rather than the rural setting where risk-spreading household production strategies were more prevalent. The loss of the wetland in Letseng-la-Letsie would therefore potentially affect more people but have less of an effect on individual households' finances than in Mfuleni. It is estimated that US$220/ha/y and US$1 765/ha/y is derived from wetland provisioning services in Letseng-la-Letsie and Mfuleni respectively.

Chapter 3: Quantification of the flow regulation services provided by Nylsvley wetland, South Africa

In this study, relatively simple and standard hydrological techniques coupled with unsteady one-dimensional hydraulic modelling and subsequent mapping of inundation areas were used. The aim of the project was to estimate the flow regulation services at an intermediate level, that are provided by the Nylsvley wetland, Limpopo Province, for a reach of the Mogalakwena River into which the wetland drains. The flow regulation services that were investigated were flood attenuation and maintenance of base flows[1]. Two wetland development scenarios were compared: one with the wetland in its current state and the second one with the wetland drained and replaced by a trapezoidal grassed canal. A quaternary catchment scale was chosen for the hydrology to enable use of readily available quaternary catchment information. The attenuation of incoming floods was estimated using flood hydrographs determined using the Unitgraph Method. The long-term maintenance of low-flows was estimated using 23-year daily inflow time series that were derived for each quaternary catchment, scaled from a patched observed daily flow time series within the catchment. Losses to evapotranspiration were also estimated and included for the long-term maintenance of low-flows modelling. Significant attenuation of floods flowing through the wetland was indicated as might be expected for a large floodplain wetland. The simulations indicated that the flood peaks generated by the quaternary catchments located downstream of the wetland, some of which had relatively significant tributaries, may become the dominant flood wave in the downstream river reach, dominating the peak flood flows, levels and inundation areas for both development scenarios. The position of a wetland within the drainage landscape is therefore an important factor that determines the flood attenuation services it provides and the attenuation capacity of the wetland is not the only important factor determining the degree to which downstream areas benefit. The long-term maintenance of low-flows simulations indicated large evapotranspiration losses for the wetland development scenario, which in turn indicated reduced low-flows at the wetland outflow point compared to the canal development scenario. A large wetland with a similar position in the landscape may therefore be a consumer of water and may reduce downstream low-flows.

[1] Note that in "WET-EcoServices" by Kotze et al. (2008), this service is termed "streamflow regulation".

Chapter 4: Valuation of the water treatment function of wetlands: a comprehensive regional-scale study of Western Cape wetlands

Wetlands are commonly understood to have the capacity to reduce the loads of excess nutrients, pathogens, sediments and other contaminants generated by various activities in their catchments. However, the quantification of these services is difficult, and most research in this field has concentrated on artificial treatment wetlands. Understanding of the value of their water treatment services, as well as the other services they provide, is increasingly recognised as being essential to achieve a balance between conservation and the activities that degrade or replace wetlands. The aim of this study was to estimate the water quality amelioration ("water treatment") capacity of wetlands at a landscape scale in the southwestern Cape, and estimate the economic value of the service performed. The outflow points of 100 subcatchments were sampled, and the measured loads of nitrogen, dissolved phosphorous and suspended solids were analysed in respect of detailed spatial data on land cover and wetland area. Wetlands were found to play a significant role in the reduction of nitrates, nitrites and ammonium, but not dissolved phosphorous or suspended solids. Estimated removal rates ranged from 307 to 9 505 kg N/ha/y, with an average of 1 594 ± 1 375 kg N/ha/y. Data from a number of water treatment works suggested that the cost of removal of ammonium-N was in the order of R26/kg. Applied to the wetlands in the study area, and assuming wetlands do play a role in total phosphorus removal, this suggested that the average value of the water treatment service provided by wetlands in the study area was about R14 350 ± 12 385/ha/y. There was no broad-scale pattern in the average value of wetlands per catchment.

Chapter 5: The tourism value of Nylsvley floodplain

A brief study was carried out to assess the tourism value of the Nylsvley floodplain in Northern Province, based on discussions with key informants and a small survey of visitors. Most recreational use occurs within the Nylsvley Nature Reserve, which protects about 1000 ha of the 16 000 ha wetland. Some 9-10 000 people visit the reserve annually, mainly for bird watching. About 85% of visitors surveyed were domestic visitors, the majority from within a few hours' drive of the study area. South Africans tended to be on short visits specifically to the site, whereas overseas visitors tended to be visiting as part of a multi-destination trip. Based on the average on-site expenditure and off-site travel expenditure attributed to visiting the nature reserve, the tourism value of the Nylsvley floodplain was estimated to be in the order of at least R9-10 million per annum. Because of the small sample size obtained, the estimate is only rough.

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ABBREVIATIONS

CAPE – Cape Action Plan for People and the Environment

DEAT – Department of Environmental Affairs and Tourism

df – degrees of freedom

DTM – digital terrain model

DWAF – Department of Water Affairs and Forestry

EC – electrical conductivity

GIS – global information system

GPS – global positioning system

ha – hectares

HDI – Human Development Index

HGM – hydrogeomorphic

hh – households

LSU – livestock units

MAP – mean annual precipitation

MAR – mean annual runoff

N – nitrogen

OTS – Organisation for tropical studies

P – phosphorus

s – second

SANBI – South African National Biodiversity Institute

SD – standard deviation

SE – **standard error**

TSS – **total suspended sediments**

WHI – Wetland Health and Importance (Research Programme)

WRC – Water Research Commission

XS – cross section

y – year

1. INTRODUCTION

1.1 Background and context

This study forms part of the resource economics component of the Wetlands Health and Importance (WHI) research programme, which falls under the National Wetlands Research Programme. The WHI research programme is concerned with the development of methods to assess the environmental condition of wetlands as well as their social importance and economic value. All of these aspects are vital for the effective management and protection of wetlands. Although techniques for the assessment of aquatic environmental condition and socio-economic values have been developed or applied in South Africa, there are currently no definitive, well-developed methods (comprehensive or rapid) specifically designed for assessing the social importance and economic value of wetlands.

In particular, there is a clear need for the development of rapid economic valuation methods in order to facilitate the incorporation of socio-economic considerations into decision-making. Current valuation methods are designed for comprehensive application, which means they are expensive. More rapid alternatives need to be investigated in terms of their feasibility for use, by assessing their relative accuracy and sufficiency for decision-making. It is not possible to develop rapid methods in the absence of comprehensive studies that can inform this process. Ideally, the development of rapid methods should come from comparison of the results of comprehensive and rapid assessments of the same wetlands. However, there is a lack of comprehensive valuation studies on South African wetlands, and this needs to be addressed first.

The overall objectives of the resource economics component were as follows:
a) Conduct a scoping study of methods to value wetland “goods and services”;
b) Evaluate Wet-EcoServices as a basis for determining the economic value of wetlands;
c) Develop a metric to assess socio-economic dependency; and
d) Develop a wetland valuation protocol which takes into consideration the different types and geographical location of wetlands.

1.2 Accompanying reports

This study forms the second volume of the Resource Economics component of the WHI research programme, and comprises a series of case studies, which, together with an international review of the literature contributed to the development of a Wetland Livelihood Value Index and a Wetland Valuation Protocol. These studies are listed below:

1. Turpie *et al., 2*010a. Wetland valuation. Vol I. Wetland ecosystem services and their valuation: a review of current understanding and practice. Report emanating from WRC project K5/1584; Wetlands Health and Importance Research Programme, Water Research Commission.

2. Turpie, 2010b. Wetland valuation. Vol III. The Wetland Livelihood Value Index: A tool for the assessment of the livelihood value of wetlands. Report emanating from WRC project K5/1584; Wetlands Health and Importance Research Programme, Water Research Commission.

3. Turpie and Kleynhans, 2010c. Wetland valuation. Vol IV. A protocol for the quantification and valuation of wetland ecosystem services. Report emanating from WRC project K5/1584; Wetlands Health and Importance Research Programme, Water Research Commission.

1.3 Selection of case studies

Case studies were selected to fill some important gaps in wetland valuation in South Africa, as well as to provide examples of studies carried out at different levels. Budgetary constraints meant that not all types of services could be considered at all scales and levels. The case studies presented here are summarised in Table 1.1. The case studies are presented as a series of stand-alone papers.

Table 1.1: Study sites, services considered, scale and level of rigour of the case studies presented in this report

Chapter	Study area	Service	Scale	Level
2	Letseng-la-Letsie, and Mfuleni	Provision of natural resources	Local	Comprehensive
3	Nylsvley	Flow regulation	Local	Intermediate
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2. A COMPARATIVE STUDY OF THE VALUE OF PROVISIONING SERVICES OF A RURAL WETLAND IN LESOTHO AND A PERI-URBAN WETLAND IN CAPE TOWN, SOUTH AFRICA[2]

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Abstract

Few studies have valued provisioning services of temperate southern African wetlands. Research was undertaken on provisioning services of a remote rural wetland, Letseng-la-Letsie, in Lesotho and a peri-urban wetland in Mfuleni, Cape Town. This aimed to quantify incomes from wetland resources, assess the relative dependency of communities on wetland provisioning services and estimate the total provisioning value of the wetlands. Data were collected from informal interviews and structured household surveys. Despite the different settings, both wetlands were mainly used for grazing livestock. The estimated total value added over the last year from grazing was US$180 078 for Letseng-la-Letsie and US$540 286 for Mfuleni. Letseng-la-Letsie and Mfuleni were also used for hunting, whilst Mfuleni was partially cultivated. A greater percentage of households used the wetlands in Letseng-la-Letsie than in Mfuleni (65% versus 13%), in spite of the greater proximity in Mfuleni. However households around Letseng-la-Letsie derived a lower proportion of their income from the wetlands (6% versus 82%). This reflects more specialised livelihood strategies in the urban rather than the rural setting where risk-spreading household production strategies were more prevalent. The loss of the wetland in Letseng-la-Letsie would therefore potentially affect more people but have less of an effect on individual households' finances than in Mfuleni. It is estimated that US$220/ha/y and US$1 765/ha/y is derived from wetland provisioning services in Letseng-la-Letsie and Mfuleni respectively.

2.1 Introduction

Wetlands provide a range of goods and services and possess a variety of attributes of value to society (Barbier, 1993). They offer provisioning, regulating, cultural and supporting services (Millennium Ecosystem Assessment, 2005) which generate economic values from their direct, indirect or potential use. Yet, despite legislation ratifying their protection, wetlands continue to be degraded and lost at an alarming rate (Turner *et al.,*

[2] This paper is derived from Lannas's MSc thesis and is also published in *Ecology and Society*.

2000). This is at least partly due to a lack of understanding of their ecological and socio-economic importance which leads to distorted policy and decision-making regarding their land-use and management (Adaya *et al., 1*997; Smit and Wiseman, 2001; Terer *et al., 2*004).

In southern Africa, many wetlands have been lost or degraded as a result of increasing demand for land and water. An understanding of the socio-economic value of wetlands is crucial when deciding on conservation and development priorities regarding land-use and the allocation of scarce water resources. Therefore, the value of wetland provisioning services of natural resources to poor communities is a critical consideration. These resources include rich, moist soils for cultivation, grazing for livestock, fisheries, reeds, sedges and grasses for crafts and timber, and water for domestic use, watering livestock and irrigation (Kotze and Breen, 1994). It is estimated that millions of rural South Africans are dependent on natural resources for their daily survival (Wynberg, 2002).

This study investigates the provisioning values of two temperate southern African wetlands that differ markedly in their ecological characteristics, geographic and social setting. The first wetland, Letseng-la-Letsie, is a high altitude mire in rural Lesotho and the second is a collection of depression wetlands surrounded by the peri-urban township of Mfuleni, in Cape Town, South Africa. These wetlands fill gaps in the international literature, which is dominated by valuation studies of mangroves, floodplains, deltas and estuaries (Sathirathai, 1997; Turpie, 2000; Kangalawe and Liwenga, 2005; Turpie *et al., 2*006) and also provide data on inland wetlands south of the Zambezi basin.

The aim of the study was to describe and compare the use and value of provisioning services of the two wetlands and to compare their importance in the livelihoods of the two types of communities surrounding them.

2.2 Study areas

2.2.1 Letseng-la-Letsie Wetland, Lesotho

Wetlands in the Lesotho highlands are classified as mires[3] (Zunckel, 2003). The Letseng-la-Letsie Wetland, located in the Quthing Province, Lesotho (Figure 2.1), is the source of the Mohlakeng River, a tributary of the Quthing River. The 819 ha wetland is a

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[3] Note that this differs from the South African classification as seeps (see Ewart-Smith *et al., 2*008)

Ramsar site, but is used for livestock grazing. Part of the wetland is permanently inundated due

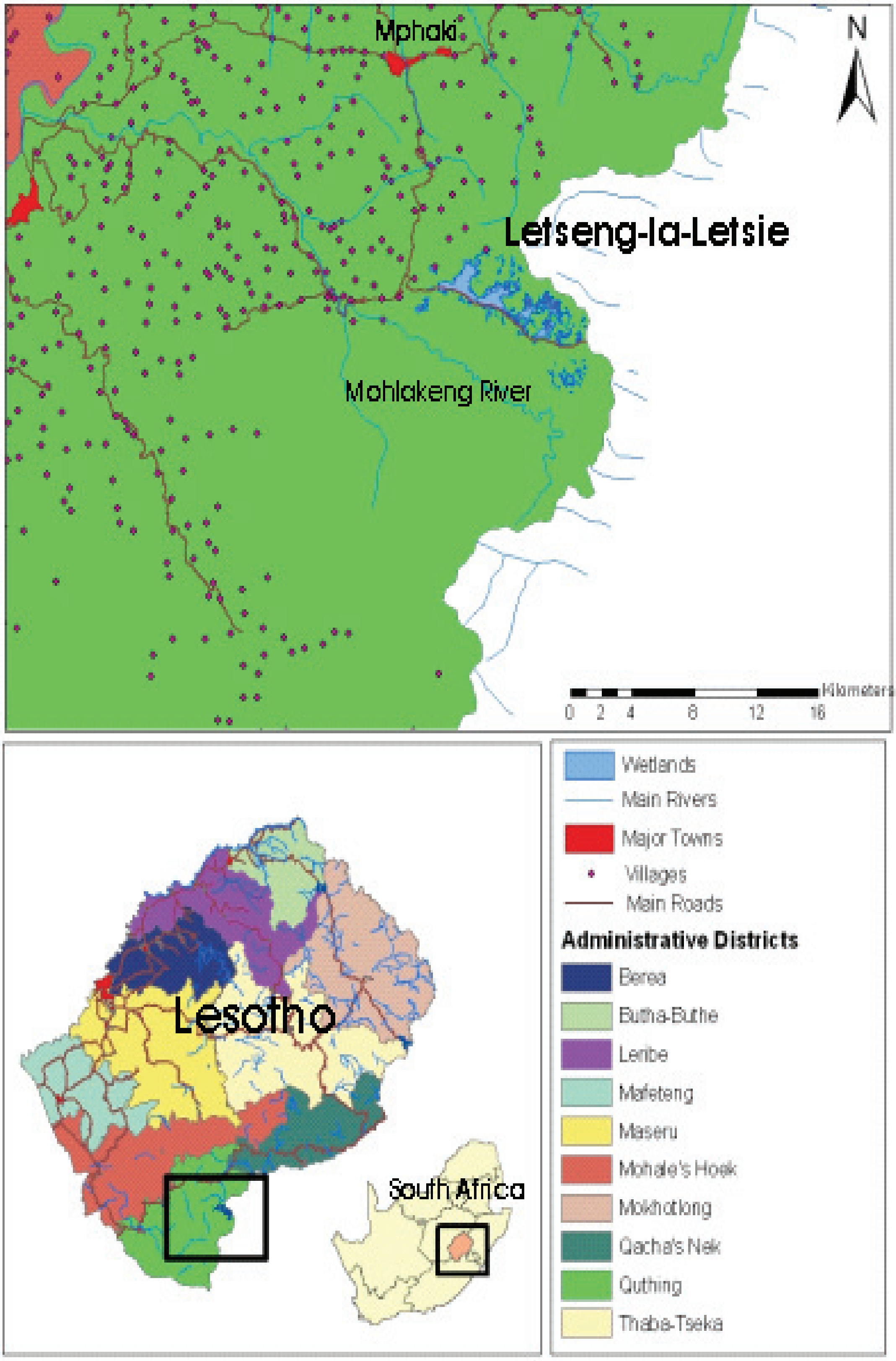

Figure 2.1: Location of the Letseng-la-Letsie Wetland in Lesotho.

to a small dam at its outflow point. There are 18 villages in the vicinity of the wetland with a total population of about 12 000 people. The closest town, Mphaki, has a population of about 940. Based on interviews with village headmen, there are an estimated 4 070 households in the study area.

Land in Lesotho belongs to the King (Morris *et al., 1*989). Grazing areas are communal and controlled primarily by local chiefs (Letsela *et al., 2*002). As a Ramsar site Letseng-la-Letsie is governed nationally by the Ministry of National Resources, then locally by governing bodies of the Quthing District and the nearest village (Water Affairs, 2006).

Communities in the remote mountainous areas are highly dependent on agriculture and natural resources, and reportedly use wetlands to harvest various natural resources (Water Affairs, 2006).

2.2.2 Mfuleni Wetlands, Cape Town, Western Cape

The township and associated informal settlements of Mfuleni fall within the Kuils River floodplain of greater Cape Town (Figure 2.2). Originally seasonal (Shand and Nicks, 1999), the Kuils River is now perennial due to urban runoff and outflows from WWTW. Around Mfuleni there are both seasonal and permanent wetlands covering some 311ha. Most land in Mfuleni is state-owned or previously belonged to the South African Development Trust (Dixon and Ramutsindela, 2006). Past studies list a number of resources harvested from open areas in the City of Cape Town including: medicinal plants; food plants such as *Aponogeton distachyos*; animals; arum lilies (*Zantedeschia aethiopica*) and *Phragmites* reeds (Turpie *et al., 2*001). Shand and Nicks (1999) estimated that 62 plant species are harvested from the wetlands of the Kuils River. Cattle are also grazed on the wetlands. Mfuleni was originally a temporary residence area for migrant workers (Dixon and Ramutsindela, 2006). The area did not have informal settlements until 1990, when squatter housing was established due to people moving to escape violence elsewhere. In 2001, Mfuleni had a population of about 22 885, with 57% being unemployed, and 79% of the population earned less than US$230/month (Stats SA, 2001a). After floods in 2001, over 4 000 people were resettled on open areas in Mfuleni (Dixon and Ramutsindela, 2006). There are 7 517 households in Mfuleni, with 1 117 of them in informal settlements. Informal settlement dwellers are the main users of the wetland areas.

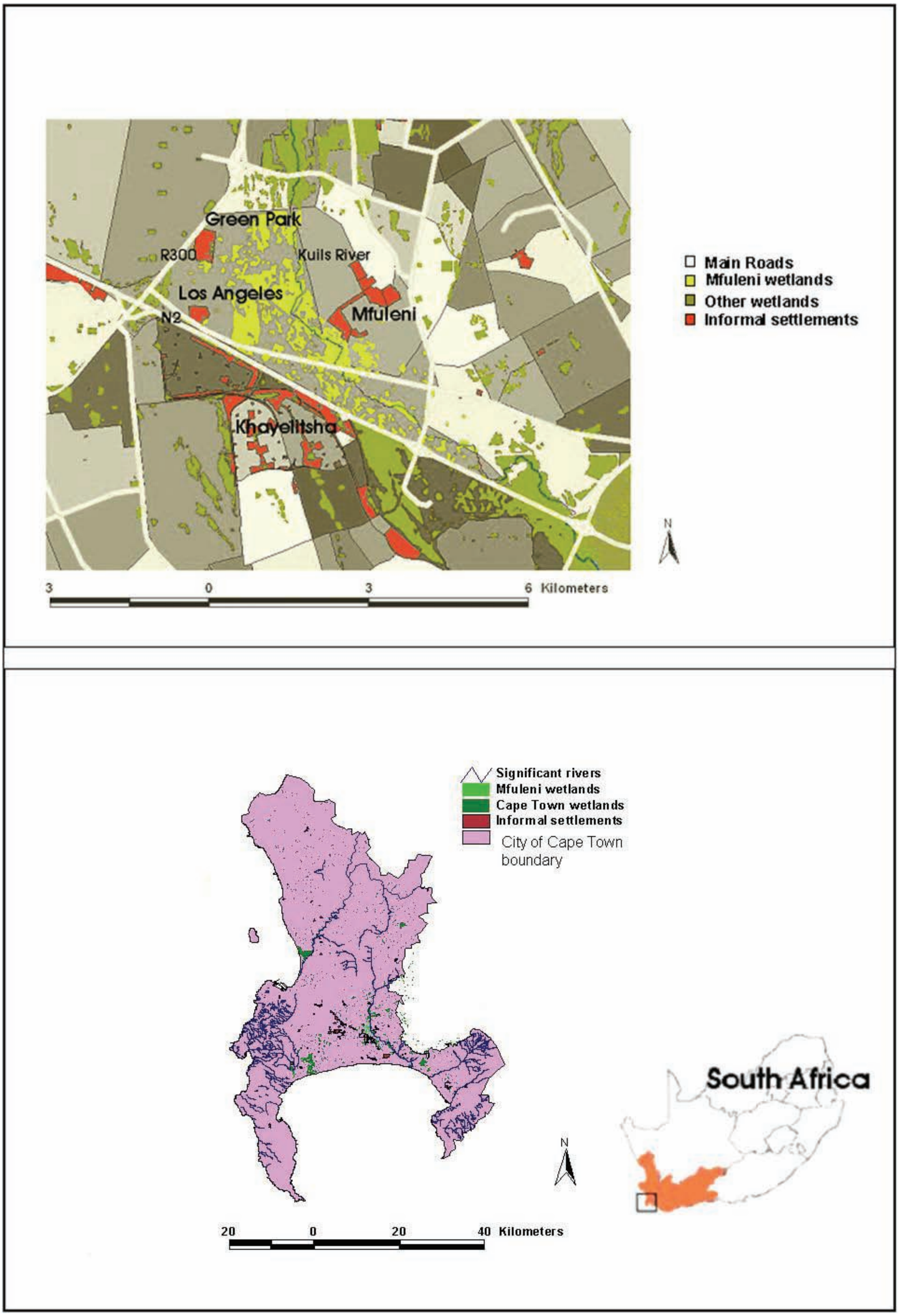

Figure 2.2: Location of wetlands around the township of Mfuleni in Cape Town.

2.3 Methods

2.3.1 Preliminary data gathering

General wetland use was assessed using rapid appraisal methods (Nichols, 1991). Informal discussions identified resources used by surrounding communities, their property rights and allocation, and numbers of households. Estimates of current prices for livestock, crops and crafts were obtained and farming practices were described. For Letseng-la-Letsie, informal discussions were held with headmen of villages, herders and villagers. In Mfuleni key informants were the local livestock cooperation's president, a traditional healer and representatives of different age groups.

2.3.2 Household surveys

The initial findings guided the design of a household questionnaire which was used to collect quantitative data on resource use and income. Questionnaires were translated into the local vernacular (Sesotho and Xhosa, respectively) and administered by native speakers trained as enumerators. In each village the number of households surveyed was determined by the size of the village and households were randomly selected by dividing the villages into sections and surveying a sample of households from each. A total of 161 households were surveyed around Letseng-la-Letsie during April to May 2007 and 280 households were surveyed in the informal settlements of Mfuleni during June to September 2007.

Data were collected on: (1) household demography; (2) type of housing, fuel, lighting and heating; (3) main sources of income and earnings; (4) field sizes and if the wetland was used, crops, harvests and sales, including how the last harvest compared to other years; (5) livestock owned, slaughtered, given to herders and sold, milk and egg production and income from wool and mohair sales; (6) natural resource harvests, proportion from wetlands, craft production and sales; and (7) sources and use of water.

2.3.3 Data analysis

Statistical analysis was carried out using Statistica 8.1. One questionnaire from Mfuleni was discarded due its content being unreliable. The currencies of Maloti in Lesotho and Rand in South Africa are equal and equivalent to about US$0.14 in 2007.

The annual value of wetland-based activities to households was determined in terms of average gross, net and cash household incomes. Gross incomes from agriculture and natural resources were estimated on the basis of average harvests and prices, irrespective of what proportion was sold (i.e. valuing subsistence consumption at market prices). Net income took input costs of seeds, hired labour and cost of capital into account. Cash income was based on sales only. The economic value added to national income was calculated by excluding capital and labour as they are internal inputs and using current market prices (Gittinger, 1982). Price distortions in the form of subsidisation of inputs were corrected.

2.3.4 Estimating income derived from wetlands

For Letseng-la-Letsie, the proportional contribution of the wetland to grazing was based on existing estimates of carrying capacities of the wetland and surrounding grassland areas. The carrying capacity of wetlands in the region of Letseng-la-Letsie is approximately 4 ha per large stock unit (LSU; Morgenthal *et al., 2*004) and grasslands reportedly have half the carrying capacity of wetlands (Grab and Morris, 1997). Based on the relative areas involved the wetland supplies about 5.2% of the estimated total grazing capacity of the area (some 3 963LSU, which is considerably lower than the current stocking rate).

Since wetlands provide the only opportunity for agriculture around Mfuleni, income from this activity was completely attributed to the wetland. In the case of grazing, the wetlands contributed about 90% of the grazing land, which was supplemented by road verges.

2.3.5 Dependency

The level of dependency on the wetlands was estimated in terms of the percentage of overall household incomes derived from the wetlands. Since there are no regional measures of poverty for Lesotho and South Africa, dependency was related to the Human Development Index (HDI). This measures the life expectancy, education levels and overall welfare in an area (StatsSA, 2001b).

2.3.6 Overall wetland value

The overall annual values of the wetlands were determined from the aggregate of the income derived by households from the wetlands:

$$\text{Value of wetland} = \sum_{ps} \%hh_{ps} \times HH \times V_{ps}$$

Where: **ps** = the different wetland provisioning services, **%hh** = the percentage of surveyed households using the particular provisioning service, **HH** = total number of households around the wetland and $\mathbf{V_{ps}}$ = average income earned per user household from the wetland provisioning service. This equation was used to calculate the total gross, net and cash income values of the wetlands and the economic value added from wetland provisioning services.

2.4 Results

2.4.1 Household characteristics

Households around Letseng-la-Letsie were relatively large (mean = 7, SD = 4 people), often consisting of extended families with reasonably high numbers of children. Average household sizes in Mfuleni did not differ significantly from those around Letseng-la-Letsie (mean = 7, SD = 5 people) and had similar compositions in the different age groups. Of the households surveyed around Letseng-la-Letsie, 98% had traditional houses and 75% of these had thatched roofs. In Mfuleni 87% of the households surveyed lived in informal housing, consisting of makeshift houses with one or two rooms. The remaining households lived in formal housing. Around Letseng-la-Letsie the major form of heating was firewood (51%) with a much lower percentage of households using paraffin heaters (12%). In Mfuleni the reverse was found with more households using paraffin heaters (58%) and a smaller percentage used firewood (16%). The highest percentage of households around Letseng-la-Letsie used firewood for cooking, whilst around Mfuleni more people used paraffin stoves.

The average annual household income around Letseng-la-Letsie was US$771 (SE = US$136), with 30% of surveyed households being formally employed (Table 2.1). In contrast, the average annual household income in Mfuleni was US$2 519 (SE = US$252), with 70% in formal employment. The total average annual household income in Letseng-la-Letsie was significantly lower than that earned around Mfuleni ($t = -5.97324$, $df = 439$, $p < 0.05$).

Table 2.1: Sources of cash income and percentage of households receiving incomes from these sources around Letseng-la-Letsie (n = 161) and Mfuleni (n = 279). (hh = households). Figures in parentheses are standard errors

	Letseng-la-Letsie			**Mfuleni**		
Sources	**%hh**	**Average annual income for hh earning (US$)**	**Average annual income for all hh (US$)**	**%hh**	**Average annual income for hh earning (US$)**	**Average annual income for all hh (US$)**
Selling home brew	**34.8**	275 (68)	96 (26)	**0.7**	943 (86)	7 (5)
Remittances	**26.1**	1 016 (250)	265 (74)	**5.0**	463 (77)	23 (11)
Grants	**No data**			**21.1**	670 (64)	141 (21)
Casual employment	**19.9**	1 104 (318)	219 (71)	**55**	3 061 (298)	1 684 (187)
Pensions	**18**	217 (27)	39 (8)	**11.8**	1 245 (89)	147 (36)
Selling agricultural products	**16.8**	86 (24)	14 (5)	**1.4**	503 (305)	7 (5)
Self employment	**9.9**	975 (332)	97 (40)	**20.3**	2 117 (442)	431 (103)
Selling medicinal plants	**5.6**	37 (17)	2 (1)	**0**		
Selling crafts	**3.1**	241 (198)	7 (6)	**0.4**	771 (0)	3 (3)
Selling livestock	**3.1**	870 (508)	27 (19)	**9.3**	1 208 (268)	65 (21)
Selling firewood	**1.6**	14 (0)	0.14 (0.09)	**0**		

2.4.2 Natural resource use – Letseng-la-Letsie

2.4.2.1 Agriculture

Many households did not have their own fields and participated in share cropping. Informal interviews revealed that fields were owned by families and passed down through generations. The geometric mean field size was 1.5 ha (SD = 4.6 ha). Of the households surveyed 11% felt that the previous year's harvest was normal but the majority felt that the harvest was much worse than previous years'. Some of the reasons given were that there had been severe frost and also insufficient rain in the preceding year. The harvests recorded were therefore lower than normal. The greatest cash income was from illegally growing cannabis (Table 2.2). No other purely cash crops were grown. No agriculture was carried out on the wetland.

Table 2.2: Average agricultural production over the previous year around Letseng-la-Letsie and Mfuleni. (hh = households; y = year)

		Letseng-la-Letsie							Mfuleni						
	Unit	**% hh growing**	**Units per growing hh**	**Per farming household**					**% hh growing**	**Units per growing hh**	**Per farming household**				
				Units harvested	**Average unit price (US$)**	**Average gross income (US$/y)**	**Average net income (US$/y)**	**Average cash income (US$/y)**			**Units harvest-ed**	**Ave. unit price (US$)**	**Ave. gross income (US$/y)**	**Ave. net income (US$/y)**	**Average cash income (US$/y)**
Maize	Kg	34.1	309	148	0.43	64	63	0.29	2.9	55	31.5	0.64	20	19	3
Peas	Kg	13	396	72	0.49	35	33	0.14	1.1	7	2	0.43	0.70	0.70	0.57
Barley	Kg	9.9	147	21	0.20	4	3	0.71	0.3	10	7	0.57	4	3	0
Potatoes	Kg	8.1	872	99	0.29	28	27	14	3.2	52	33	1.07	36	34	9
Cabbages	Kg	8	202	23	0.40	9	8	3	2.5	23	10	0.57	6	4	3
Spinach	Handfuls	1.9	128	3	0.36	1	1	0	3.6	17	13	0.43	5	4	3
Pumpkin	Kg	0.6	1	0.04	0.57	0.14	0.14	0	1.1	42	16	0.71	12	10	5
Onions	Kg	0.6	183	3	0.50	2	0.14	0							
Wheat	Kg	24.8	125	44	0.40	18	16	2							
Sorghum	Kg	11.8	183	30	0.57	17	16	0.14							
Cannabis	Kg	1.9	647	17	1.86	31	30	31							
Japanese radishes	Kg	19.3	552	149	0.57	85	84	8							
Beans	Kg	6.8	66	6	0.50	3	2	1							
Wheat straw	Bundles	11.2	38	6	2.86	17	16	0.14							
Millet	Kg								0.3	15	1	0.57	0.60	0.57	0.57
Rape	Kg								1.4	55	12	0.50	6	5	6
Cauliflower	Kg								0.3	6	0.4	0.57	0.30	0.29	0.29
Tomatoes	Kg								1.4	35	10	0.50	5	4	0.14
Carrots	Kg								0.7	20	1	0.43	0.50	0.57	0
Sweet potatoes	Kg								0.3	0.5	0.04	0.86	0.20	0.03	0
Butternut	Kg								0.3	32	2	0.57	1	1	1
Turnips	Kg								0.3	100	7	0.21	2	2	2
Beetroot	Kg								0.3	7.5 kg	0.5 kg	0.21	0.10	0.14	0
Total						**314.14**	**299.28**	**60.42**					**99.40**	**88.30**	**33.57**

Table 2.3: Average incomes from natural resources around Letseng-la-Letsie and Mfuleni over the previous year. Harvested units are head bundles for all but wild vegetables and medicines which are measured as handfuls. (hh = households; y = year)

	Letseng-la-Letsie								Mfuleni							
		Per harvesting household								Per harvesting household						
Resource	**% hh**	**Average amount harvested**	**% hh selling**	**Average amount sold**	**Average unit price (US$)**	**Average gross income (US$/y)**	**Average net income (US$/y)**	**Average cash income (US$/y)**	**% hh**	**Average amount harvested last year**	**% hh selling**	**Average amount sold**	**Average unit price (US$)**	**Average gross income (US$/y)**	**Average net income (US$/y)**	**Average cash income (US$/y)**
Firewood	82	184	5	2	1.70	313	312	3	14	1 553 kg	0.3	128 kg	2	2 662	2 661	220
Reeds	1.9	3	1.2	2	1.43	4	3	3								
Grass	9.9	7	2.5	1	1.43	10	9	1								
Sedge	11.2	2	1.2	1	1.43	3	2	1								
Wild vegetables	65.2	1254	0		1.14	1 433	1 432		0.4	5 kg	0		1	5	4	
Natural medicines	28.6	74	2.5	7	1.43	106	104	10	1.4	33	0		1	30	29	

2.4.2.2 Natural resources harvested

Of the natural resources harvested, very little was realised as cash income as most was used for subsistence (Table 2.3). Less than 5% of the households surveyed made crafts from natural products. Brooms were manufactured from grasses, whilst ropes were made from sedges. None of the households harvested natural resources from Letseng-la-Letsie itself but from surrounding areas.

2.4.2.3 Hunting

Overall 5% of the households surveyed hunted. Of the households that hunted 75% used dogs for hunting and one household used a catapult. The animals which tended to be hunted the most were hares (Table 2.4). The only two households that reported fishing did so in nearby rivers and not in the wetland.

Table 2.4: Number of animals caught per year around the Letseng-la-Letsie Wetland and Mfuleni

	Letseng-la-Letsie				**Mfuleni**
	Average number caught by hunting households	**Estimated value per animal (US$)**	**Average gross income (US$/year)**	**Average net income (US$/year)**	**Average number caught by hunting households**
Rabbits	0.6	2	1	1	0.01
Hares	0.8	2	2	1	0
Antelope	0.1	7	1	1	0
Francolins	0.3	2	1	1	0
Rock rabbits	0.1	2	0.30	0.30	0
Ducks	0				0.007
Other birds	0.3	2	1	1	0

2.4.2.4 Livestock

Of the households surveyed 62.1% owned cattle, sheep or goats. The highest proportion of surveyed livestock owners had mixed herds of all three animals, with the next highest just owning cattle. Thirty-nine percent of the owners had livestock posts at Letseng-la-Letsie. Households were unable to graze their livestock around Letseng-la-Letsie all year due to the extremely cold winters. There was no significant correlation between household herd sizes and overall cash incomes for cattle and goats, but there was a significant correlation for sheep (r = 0.2798, P < 0.05). In addition to income from selling livestock, households derived other benefits such as milk, wool and mohair. The average amount of milk produced monthly was 190 l and approximately 170 l was sold generating an income of US$874/y. Five percent of the owners rented their livestock for ploughing and earned on average US$177 a year from this. Twenty-three percent of the surveyed households sold wool and earned on average US$244 and 19% of the households sold mohair earning US$78. Due to households keeping different combinations of livestock the overall net income and value added from livestock was calculated.

2.4.2.5 Water use

None of the households used water from the wetland itself. The majority of households had access to tap water for their domestic consumption, yet households using spring water tended to consume more water. Seventy percent of households used rivers to wash their clothes.

2.4.3 Natural resource use – Mfuleni

2.4.3.1 Agriculture

Of the households surveyed, 7.2% practised agriculture and 6.1% had fields. Some households shared their fields with others and agriculture was practised on the wetland itself. The geometric mean field size in Mfuleni was 0.002 ha (S.D. = 5.8ha) and these tended to be small food gardens next to people's houses. The highest proportion of surveyed households practising agriculture felt the previous harvest had been a normal one. A range of vegetables were grown, however, the highest percentage of households grew spinach (Table 2.2).

2.4.3.2 Natural resources harvested

A number of herbalists reported collecting *imphepho* or *Helichrysum odoratissimum* which is used medicinally. This was not strictly a wetland species as it was also found in other areas. There were no crafts made in Mfuleni from harvested resources. Resources harvested around Mfuleni were firewood, medicinal plants and wild vegetables (Table 2.3) but were not specifically from wetlands. Medicinal plants and wild vegetables were for personal use whereas firewood was sold by some households.

2.4.3.3 Hunting

Two households reported fishing, but this was in the river. Only 1% of the households reported hunting on the wetlands and caught ducks and rabbits. The relative number of animals hunted was reportedly low but households kept packs of dogs to hunt with and this suggested that households hunted regularly.

2.4.3.4 Livestock

Around Mfuleni 8.6% of the households surveyed owned livestock. The greatest proportion of livestock owners surveyed kept mixed herds of cattle and goats. Of the owners surveyed, 87.5% used the wetlands to graze their livestock. The overall productivity of cattle and goats was higher than for sheep over the previous year (Table 2.5). Besides earning an income from selling livestock, 4.5% of the households obtained a small income from milk production. On average 374L of milk was collected a month by cattle owners and gave an average annual income of US$1 290. A higher average volume of milk was produced by households in Mfuleni than in Letseng-la-Letsie. The households around Mfuleni did not obtain wool or mohair from their sheep and goats. There was a negative correlation between the cash incomes earned by households and their herd sizes for cattle (r = -0.0331, $P < 0.01$) and goats (r = -0.0628, $P < 0.05$), with the more affluent households tending not to own livestock. There were insufficient sheep owners to do a correlative analysis of household cash incomes and sheep herd sizes. Again, due to owners having different herd compositions, overall average incomes earned from livestock in general were calculated.

2.4.3.5 *Water use*

Less than 1% of surveyed households in Mfuleni used water from the wetlands. The majority of households used tap water for their domestic water needs and those using tap water tended to consume the highest volume of water. About 4% of the households surveyed used river water for clothes washing.

Table 2.5: Average incomes of livestock-owners around Letseng-la-Letsie over the past year. (hh = households)

	Letseng-la-Letsie				**Mfuleni**			
	Livestock in general	**Cattle**	**Goats**	**Sheep**	**Livestock in general**	**Cattle**	**Goats**	**Sheep**
% hh	62.1	47.2	32.3	39	8.6	7.2	5.4	0.7
Average number owned		5.6	11.6	30.3		20.5	14.7	30.3
Average number slaughtered		1.1	0.6	1.1		0.5	0.8	1.5
Average number to herders		0.01	0.2	0.4		0.05	0.2	0.4
Average number sold		0.2	0	0.8		2.1	1.9	0
Average annual production		1.4	0.8	2.3		2.7	2.7	1.8
Price (US$)		357	100	100		500	107	107
Average gross income (US$/year)	2 360	1 777	154	429	4 360	3 920	289	150
Average cash income (US$/year)	166	86	0	80	1 254	1 050	204	0
Average net income (US$/year)	**714**				**2 129**			

2.4.4 Dependence on wetlands

A higher average income was earned by people in Mfuleni than those living round Letseng-la-Letsie and this is reflected in the HDI (Table 2.6). Although a higher proportion of people used the wetlands around Letseng-la-Letsie than around Mfuleni, the relative contribution of wetlands to peoples' incomes was lower. Many households near Letseng-la-Letsie practised agriculture in the surrounding areas. In Mfuleni wetlands tended to be the only open areas as other land was built upon.

Table 2.6: Average incomes earned in Letseng-la-Letsie and Mfuleni and relative dependency upon the wetlands

	Letseng-la-Letsie	**Mfuleni**
Average annual income in area	US$886	US$2 765
Population density (people/km^2)	66	1 600
Human Development Index (HDI)*	0.549 (UNDP 2007)	0.76 (StatsSA 2001b)
% households using wetland	65%	12.8%
Average annual income of wetland users	US$826	US$2 454
Average annual income from wetlands	US$66	US$2 003
Proportion of income of wetland users from wetlands	8.0%	81.6%

*A composite measure that includes measures of life expectancy, income, education, access to clean drinking water and 'voice', out of 1.

2.4.5 Overall value of wetlands

The estimated total incomes from livestock were higher around Letseng-la-Letsie than Mfuleni (Table 2.7). This is despite the fact that the price of cattle was 40% higher in Mfuleni compared to Letseng-la-Letsie and was 7% higher in Mfuleni for sheep and goats. The incomes earned specifically from the wetland were lower, however, as around Letseng-la-Letsie there was other land available to be used. In Mfuleni the wetlands contributed a greater proportion total household income, since households had no other open land available to them. The estimated value of provisioning services per hectare was higher in Mfuleni than Letseng-la-Letsie. The value added was higher than the net income as it did not include capital and labour costs.

Table 2.7: Estimated total incomes earned and incomes from wetland provisioning services for Letseng-la-Letsie (819 ha) and Mfuleni (310 ha). Values are in United States Dollars. (hh = households)

			Total			From wetland			
	% hh	Estimated number of hh	gross income '000	net income '000	value added '000	gross income '000	net income '000	value added '000	Value added/ha
Letseng-la-Letsie									
livestock	24.2	986	2 329	705	3 593	116	35	180	219
hunting	5	203	1	1	1	1	1	1	1
Total			**2 330**	**706**	**3 594**	**117**	**36**	**181**	**220**
Mfuleni									
livestock	8.5	95	414	202	600	373	182	540	1 742
crops	7.1	79	8	7	7	8	7	7	23
Total			**422**	**209**	**607**	**381**	**189**	**547**	**1 765**

2.5 Discussion

2.5.1 General livelihood activities in Letseng-la-Letsie and Mfuleni

Around Letseng-la-Letsie the main incomes were from casual employment and remittances. Households with lower incomes tended to engage in agriculture and harvesting natural resources. Lower income households in Letseng-la-Letsie probably diversify their activities to reduce risk and ensure a sustainable income (Shackleton *et al.,* 2001; Block and Webb, 2001). Fewer households were employed in Letseng-la-Letsie than in Mfuleni. In Mfuleni the main sources of income were casual employment and grants and households were less reliant on agriculture and natural resources. In both areas, crops which were harvested mainly contributed to household subsistence. This was also found in the Okavango, where only a small proportion of crops are sold (Turpie *et al.,* 2006).

Few natural resources were harvested by either of the two communities, apart from firewood which many households in both areas relied on for heating and cooking. In both areas the sale of crafts was ranked low as a source of income. This is in contrast to other parts of Africa, where harvesting natural resources for crafting is a major contribution to livelihoods (Schuyt, 2005; Shackleton and Campbell, 2007). At Letseng-la-Letsie, the wetland vegetation has low diversity and abundance of species normally used in craft making (Grab and Morris, 1997) and the vegetation is nearly all grazed. At Mfuleni the reliance on harvesting natural resources was relatively low due to availability of substitutes in the urban environment.

More households reared livestock in rural Letseng-la-Letsie than in peri-urban Mfuleni, as would be expected from the difference in rangeland area available. Around Letseng-la-Letsie there was a correlation between household income and number of sheep (the dominant form of livestock), which is consistent with a situation in which livestock provide multiple social benefits including a wealth store function (Meltzer, 1995; Grab and Morris, 1997; Dovie *et al., 2*005; Shackleton *et al., 2*005) and where high stocking rates are favoured over production. Small livestock also yield better returns from reproduction (Meltzer, 1995), and generate a substantial income from mohair and wool (Dovie *et al., 2*006). Thus livestock in this area may generate better incomes than in other communal livestock systems where production values are typically low (e.g. Meltzer, 1995; Turpie *et al., 1*999; Turpie *et al., 2*006). Around Mfuleni, on the other hand, there was a negative correlation between household income and livestock numbers (dominated by cattle), with higher income earning households not keeping livestock. This suggests that lower income households are more dependent on livestock for their livelihoods. In both areas, the limited degree of control over grazing, coupled with the objective of maximising animal numbers rather than production, means that the value of grazing is probably lower than its potential. This activity probably compromises ecosystem health, the production of natural resources and ecosystem functions.

2.5.2 Provisioning services and incomes derived from the wetlands

Scarcity of high quality grazing is one of the greatest limiting factors to livestock production in Africa (Meltzer, 1995). Wetlands are preferentially grazed by both small and large stock (Grab and Morris, 1997), and grazing is a common use of wetlands (Palmer *et al., 2*002; Bisaro, 2007). Alpine wetlands in Lesotho have been found to be particularly important in providing forage during the change of seasons when surrounding grasslands are dry (Grab and Morris, 1997). The timing of when wetlands provide grazing may be as important as the amount of fodder they produce and they may play a major role in maintaining stock numbers and reducing mortality in times of drought. A negative aspect of grazing on wetland areas is that wetlands can increase the risk of livestock parasite infections and the occurrence of foot rot which can result in mortality (Begg, 1986).

In Letseng-la-Letsie herders reported that the wetland provided the best grazing in the region. It contributed an estimated 5%, or US$35, of the average livestock owner's net income. At Mfuleni the wetland contributed a net income of some 90%, or US$1 916 of average income from livestock. Estimates of incomes from grazing of wetlands vary depending on wetland type and context, particularly relating to the proportion of grazing derived from the wetland, as well as the proportional ownership of cattle. For the Barotse Floodplain in the Zambezi Basin, the estimated net household income from grazing livestock on the floodplain was US$120/y (Turpie *et al., 1*999). Although also a rural setting, the floodplain area formed a much greater proportion of the landscape. For a much smaller wetland in Craigieburn in the Mpumalanga Province of South Africa, livestock owners derived a relatively high proportion of grazing from the wetland, which was estimated to provide a net income of US$1 296 per household (Pollard *et al., 2*007). At Mfuleni, the small proportion of households that owned livestock were the most reliant on the wetland.

Households did not use Letseng-la-Letsie for fishing and domestic water consumption. In Mfuleni, fishing was restricted to the Kuils River and only a small proportion of surveyed households used water from wetlands for domestic consumption. In both areas some households derived a small income from hunting on the wetlands. Due to the illegal nature of this activity, hunting values may have been underestimated in this study.

Wetlands are often important in allowing year round crop production by providing water in dry periods, and enhance yields by increasing the soil nutrient and sediment levels (Emerton *et al., 1*999). A higher yield of crops from wetland areas can give households greater food security and improve their livelihoods. However, if they are not drained overall crop yields may be affected by excessive moisture. Certain crops are better suited to growing in wet conditions than others. At Mfuleni vegetables were cultivated mainly for subsistence, and only a small proportion was sold. Subsistence agriculture generates food at a lower cost than in markets, a value of natural ecosystems which is often overlooked (Delang, 2006a; b). Farming households generated at least US$100/y from the Mfuleni wetlands. In Craigieburn the average farming household earned US$182 a year from wetland agriculture (Pollard *et al., 2*007) and in Mbongolwane in KwaZulu-Natal in South Africa, farming households earned on average US$39/y from wetland cultivation (Kotze *et al., 2*002). The overall yields and size of people's fields in Mfuleni were small in comparison to other wetland areas in Africa.

2.5.3 Dependence upon the wetlands for income, risk-spreading and as a safety-net

As well as the generation of income *per se*, wetlands can provide an opportunity to spread risk as well as a safety-net function, both of which are important to people's livelihoods in different ways. Many wetlands have been shown to provide substantial value in spreading risk by providing resources that enable households to broaden their activity portfolios (Turpie *et al., 1*999; Schuyt, 2005). This was not the case for the wetlands in this study. Letseng-la-Letsie essentially adds to the productivity of one of the activities typically undertaken by households. Nevertheless, when one considers the contribution of the wetland to productivity during the dry season, it is apparent that the wetland was important for risk-spreading and income-smoothing. In Mfuleni, households did not typically engage in multiple activities, and the wetland did not form part of a risk-spreading strategy. However, being an open access resource in an urban area, it did provide an opportunity for newcomers (e.g. jobseekers) to derive a livelihood, thus performing more of a safety-net function. The safety-net value of the wetlands is much more far-reaching than the simple estimates of income provided in this study. This function eases the burden on the state to provide social security, but comes at the potential cost of ecosystem health.

The two areas provide an interesting contrast in that one represents a situation of a high proportion of households deriving a small proportion of their income from the wetland, while the reverse is true for the other community, which also has a higher average income in general. This begs the question as to which community is more dependent on the wetland. In Mfuleni, if the wetland were lost there are other occupations people could turn to. The overall social cost of wetland loss or degradation is therefore likely to be higher around Letseng-la-Letsie than Mfuleni, although the cost to individuals would be greater in Mfuleni. In neither case could the community be said to be highly dependent on the wetlands.

When households are completely reliant on natural resources for their livelihood it is a sign of extreme poverty and deprivation (Béné, 2003). The percentage of households using a wetland may be a good indicator of the importance of a wetland to people's livelihoods (Kangalawe and Liwenga, 2005). In a study on the Yala swamp in Kenya it was found that 86% of the population relied on the wetland for the provision of building materials such as clay, sand, wood and papyrus (Jansen and Schuyt, 1998 cited in Schuyt, 2005). In Craigieburn in South Africa, it was found that 73% of the households around the wetland made use of the wetland provisioning services (Pollard *et al., 2*007).

Of these households, 63% were from the lowest wealth group and received only occasional incomes with many dependents relying on this. By identifying the number of people using wetlands and their overall dependence upon wetlands, decision makers can see how the loss of wetlands could affect the welfare of communities living around them. The wetlands in Mfuleni contribute more to individual's livelihoods than the rural wetland in Letseng-la-Letsie. However, in Letseng-la-Letsie a larger number of people are reliant on the wetland and therefore the loss of the wetland would have a greater regional impact.

2.5.4 Overall wetland value

The value of Letseng-la-Letsie (US$220/ha/y) falls within the range of most estimated values of rural wetlands elsewhere. In the Hadejia-Nguru Wetland in Nigeria the annual value derived from agriculture, fishing and firewood provision was approximately US$34-54/ha (Barbier *et al., 1*997). The Nakivubo Wetland in Uganda was estimated to generate approximately US$500/ha annually from agriculture (Emerton *et al., 1*999). Wetlands in the Zambezi Basin ranged in value from US$16/ha in the Barotse Wetland, to US$97/ha in the Caprivi Wetland from grazing (Turpie *et al., 1*999). Crop cultivation in the Lower Shire Wetlands in the Zambezi Basin contributes a high income of US$203/ha, however, other wetlands within the basin had lower agricultural returns. In the Olifants River catchment in South Africa, it was estimated that floodplains generate incomes of US$1-14/ha/y from harvestable resources (Palmer *et al., 2*002). Seeps were predicted to generate higher annual incomes of US$260-360/ha as they were used for agriculture. An estimate of the annual value from wetlands in southern Africa for grazing was US$257-343/ha. The value of wetlands in Mfuleni (US$1 742/ha/y) was far higher. This is likely to be due to the more intensive use of Mfuleni due to population pressure, coupled with the higher incomes derived per unit of production as a result of being closer to markets.

The results reported may be affected by inaccuracies in reporting by households, which relied on the respondents' recall of resources harvested and incomes derived over the previous year. Values reported here were for 2007, but these are likely to vary over time with resource availability, socio-economic factors and land management practices. In the case of Letseng-la-Letsie households stated that the harvest was lower than in previous years, implying that higher economic values may potentially be obtained. In Mfuleni households stated that the harvests were normal compared with other years.

2.5.5 Are the wetland values sustainable?

Uses which maximise private returns may not be environmentally sustainable and it is important to consider longer term implications of these activities (Kotze and Breen, 1996; Huitric, 2005). Cultivation on wetlands may alter the regulatory function of wetlands, reducing their water storage capacity and result in more variable stream flows (Dixon and Wood, 2003). It is worth considering whether some activities will have an irreversible effect and detract from the future value of wetlands.

There may be a negative relationship between social and ecological resilience, especially where communities are highly dependent upon natural resources for their livelihoods (Adger, 2000). Indeed, the Letseng-la-Letsie and Mfuleni wetlands are already degraded. Letseng-la-Letsie has been modified by dam construction and overgrazing. The wetlands around Mfuleni are encroached upon by urban development, polluted and hydrologically altered. Furthermore, the number of people using the wetlands in Mfuleni is increasing due to more people migrating to the area.

In Letseng-la-Letsie for instance, although chiefs ostensibly control grazing, there are often power disputes between chieftainships and village development councils over regulating open access to resources (Letsela *et al., 2*002). If stricter property rights were introduced and the number of people using the wetlands was limited the value generated might be higher and more sustainable, but possibly at the cost of the safety-net function provided by the wetland. At times the direct use value of open access resources may be lower than the value of what they contribute as a safety net to communities during times of financial need such as retrenchment or death of a breadwinner (Shackleton *et al., 2*001). The wetlands in Mfuleni may play an important role in supporting the unemployed. Removing the open access to the wetlands would probably affect the poorest households most as they are less likely to have alternative private resources to utilise.

The level of use that is desirable will ultimately depend on the trade-off between productive value through sustainable use and the degree to which value is distributed to those most in need. The scenario in this paper of many households having low dependence upon the wetland for their livelihoods compared to a few households being highly dependent offers a challenge when estimating the economic value of wetlands. The overall social cost of the wetlands loss to the whole community needs to be considered. In developing a protocol for valuing wetlands it would therefore be important to consider how diversified local community livelihoods are and their other potential safety nets in times of financial stress. The number of people using the wetland may eventually reach a critical point at which the ecological resilience will be surpassed and signs of wetland degradation should therefore be monitored and incorporated into the valuation.

2.6 Conclusion

The main use of both the wetlands in Letseng-la-Letsie and Mfuleni by surrounding communities was for livestock grazing. Whilst other provisioning services such as wildlife for hunting and land for crop cultivation in Mfuleni were also utilised, these activities were minor and did not generate significant income to households. Nevertheless, values of the wetlands were comparable to those found for other wetland systems in Africa. The rural Letseng-la-Letsie wetland performed a risk spreading function for a large proportion of the community, by contributing to income during the dry season. The peri-urban Mfuleni wetland performed a safety-net function to a small proportion of the community, offering income opportunities to unemployed migrants. This was due to differences in the degree of control of resources in the two wetlands (more control for Letseng-la-Letsie), as well as the nature of the communities. In this respect, it was challenging to determine which community was more dependent on the wetlands.

There is a need for more studies to be conducted on wetlands in southern Africa and for a standard protocol to make these studies comparable. Wetland valuation studies need to put values into perspective by describing their role in income smoothing as well as contribution to overall household income and the sustainability of this income. Furthermore, a way needs to be found to express the safety-net value of wetlands, as descriptions of income derived may belie the importance of this function. Once a wider data base has been established it may be possible to develop more rapid ways of estimating the value of wetlands using key indicators and characteristics. This would be a great asset as it is expensive to undertake a comprehensive study of wetland value and often not much information is available. If more data were available for a wider range of wetlands in southern Africa, it would be useful to see how wetland value varies with wetland characteristics.

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2.8 References

Adaya AL, Bdliya H, Bitrus H, Danjaji M, Eaton D, Gambo MB, Goggobe M, Makinta A, Okali D, Omoluabi AD, Polet G, Salisu M, Sanusi SS, Sarch MT, and Shuaibu M. 1997. Local-level assessment of the economic importance of wild resources in the Hadejia-Nguru Wetlands, Nigeria. Hidden Harvest Project, Research Series Vol. 3, No. 3.

Adger NW. 2000. Social and ecological resilience: are they related? Progress in Human Geography 24(3): 347-364.

Barbier EB. 1993. Sustainable use of wetlands. Valuing tropical wetland benefits: economic methodologies and applications. The Geographical Journal 159(1): 22-32.

Barbier EB, Acreman M and Knowler D. 1997. Economic valuation of wetlands: a guide for policy makers and planners. Ramsar Convention Bureau, Gland, Switzerland.

Begg G. 1986. The wetlands of Natal (Part 1): an overview of their extent, role and present status. Natal Town and Regional Planning Report, Vol. 68.

Béné C. 2003. When fishery rhymes with poverty: A first step beyond the old paradigm on poverty in small-scale fisheries. World Development 31: 949-975.

Bisaro S. 2007. Formal and informal institutions in the wetlands of the Lesotho Highlands. In: Pahl-Wostl C, Kabat P and Moltgen J (eds.) International conference on adaptive and integrated water management: coping with complexity and uncertainty, Basel, 2007. Springer, Berlin, Germany.

Block S and Webb P. 2001. The dynamics of livelihood diversification in post-famine Ethiopia. Food Policy 26: 333-350.

Delang CO. 2006a. Economic valuation of non-marketed wild edible plants in Thailand. Environmental Conservation 32: 285-287.

Delang CO. 2006b. Not just minor forest products: the economic rationale for the consumption of wild food plants by subsistence farmers. Ecological Economics 59(1):64-73.

Dixon J and Ramutsindela M. 2006. Urban resettlement and environmental justice in Cape Town. Cities 23(2): 129-139.

Dixon AB and Wood AP. 2003. Wetland cultivation and hydrological management in eastern Africa: matching community and hydrological needs through sustainable wetland use. Natural Resources Forum 27(2): 117-129.

Dovie DBK, Witkowski ETF and Shackleton CM. 2005. In the field: monetary valuation of livelihoods for understanding the composition and complexity of rural households. Agriculture and human values 22: 87-103.

Dovie DBK, Shackleton CM and Witkowski ETF. 2006. Valuation of communal area livestock benefits, rural livelihoods and related policy issues. Land Use Policy 23(3): 260-271.

Emerton L, Iyango L, Luwum P and Malinga A. 1999. The present economic value of Nakivubo urban wetland, Uganda. IUCN Biodiversity Economics for Eastern Africa.

Gittinger JP. 1982. Economic analysis of agricultural: 2nd edn,. The Johns Hopkins University Press, Baltimore and London.

Grab S and Morris C. 1997. A threatened resource: Lesotho's alpine wetlands, unique in many ways, are facing a complexity of threats. African Wildlife 51(3): 14-16.

Huitric M. 2005. Lobster and conch fisheries of Belize: a history of sequential exploitation. Ecology and Society 10(1): 21-47. Accessed online at [http://www. ecologyandsociety.org/vol10/iss1/art21/].

Kangalawe RYM and Liwenga ET. 2005. Livelihoods in the wetlands of Kilombero Valley in Tanzania: Opportunities and challenges to integrated water resource management. Physics and Chemistry of the Earth 30: 968-975.

Kotze D and Breen CM. 1994. Agricultural land-use impacts on wetland functional values. WRC report no. 501/3/94. Water Research Commission, Pretoria.

Kotze D and Breen CM. 1996. Wetlands and people. What values do wetlands have for us and how are these values affected by our land-use activities? Wetland use booklet 1. Share-net, Umgeni Valley, South Africa.

Kotze DC, Memela B, Fuzani N and Thobela M. 2002. Utilisation of the Mbongolwane wetland in KwaZulu-Natal, South Africa. Report for the International Water Management Institute (IWMI), Pretoria.

Letsela T, Balkwill K and Witkowksi ETF. 2002. Conservation and sustainable livelihoods in Bokong and Tsehlanyane in Lesotho. In: Benjaminsen TA, Cousins B and Thompson L (eds.) Contested Resources – Challenges to governance of natural resources in Southern Africa. Programme for Land and Agrarian Studies (PLAAS), School of Government, University of the Western Cape. pp. 192-200.

Meltzer MI. 1995. Livestock in Africa: the economics of ownership and production, and the potential for improvement. Agriculture and human values 12(2): 4-18.

Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: synthesis. Island Press, Washington DC.

Morgenthal TL, Newby T, Smith HJC and Pretorius DJ. 2004. Developing and refinement of a grazing capacity map for South Africa using NOAA (AVHRR) satellite derived data. Report GW/A/2004/66. ARC, Pretoria.

Morris CD, Bolene TS and Tainton NM. 1989. Report on investigations of fire and grazing regimes and conservation needs of the eastern alpine catchments of Lesotho. Department of Grassland Science, University of Northern Province.

Nichols P. 1991. Social survey methods: a fieldguide for development workers. Development guidelines, Vol. 6. Oxfam publications, Oxford.

Palmer RW, Turpie J, Marnewick GC and Batchelor AL. 2002. Ecological and economic evaluation of wetlands in the Upper Olifants River Catchment, South Africa. Report number 1162/02. Water Research Commission.

Pollard S, Kotze D and Ferrari G. 2007. Valuation of the livelihood benefits of structural rehabilitation interventions in the Manalana wetland, Craigieburn village, Mpumalanga

Province. Unpublished report. Association for Water and Rural Development and the University of KwaZulu-Natal.

Sathirathai S. 1997. Economic valuation of mangroves and the roles of local communities in the conservation of natural resources case study of Surat Thani, South of Thailand. EEPSA report series. Ottawa, Ontario, Canada.

Schuyt KD. 2005. Economic consequences of wetland degradation for local populations in Africa. Ecological Economics 53: 177-190.

Shackleton SE and Campbell BM. 2007. The traditional broom trade in Bushbuckridge, South Africa: helping poor women cope with adversity. Economic Botany 61(3): 256-268.

Shackleton CM, Shackleton SE and Cousins B. 2001. The role of land-based strategies in rural livelihoods: the contribution of arable production, animal husbandry and natural resource harvesting in communal areas in South Africa. Development South Africa 18(5):581-604. Accessed online at [http://dx.doi.org/10.1080/3768350120097441].

Shackleton CM, Shackleton SE, Netshiluvhi TR and Mathabela FR. 2005. The contribution and direct-use value of livestock to rural livelihoods in the Sand River catchment, South Africa. African Journal of Range and Forage Science 22(2): 127-140.

Shand N and Nicks C. 1999. Kuils River Metropolitan Open Space System (MOSS). Vol. 1: Final report. Report No. 2913. Ninham Shand Inc., Cape Town.

Smit L and Wiseman K. 2001. Environmental resource economics as a tool for environmental management in the City of Cape Town. Forum for Economics and Environment – First Conference Proceedings. pp. 190-218. Accessed online at [http://www.econ4env.co.za/archives/ecodivide/Theme4e.pdf].

StatsSA. 2001a. City of Cape Town – Census 2001 – Mfuleni. Strategic Development Information and GIS. Statistics South Africa. Accessed online at [http://www.capetown.gov.za/
en/stats/2001census/Documents/Mfuleni.htm].

StatsSA. 2001b. Human Development Index. Statistics South Africa. Pretoria: Accessed online at: [http://www.statssa.gov.za/publications/P0015/P00151980.pdf].

Terer T, Ndiritu GG and Gichuki NN. 2004. Socio-economic values and traditional strategies of managing wetland resources in Lower Tana River, Kenya. Hydrobiologia 527: 3-14.

Turner RK, van den Bergh JCJM, Soderqvist T, Barendregt A, van der Straaten J, Maltby E and van Ierland EC. 2000. Ecological-economic analysis of wetlands: scientific integration for management and policy. Ecological Economics 35: 7-23.

Turpie J. 2000. The use and value of natural resources of the Rufiji Floodplain and Delta, Tanzania. IUCN – Eastern Africa Regional Office.

Turpie J, Smith B, Emerton L and Barnes J. 1999. Economic value of the Zambezi Basin wetlands. IUCN Regional Office for Southern Africa.

Turpie J, Joubert A, van Zyl H, Harding B and Leiman T. 2001. Valuation of open space in the Cape Metropolitan Area: a pilot study to demonstrate the application of environmental and resource economics methods for the assessment of open space values in two case study areas: Metro South and Metro South-east. City of Cape Town.

Turpie J, Barnes J, Arntzen J, Nherera B, Lange G and Buzwani B. 2006. Economic value of the Okavango Delta, Botswana, and implications for management. Okavango Delta Management Plan.

UNDP. 2007. Lesotho – GDP. United Nations Statistics Division. Accessed online at: [http://millenniumindicators.un.org/unsd/snaama/resultsCountry.asp?Country=426].

Water Affairs. 2006. Conservation and rehabilitation of wetlands in Lesotho. Department of Water Affairs, Ministry of Natural Resources, Government of Lesotho.

Wynberg R. 2002. A decade of biodiversity conservation and use in South Africa: tracking progress from the Rio Earth Summit to the Johannesburg World Summit on Sustainable Development. South African Journal of Science 98: 233-243.

Zunckel K. 2003. Managing and conserving southern African grasslands with high endemism: the Maloti-Drakensberg Transfrontier Conservation and Development Programme. Mountain Research and Development 23(2): 113-118.

3. QUANTIFICATION OF THE FLOW REGULATION SERVICES PROVIDED BY NYLSVLEY[4] WETLAND, SOUTH AFRICA

M Kleynhans[1], J Turpie[2], F Rusinga[1] and A Görgens[1]

[1] Aurecon

[2]Anchor Environmental

Abstract

In this study, relatively simple and standard hydrological techniques coupled with unsteady one-dimensional hydraulic modelling and subsequent mapping of inundation areas were used. The aim of the project was to estimate the flow regulation services at an intermediate level, that are provided by the Nylsvley wetland, Limpopo Province, for a reach of the Mogalakwena River into which the wetland drains. The flow regulation services that were investigated were flood attenuation and maintenance of base flows[5]. Two wetland development scenarios were compared: one with the wetland in its current state and the second one with the wetland drained and replaced by a trapezoidal grassed canal. A quaternary catchment scale was chosen for the hydrology to enable use of readily available quaternary catchment information. The attenuation of incoming floods was estimated using flood hydrographs determined using the Unitgraph Method. The long-term maintenance of low-flows was estimated using 23-year daily inflow time series that were derived for each quaternary catchment, scaled from a patched observed daily flow time series within the catchment. Losses to evapotranspiration were also estimated and included for the long-term maintenance of low-flows modelling. Significant attenuation of floods flowing through the wetland was indicated as might be expected for a large floodplain wetland. The simulations indicated that the flood peaks generated by the quaternary catchments located downstream of the wetland, some of which had relatively significant tributaries, may become the dominant flood wave in the downstream river reach, dominating the peak flood flows, levels and inundation areas for both development scenarios. The position of a wetland within the drainage landscape is therefore an important factor that determines the flood attenuation services it provides and the attenuation capacity of the wetland is not the only important factor determining the degree to which downstream areas benefit. The long-term maintenance of low-flows simulations indicated large evapotranspiration losses for the wetland development scenario, which in turn indicated reduced low-flows at the wetland outflow point compared

[4] Also spelt “Nylsvlei”.

[5] Note that in “WET-EcoServices” by Kotze et al. (2008), this service is termed “streamflow regulation”.

to the canal development scenario. A large wetland with a similar position in the landscape may therefore be a consumer of water and may reduce downstream low-flows.

3.1 Introduction

The commonly-cited flow regulation functions performed by wetlands include flood attenuation (e.g. Ogawa and Male, 1986; Smithers and Schulze, 1993; Smakhtin and Batchelor, 2005), groundwater recharge and base flow maintenance, by storing precipitation and/or floodwater and releasing it later more evenly over time (e.g. Thompson and Hollis, 1995; Smakhtin and Batchelor, 2005). A wetland regulates flow through storage of high flows on the floodplain and in the wetland soils, depending on the particular wetland's characteristics. Storage on the floodplain occurs through the resistance to flow that the wetland vegetation provides and in depressions and abandoned channels.

Thiesing (2001) defines wetland assessment methods, some of which include estimation of flow regulation functions. The methods that estimate the flow regulation functions include rapid qualitative methods like the US Army Corps of Engineers' Wetland Evaluation Technique (Adamus *et al., 1*987). Kusler (2006) states that hydraulic and hydrologic models are increasingly being used in the USA in more comprehensive assessments to evaluate the flow regulation functions that wetlands and floodplains fulfil.

Ogawa and Male (1986) developed a simulation methodology for evaluating quantitatively the flood mitigation potential of inland wetlands. The methodology made use of various computer models available at that time including the US Army Corps of Engineers programs HEC-1 (now available in updated form as HEC-HMS) for hydrological modelling of the catchment upstream of the wetland and tributaries feeding into the rivers downstream of the wetlands, and HEC-2 (now available in updated form as HEC-RAS) for unsteady hydraulic routing of flows downstream of the wetlands to the points of interest. Various scenarios of wetland infilling in Massachusetts, USA, were modelled after calibration of the models with observed data.

In South Africa Kotze *et al.* (2008) presented two qualitative methods, depending on the available budget, for the assessment of flood attenuation and base flow maintenance services provided by inland palustrine wetlands. These methods rely on scoring sheets using variables that are estimated to fall within certain ranges by the assessor. The variables used in the estimation of flood attenuation services include among others, presence of depressions, surface roughness, slope, size of the wetland in relation to its catchment area and sinuosity of the stream channel. The variables used in the estimation of base flow maintenance include among others, hydrological zonation, presence of fibrous peat or unconsolidated sediments below floating marsh and reduction in evapotranspiration through frosting back of the wetland vegetation.

Smakhtin and Batchelor (2005) quantitatively investigated the flow regulation services provided by the Rustenburg Nature Reserve wetland, situated near Rustenburg in South Africa. Two stream flow gauges are situated in relative proximity to the wetland on the stream that flows through it, one upstream and one downstream. Thus it was possible to analyse the impact the wetland has on flows downstream of the wetland using observed flows, the most desirable method to use in wetland hydrology studies wherever this is possible (Smakhtin and Batchelor, 2005). They state that three methods can be used to derive the 'no wetland' reference condition: firstly, using hydrological rainfall-runoff modelling calibrated using the observed flows and subsequent 'removal' of the wetland (not used due to lack of good rainfall data and the desire to use observed data wherever possible); secondly, flood routing (not used due to a lack of observed flow data at the required temporal resolution) and thirdly, hydrological regionalisation combined with spatial interpolation of stream-flow records using regionalised flow duration curves. The third option was used in this study. The method consists of three steps: estimation of a regional non-dimensional flow duration curve, calculation of the actual flow duration curve at the required site by multiplying the non-dimensional curve by the long-term mean discharge at the site and finally, conversion of an actual flow duration curve at a site into a continuous stream-flow hydrograph using a spatial interpolation technique.

3.2 Study area

3.2.1 Location and characteristics

The Nylsvley floodplain is an important wetland in Limpopo Province that drains into the Mogalakwena River, which in turn joins the Limpopo River downstream. The Nylsvley floodplain has been recognised as an internationally important wetland site under the Ramsar Convention since 1998. The Nylsvley supports a high level of biodiversity, including many important bird species especially when it is inundated (Tarboton, 1991).

The floodplain is large, being about 65 km long and varying between 100 m and 5 km in width. The Nylsvley floodplain is the largest example of a Floodplain Vlei in South Africa (Rogers and Higgins, 1993), is approximately 24 250 ha in extent and includes the

Nylsvley Nature Reserve which preserves about 3 000 ha of the floodplain (Higgins and Rogers, 1993).

The Nylsvley floodplain receives most of its inflows from streams draining the Waterberg Mountains to the northwest. Inundation of the entire floodplain does not occur every year due to its size in comparison to the size of the inflowing streams, and hence outflows from the floodplain do not occur every year either (Tarboton, 1987).

The wetland was defined for this project to run from the outflow of quaternary catchment A61A to the outflow of quaternary catchment A61F (between cross-sections 152 419.8 and 48 060.48 respectively – (see Figure 3.4) for the locations of the cross-sections). These boundaries in fact are situated very close to the actual wetland boundaries. A small portion of wetland lies upstream of the A61A/A61B boundary on the Klein and Groot Nyl Rivers, but it is not a significant portion, and the A61F/A61G boundary falls precisely at a significant change in channel slope that according to the inspection of aerial photographs marks the point where the Nylsvley floodplain ends and the Mogalakwena River begins.

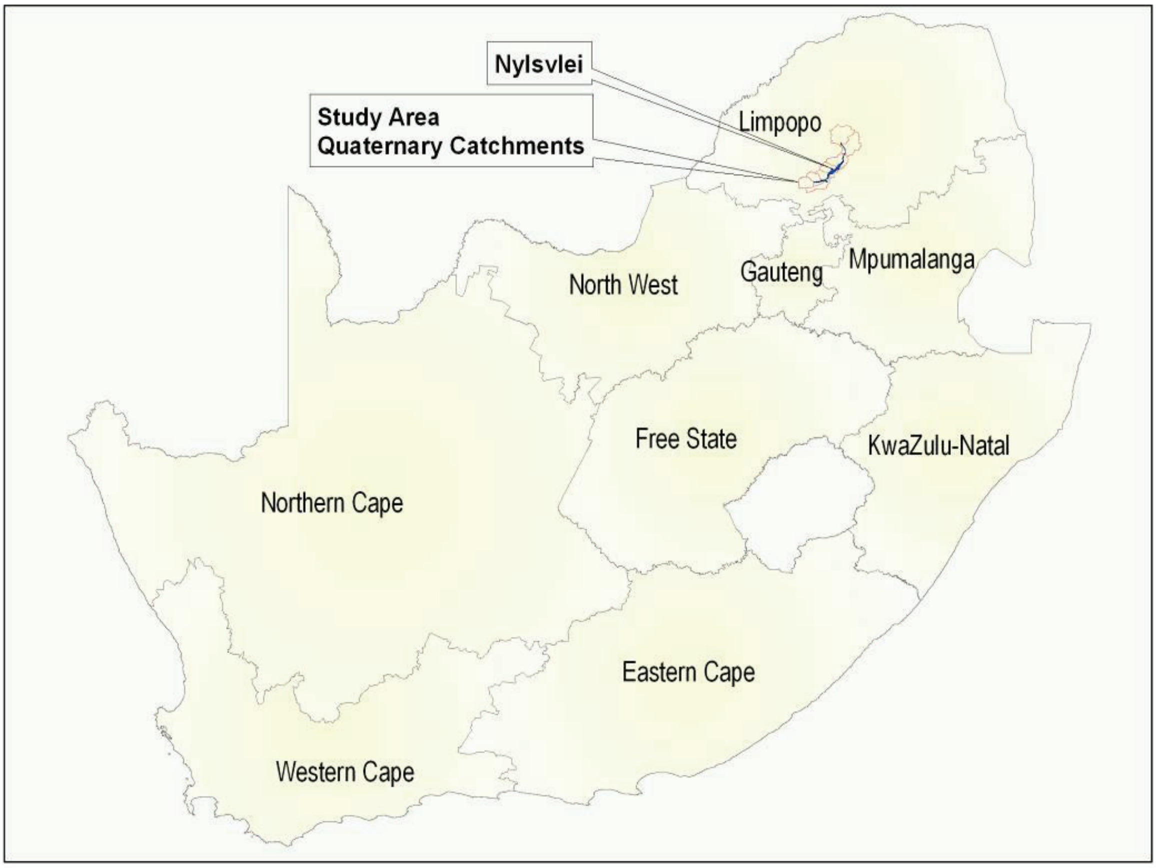

Figure 3.1: Location of the Nylsvlei (Nylsvley) and study region in South Africa.

3.2.2 Previous studies of flooding at Nylsvley

Various studies have been undertaken to simulate the inundation of the Nylsvley floodplain.

Two studies conducted in the late 1980s and early 1990s attempted to model the wetland using hydrological techniques. The first did not account for the losses to floodwaters in the wetland adequately, while the second attempted to model the wetland as a series of dummy dams (Morgan, 1996). Both models ran on a monthly time step and could not output useful information such as inundated areas.

Morgan (1996) used a digital terrain model (DTM) and geographic information system (GIS) to model inundation areas on the floodplain.

From the late 1990s to 2004, an in-depth study was conducted for the Department of Water Affairs and Forestry (DWAF) by an inter-disciplinary team of hydrologists, hydraulicians and ecologists. Birkhead *et al.* (2007) and Birkhead *et al.* (2004) describe the hydraulic modelling and Kleynhans *et al.* (2007) describe the application of the model for environmental impact assessment.

For the DWAF project, the US Army Corps of Engineers' river hydraulic modelling software HEC-RAS and Boss International's pre- and post-processing software for HEC-RAS: QuickSurf (used to draw the high resolution floodplain contour map) and RiverCAD (used to cut cross-sections from the contour map for HEC-RAS and to map inundated areas using data from the HEC-RAS simulations) were used.

The DWAF study included an initial phase that spanned several years prior to the modelling, where stage-discharge relationships were derived at various key points on the floodplain from observed flows and stages and where stages were observed at regular intervals at various points on the floodplain. The availability of high quality observed historical stages and stage-discharge relationships allowed calibration of the hydraulic model.

Unfortunately, the hydraulic model only spanned part of the floodplain, from the N1 culvert near the head of the wetland to the Lephalale (Naboomspruit) – Crecy Road downstream of the farm Mosdene, which lies approximately half way along the length of the floodplain. Only this portion of the floodplain was modelled as it is the most frequently-inundated portion. Due to only half the floodplain being included in the DWAF study, it was decided to construct a new hydraulic model using the proposed rapid method. Averages of the Manning's resistance values that were derived in the calibration process and evapotranspiration rates derived for the DWAF study were used in this study.

3.3 Methods

3.3.1 Modelling Scenarios

In order to evaluate the services provided by the wetland, with-wetland and without-wetland scenarios was modelled in each case using the hydraulic river modelling software HEC-RAS distributed by the US Army Corps of Engineers. The with-wetland scenario was defined as the present day system, including the wetland. The without-wetland scenario was defined to be the Nylsvley floodplain transformed by the construction of a grassed trapezoidal canal to drain the floodplain and route flows downstream without spilling onto the floodplain.

The hypothetical canal was “cut” into the model with a bottom width of 20 m and side slopes of 1V:3H (Figure 3.2) – a cross-section that was chosen as the likely design for a river of this size. The canal was cut deep enough into the terrain so that even the largest floods modelled would be contained within the canal cross-section.

The same HEC-RAS model set up (discussed in detail in Section 3.3.3) was used to model the flood attenuation and baseflow maintenance services. The difference between the models used for the two services amounted only to different inflow time series.

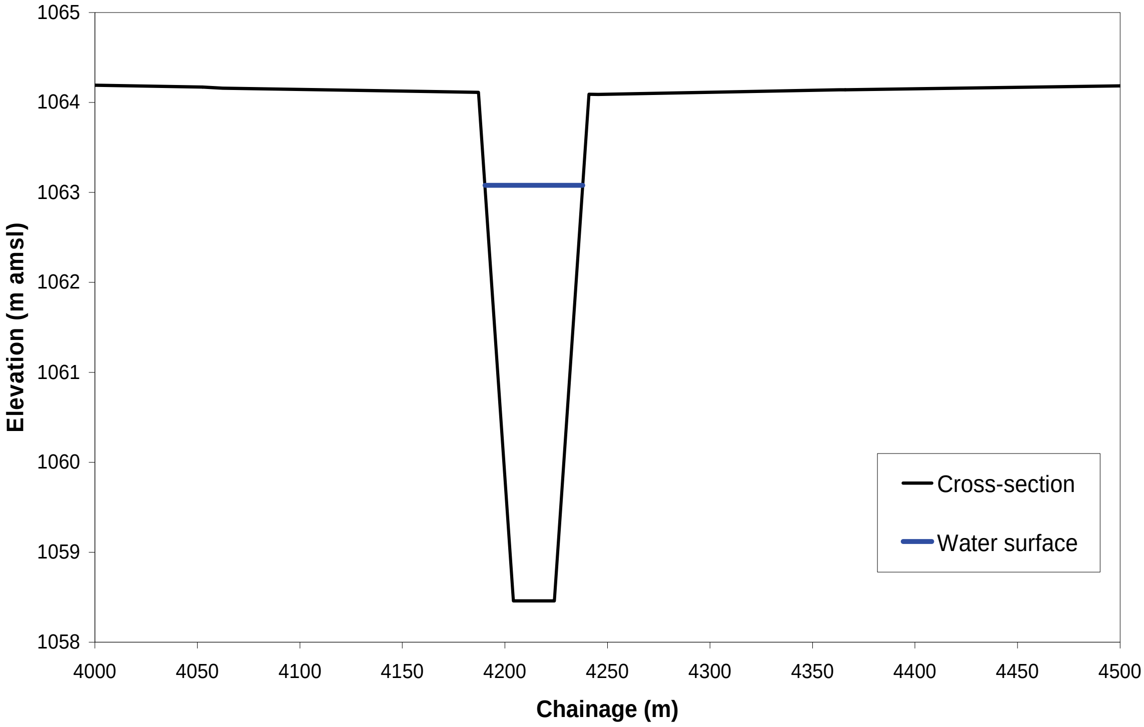

Figure 3.2: Example of canal cut into cross-section (zoom-in of canal portion of cross-section near Mosdene).

3.3.2 Flood attenuation services

3.3.2.1 Derivation of design flood hydrographs

Design flood hydrographs were determined for each quaternary catchment. The output required from the design flood determination process was a flood hydrograph at the nearest quaternary catchment boundary to the upstream boundary of the wetland, and at each quaternary catchment outflow point which occurred in the wetland. A flood hydrograph includes information about the volume of floodwater and the flood peak and both of these are required to calculate the attenuation that a wetland can provide during a flood. The use of design floods as input to the hydraulic model allows the comparison of flood discharges and stages in terms of return periods, in the areas of interest downstream of the wetland.

Seven quaternary catchments were used for the application of this methodology on the Nylsvley: A61A to A61G. The use of quaternary catchments to determine design flood hydrographs simplifies the process of incrementally adding flood hydrographs in long river reaches, by eliminating the need to delineate and measure catchment areas of individual tributaries.

Design flood hydrographs were determined using the Unitgraph method (Midgley, 1972; HRU, 1973; Cullis *et al., 2*007). The Unitgraph method outputs a design flood hydrograph as required, has a relatively low data input requirement and is widely used in South Africa for design flood determination. It is a method that is familiar to hydrologists and engineers, and because it is widely used for other studies such as for dams, the outputs from these wetland services studies can be used in comparisons with other competing projects that would perhaps transform or affect the wetland.

The method involves using a single design storm for the entire catchment. The design rainfall was calculated for the quaternary catchments using relevant rainfall gauges in or close to the study area (four rainfall gauges were used: 0589732AW, 0590307W, 0590361W and 0633796W) and relevant catchment characteristics were described (length of the longest water course, slopes, veld zone type and lag coefficient). A range of critical storm durations was chosen taking into account the basin lag. The Thiessen polygon method was applied to obtain design rainfalls for the entire catchment for each return period and storm duration, and an area reduction factor (Alexander, 1990) was applied to account for aerial variations in rainfall between single rain gauges and a catchment. Storm losses using veld zone and duration were included. The design rainfalls were applied to each quaternary catchment using the ratio of the mean annual precipitation (MAP) of each quaternary to the area-weighted MAP of the entire catchment to ensure that high rainfall areas receive more storm rainfall than dry areas, as would be expected in reality. The ratio of mean annual runoffs (MARs) could also be used. The program HDYPO1 (HRU, 1973) was used to calculate the hydrographs for each catchment at a range of storm durations.

The design rainfalls used for the Nylsvley quaternary catchments are given in Appendix A and the design flood hydrographs for each quaternary catchment are given in Appendix B. The 24 hour storm was found to be the critical storm for the Nylsvley study area. Due to time constraints only the 24 hour 1:50 year return period storm was modelled for this study, but in a full study it would be preferable to model a range of return period floods to gain an understanding of how the services provided by the wetland vary with different return periods.

An example of the 1:50 year return period design flood hydrograph, resulting from the critical 24 hour storm, draining quaternary catchment A61A, is shown in Figure 3.3.

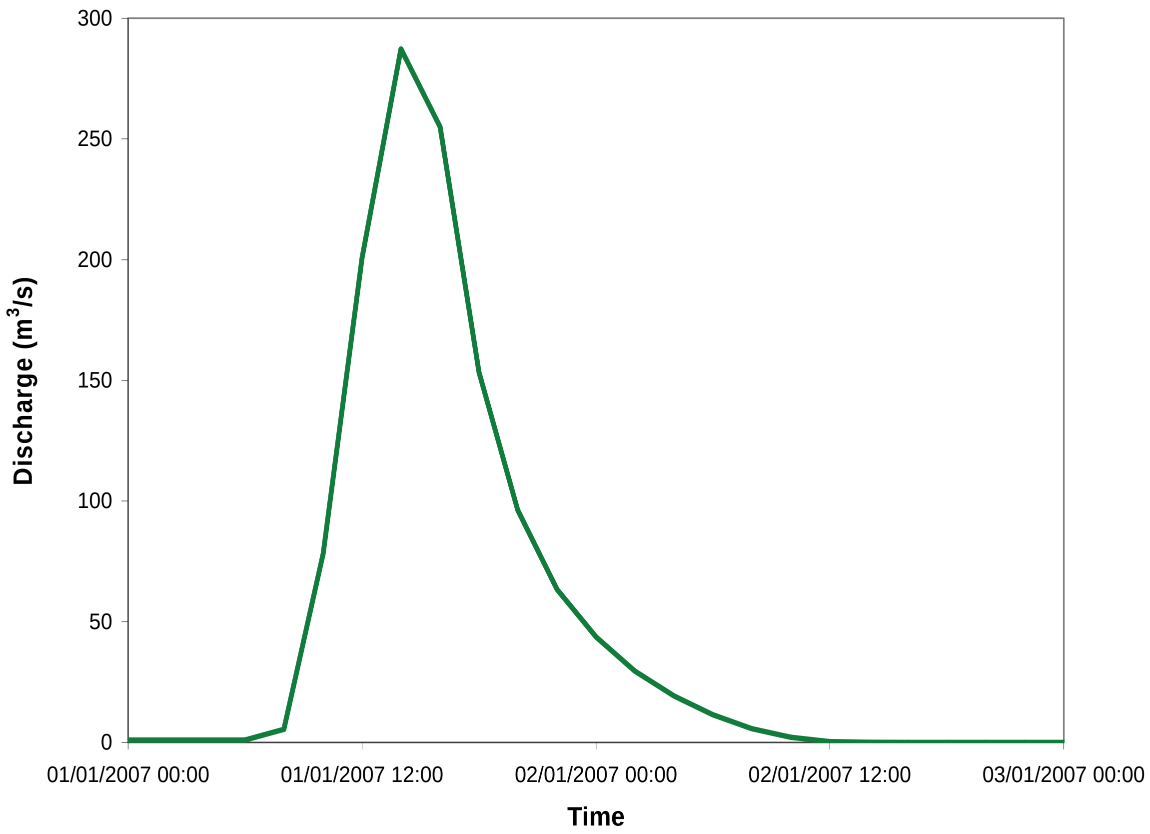

Figure 3.3: Design flood hydrograph draining quaternary catchment A61A.

3.3.2.2 Hydrodynamic modelling

The design flood hydrographs were routed through the HEC-RAS hydraulic model of the wetland and the river reach downstream (discussed in more detail in Section 3.3.3) using unsteady hydrodynamic modelling. This part of the methodology includes the two scenarios mentioned earlier by including and excluding the wetland from the hydraulic model. Hydrographs were extracted at cross-sections downstream of the wetland for the two scenarios and compared to gain a sense of the level of attenuation that the wetland performs.

3.3.2.3 Assessment of areal extent of inundation areas

Inundated areas representing the maximum areal extent of flooding for the two scenarios were mapped using the US Army Corps of Engineers' software HEC-GeoRAS for the areas downstream of the wetland.

3.3.3 Description of the Nylsvley hydraulic model

A hydraulic model was set up for the wetland and a reach of river downstream and used to model both the flood attenuation service and the base flow maintenance service. The model was set up using digital elevation data obtained from the Chief Directorate: Surveys and Mapping. At Nylsvley most of the area was covered by the 5 m digital contour data, but the downstream-most reach was covered by 20 m contour data only. A total of 47 cross-sections were extracted from the digital elevation data and their positions are shown in Figure 3.4.

For this study, the calibrated Manning's resistance values from the previous DWAF study (Birkhead *et al., 2*004), were averaged for the entire model. The Manning's resistance values used in this study are given in Table 3.1. Manning's resistance values were calibrated separately for the channel and floodplain in the DWAF study, but for the sake of simplicity in running the model, only one Manning's resistance value was used for each cross-section in this study. However in an intermediate-level assessment, if the data are available, it would be preferable to use separate values for the channel, left-bank and right-bank floodplains.

Table 3.1: Manning's resistance values used in this study

Reach	**Manning’s resistance**
Wetland portion	0.31
Mogalakwena River portion	0.04
Canalised portion	0.03

The contraction and expansion coefficients that were used were 0.1 and 0.3 respectively, the default HEC-RAS values. These are used in HEC-RAS to calculate energy losses due to contraction and expansion of flow between cross-sections.

Figure 3.4 shows the locations of the various quaternary catchments and their outflow boundaries, which represent the incremental inflows due to the quaternary catchments upstream of those points. The quaternary catchment boundaries do not always coincide with the inflow positions of tributaries to the main river stem. However, this is not a significant problem due to the relatively small size of the quaternary catchments themselves.

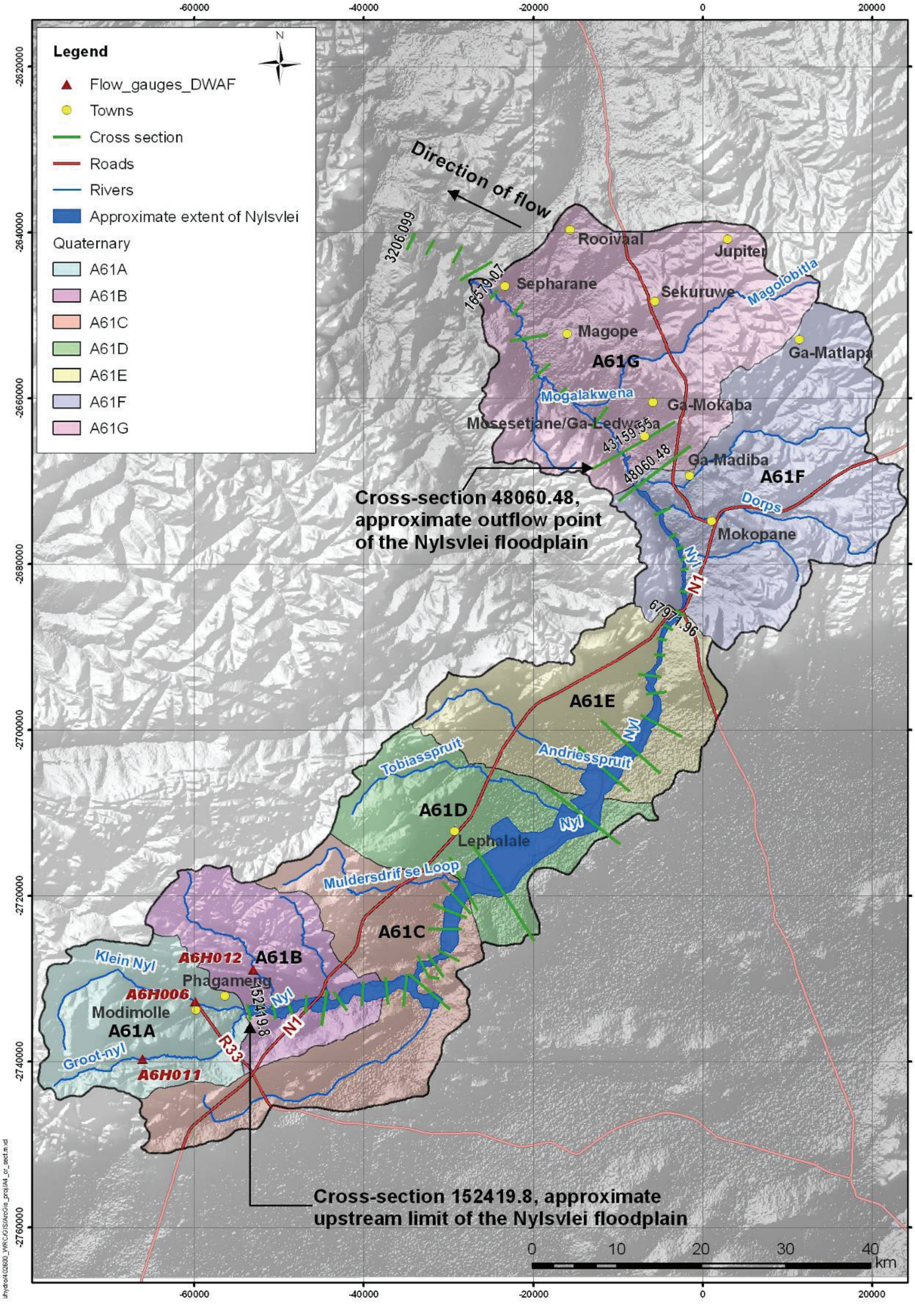

Figure 3.4: Quaternary catchments and locations of cross-sections used in the application of the methodology at Nylsvley.

Quaternary catchments A to E discharge into the wetland reach between cross-sections 152 419.8 and 67 971.96, while quaternary catchments F and G discharge into the Mogalakwena River reach at cross-sections 48 060.48 and 16 579.07, respectively.

The Nylsvley floodplain between cross-sections 48 060.48 and 152 419.8, which approximately define respectively the downstream and upstream limits of the floodplain, has a relatively flat average channel slope of 1:1200. Cross-section 48 060.48 marks the downstream boundary of the Nylsvley floodplain, and the upstream boundary of the Mogalakwena River. Downstream of this point, the river becomes steeper and has an average slope of 1: 480. Figure 3.5 shows the long section profile of the river reach, in which the sudden change in slope at cross-section 48 060.48 (location shown in Figure 3.4 can be clearly seen.

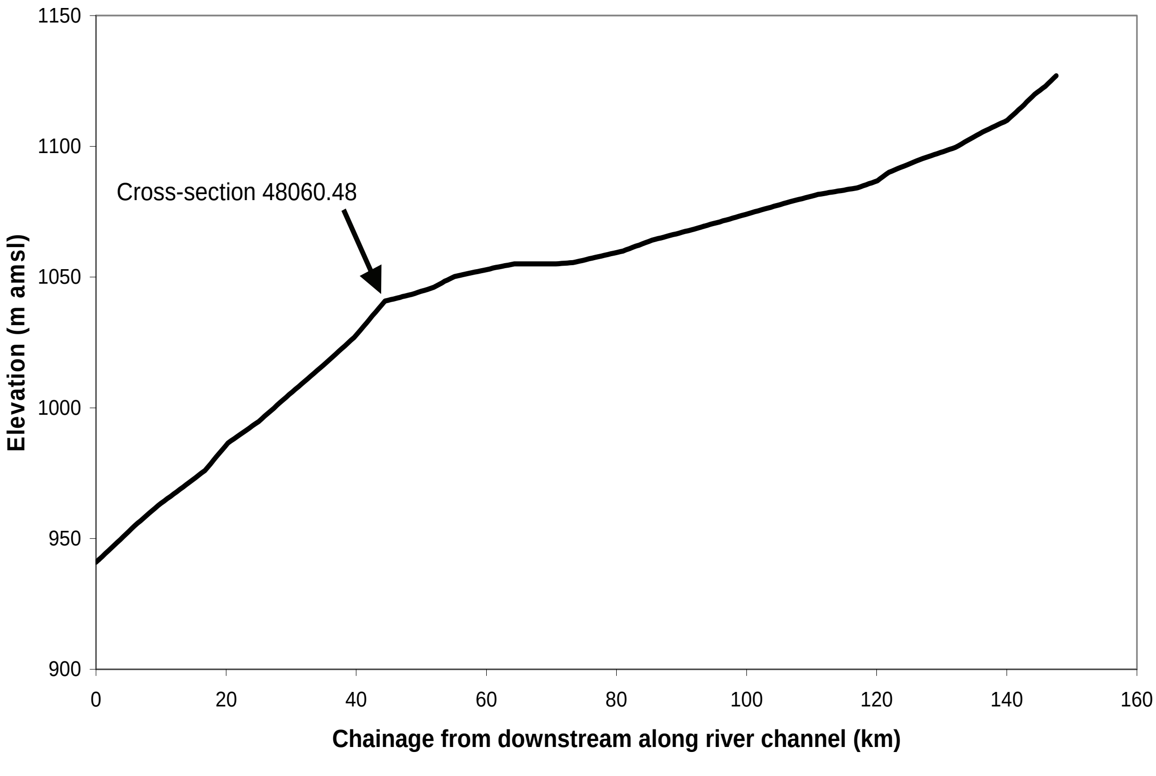

Figure 3.5: Long section profile of the study reach, showing the locations of the cross-sections.

3.3.4 Maintenance of base flows

The baseflow maintenance services were investigated using the same hydraulic model as for the flood attenuation services, but using a long-term inflow time series of 20 years. Baseflow maintenance is a long-term function that requires the analysis of many years of flow data to ensure that drought and wet periods are included in the inflow data time series. A daily time step was used.

3.3.4.1 Estimating daily flow time series simulation of baseflow maintenance

Daily flows were based on observed daily flow data from the DWAF gauging station A6H006, which is situated on the Little Nyl River in the town of Modimolle (originally Nylstroom). Missing data were patched using DWAF gauges A6H011 and A6H012, which were situated relatively close by.

A daily inflow time series was then derived for each quaternary catchment using the MARs for each year in the observed record and for each quaternary catchment from WR90 (Midgley *et al., 1*994). The ratio of annual MARs for each individual year were used, to ensure that variations in runoff between the quaternaries and the DWAF gauge that may occur during dry and wet years were taken into account.

3.3.4.2 Estimating losses and additional inflows due to rainfall on the wetland surface

Losses of floodwater in the wetland to evapotranspiration, infiltration into the soils and to ponded areas where water cannot return to the channel when the wetland dries out again need to be included in a long-term model. Additional water due to rainfall on the inundated wetland surface also needs to be accounted for.

At Nylsvley, losses are very significant with the floodplain in many years experiencing no outflow at all. despite the inflowing rivers supplying water to the floodplain every year (Kleynhans, 2005).

These losses need to be included in the model in some way. Various options exist for this, including subtracting them off the inflow time series to obtain a ‘corrected’ time series or removing water along the reach using simulated pumps. This all depends upon the capabilities of the modelling software used. In the DWAF study (Birkhead *et al., 2*007) evapotranspiration, infiltration and ponding losses were subtracted from the hydraulic model using pumps set at regular intervals along the channel.

The losses and additions of water from, and to, the wetland depend on the extent of inundated area which changes at every simulation time step. This could be calculated using inundated areas obtained from HEC-GeoRAS (which would involve a lot of work) or from the cross-section data output from HEC-RAS, but in both cases this would involve an iterative procedure. In the previous DWAF study a relationship was derived between inflow and inundated area, so that losses could be estimated based on the inflows that entered the wetland each day.

The above method using inflows was attempted for this study as well, but due to the attenuation that takes place in the Nylsvley floodplain it was found to be unsuitable for the entire floodplain – the DWAF study divided the upstream section of the floodplain into three separate model reaches and losses were modelled in each separately. The relationship was not suitable for the entire floodplain as inflows can take place over short periods of time but tend to lead to prolonged durations of inundation – there is therefore no direct relationship between the two for the entire floodplain.

HEC-RAS is able to output volumes of water contained within the model at each time-step downstream of any chosen cross-section. The volume of water contained within the Nylsvley floodplain and the Mogalakwena River downstream were output from HEC-RAS for the with-wetland scenario, from the flood attenuation simulation using inflows for all the quaternary catchments. These volumes were compared to areas inundated for the same simulation at the same time-steps.

Areas were determined using two methods for various time-steps: using the water surface top-widths at each cross-section and the reach lengths between cross-sections, which is the approach used for the DWAF study; and out of interest, after the modelling was completed using HEC-GeoRAS for each time-step.

Relationships between volume and inundated area were then derived by regression, using the areas calculated from water surface top widths and reach lengths, and the areas calculated using HEC-GeoRAS mapped inundated areas. These are shown in Figures 3.6 and 3.7 respectively. The relationship using the areas calculated from the water surface top widths and reach lengths was used to calculate the inundated areas in this study. However, it is recommended to use the HEC-GeoRAS method as this method takes into account 'hidden' areas of inundation that may not be taken into account by the cross-sections, such as side valleys that may inundate during flood events. A comparison of the two figures shows that HEC-GeoRAS predicts larger inundated areas at the same time steps than those calculated simply from cross-section inundated widths and reach lengths alone. This could mean that areas and therefore losses were underestimated in this study to some degree.

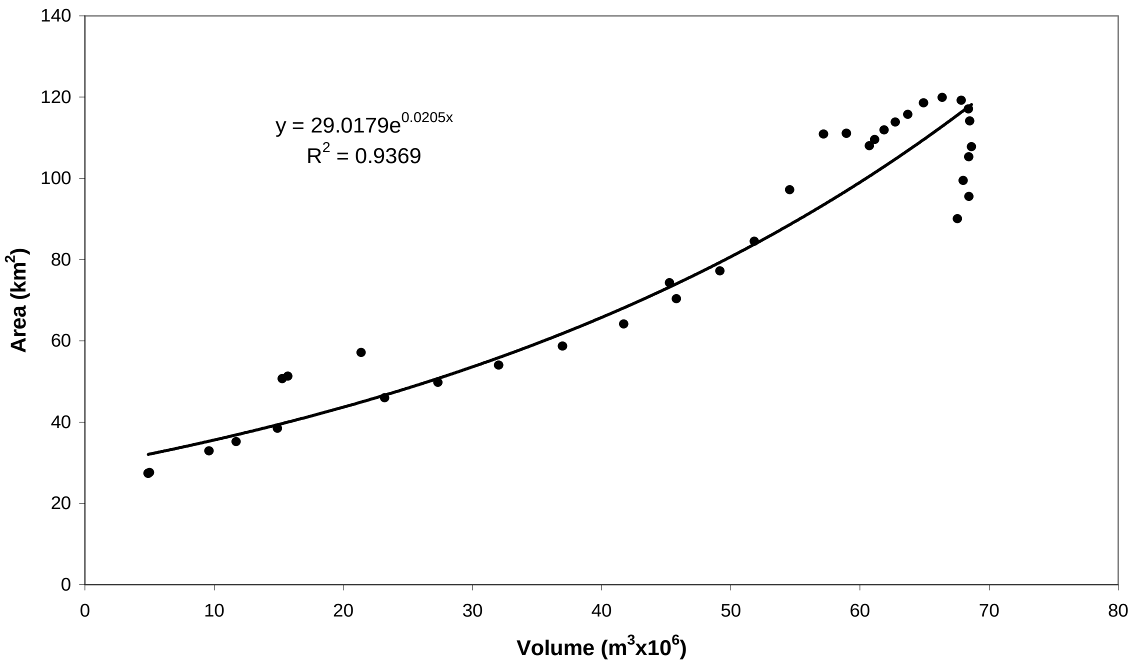

Figure 3.6: Volume of water contained in study reach versus inundated area regression, based on water surface top widths for each cross-section.

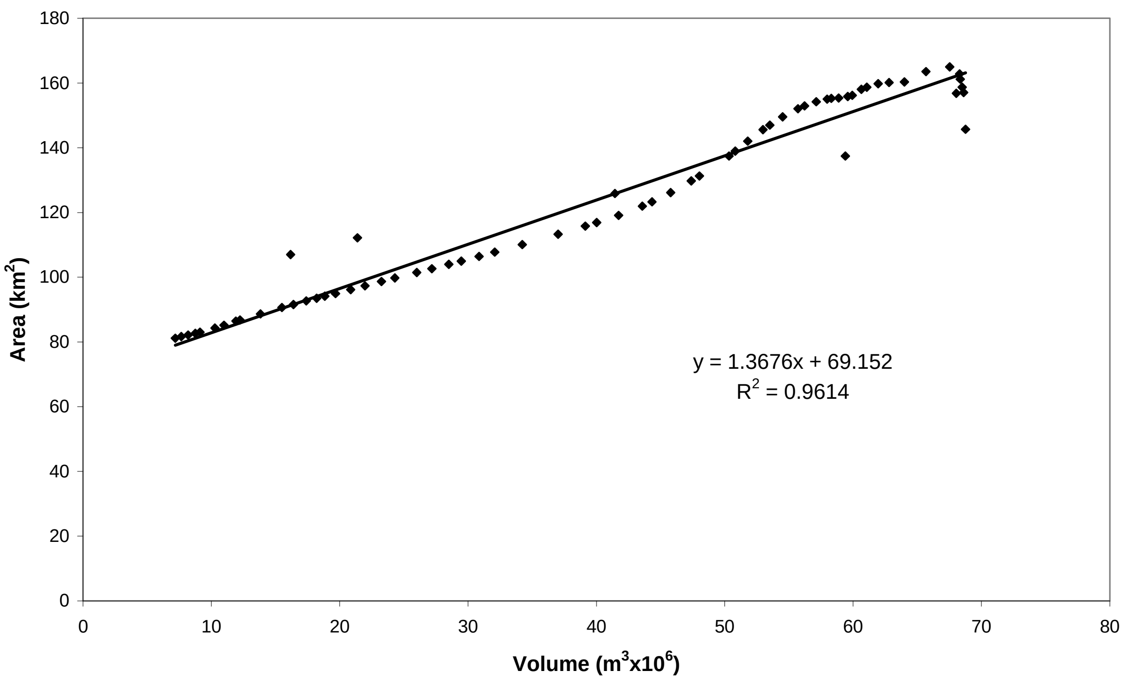

Figure 3.7: Volume of water contained in study reach versus inundated area, based on inundated areas mapped using HEC-GeoRAS.

Figure 3.8 shows how the inundation area – volume relationship varies according to whether the inundation that is taking place is on the rising or receding limb of the flood hydrograph. Many more points were plotted for the receding limb due to the receding limb spanning a far longer period. The regression relationships represent an average of the rising and receding limbs, but with a weighting towards the receding limb due to the greater number of points on that part of the hydrograph.

An inundation area – total inflow relationship was derived for the without-wetland scenario for the Mogalakwena River reach (Figure 3.9) as the hydrographs pass through the study area quickly enough to allow the derivation of such a relationship. The canal inundated areas were taken as constant with a water surface width of 30 m. It is recommended that in a comprehensive assessment the variable widths that depend on depth associated with a trapezoidal cross-section are output from HEC-RAS and used.

The derivation of a relationship between inflows and inundated areas allows the calculation of revised inflows, or the subtraction of the losses through pumps, without an initial run of the model with the original inflow time series which is used to determine a time series of volumes.

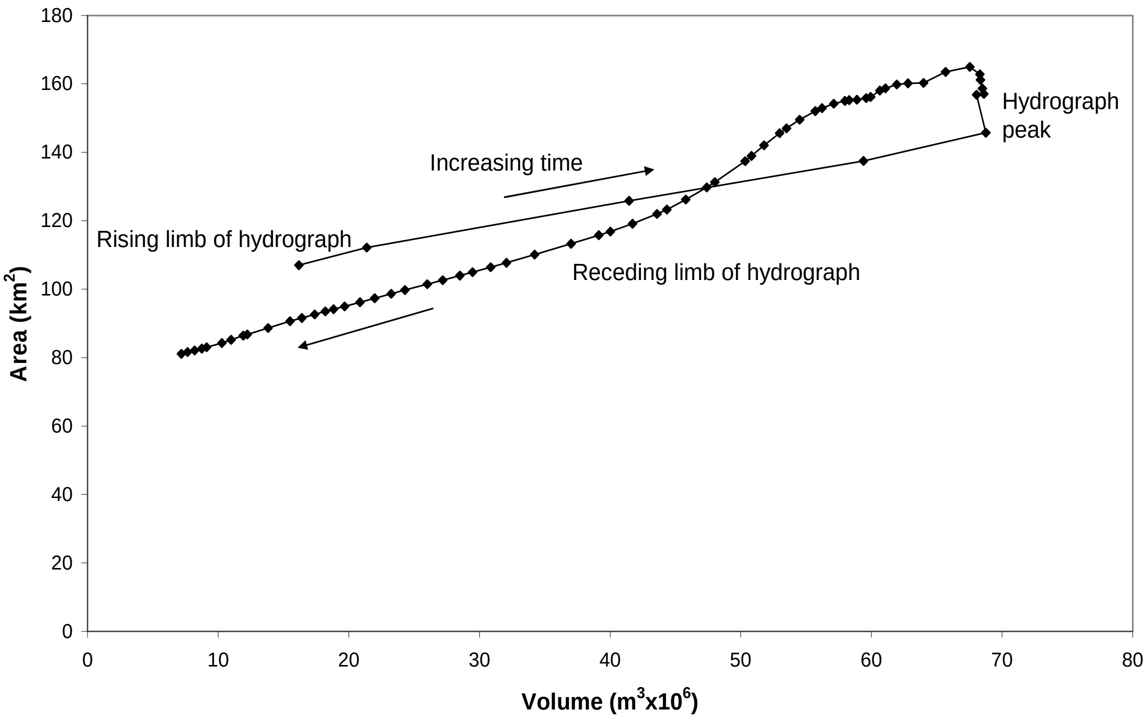

Figure 3.8: Volume of water contained in study reach versus inundated area, based on inundated areas mapped using HEC-GeoRAS, showing rising and recession relationship for the with-wetland scenario.

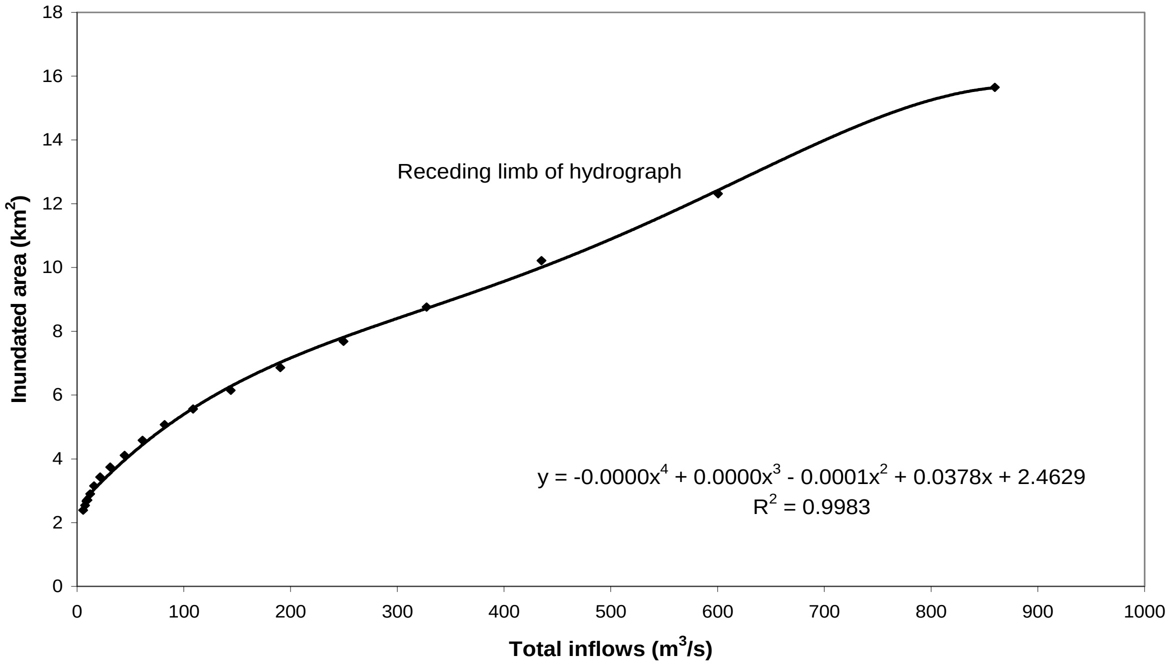

Figure 3.9: Total inflows to study reach versus inundated area regression, based on water surface top widths for each cross-section for the Mogalakwena River reach under the without-wetland scenario.

The same evapotranspiration rates as those derived for use in the DWAF study were used (Table 3.2).

Table 3.2: Average monthly evapotranspiration for Nylsvley (after Birkhead *et al., 2*004)

Evapotranspiration (mm/day)											
Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
2.3	3.0	3.7	4.4	4.7	2.6	2.2	1.9	1.6	1.6	0.4	2.3

The evapotranspiration rates were multiplied by the inundated areas calculated for each day. The inundated area – volume relationship derived for the wetland, canal water surface area, and the inundated area – total inflow relationship derived for the Mogalakwena River reach were used for both scenarios.

The calculation of losses of floodwater to infiltration and ponding is difficult without knowledge of infiltration losses for the wetland derived by experiment – such as through the use of instruments like the Guelph Permeameter, infiltrometers or through interpretation of borehole data together with detailed knowledge of the volumes of ponded water. In addition there was no full water balance – which would include observed inflows and outflows, rainfall and evapotranspiration data.

Instruments such as the double ring infiltrometer and the Guelph Permeameter may give estimates of infiltration losses at a relatively low level of confidence due to influences which may be beyond the reach of these methods such as the positions of deeply located impermeable clay layers in the wetland sediments.

Conducting a full water balance using observed historical inflow and outflow data would be preferable, but the existence of these observed data would allow the determination of the wetland's flow regulation services directly from the observed data (such as the method used by Smakhtin and Batchelor, 2005), which is always preferable to using modelled data and would therefore negate the need to model the wetland in the first place.

An alternative method would be to find a DWAF flow gauge downstream of the wetland and close to the study reach, and to compare the historical flows at the gauge with the simulated flows (which include evapotranspiration losses and rainfall – explained later) at that point. With some judgement, the differences between the flows could then be taken as being the losses due to infiltration, ponding etc. This would also provide estimates of these losses at a relatively low level of confidence.

At Nylsvley, no flow gauge exists in proximity to the outflow of the wetland that measures flow. Losses were estimated in the previous DWAF study based on water balances and observed infiltration data, but, these losses were ignored for both scenarios in this study due to time constraints. Various previous studies at Nylsvley have concluded that the aquifer below the floodplain surface is generally separated from the floodplain by clay lenses and that very little recharge occurs (Porszasz and Bredenkamp, 1973; Scott and Wijers, 1992; Morgan, 1996).

Losses should be included wherever possible, especially in a comprehensive assessment as they can be significant. Similarly, rainfall was ignored in this study for both scenarios due to time constraints but should be included in a comprehensive assessment.

It would be good practice to subtract losses where they actually would occur in the wetland. Due to time-constraints, the evapotranspiration loss time series was subtracted directly off the total inflows time series for the study area in this study.
The losses which had been determined for the entire wetland were apportioned to each quaternary catchment according to the ratios of the originally determined quaternary inflows to the total inflows, which vary annually due to the annual ratio in MARs being

used to determine the quaternary inflow time series from the historical data at A6H006. This is not strictly correct as losses actually depend on inundated area which is not directly dependent on inflow, but in this case study it was done due to time-constraints. Ideally a separate volume – inundated area relationship would be derived for each quaternary catchment and applied to the volume time series output from HEC-RAS for each quaternary catchment.

The difference in flows in the with-wetland scenario when evapotranspiration losses are accounted for, and are not accounted for, in the model is shown in Figure 3.10.

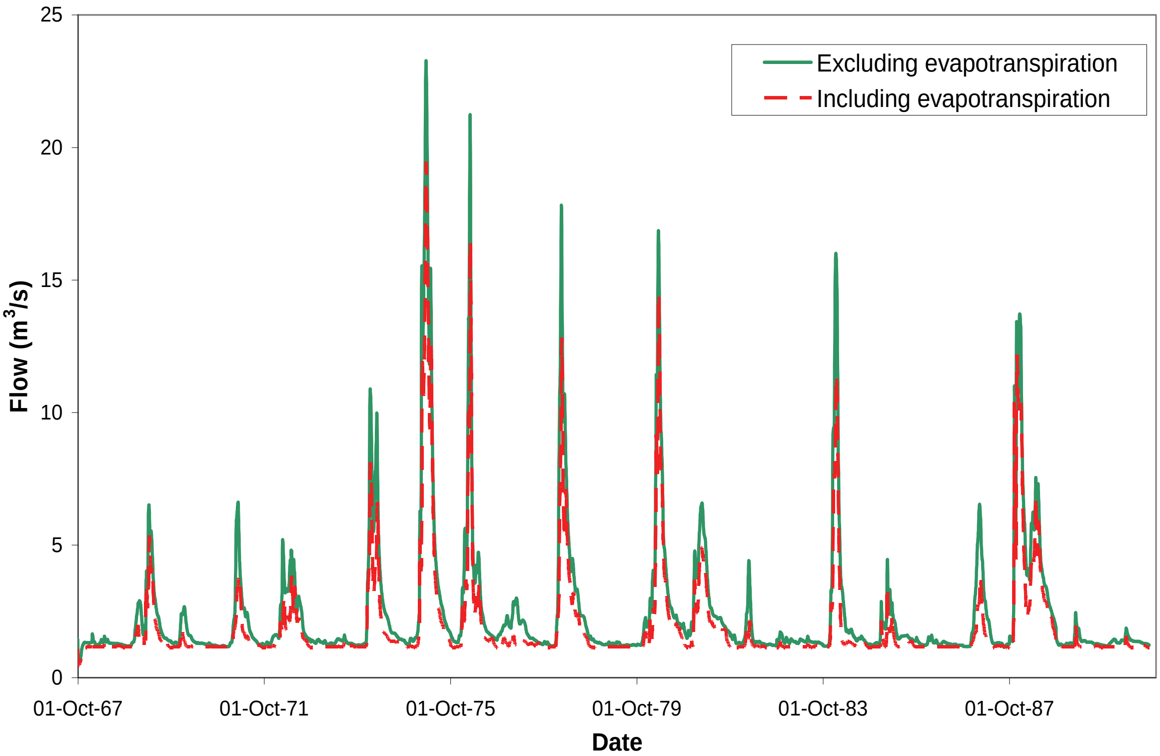

Figure 3.10: Flow time series at outflow from study reach, showing difference in flows when evapotranspiration losses are accounted for, and are not accounted for.

3.3.5 Valuation of flow regulating services

In the case of flood attenuation, a GIS map was produced of the area inundated in the without-wetland scenario relative to the with-wetland scenario. In order to value the potential cost of this additional flooding, the annual production and/or capital infrastructure value of the affected areas was estimated using a combination of GIS and agricultural census data. The additional flooded area was intersected with a detailed land cover map (National Land Cover, 2000) to ascertain the affected area of each type of land-use. For production values, damage was expected to be equivalent to the annual output. Capital infrastructure losses were valued at their replacement cost. The total value was multiplied by the return period as the probability of being damaged.

In the case of direct contribution to the maintenance of downstream flows, results of this study suggested no such service was performed. Losses to infiltration, which amount to groundwater recharge, are probably significant, but could not be estimated in this study due to time constraints.

3.4 Results

3.4.1 Flood attenuation

3.4.1.1 With-wetland scenario

Due to the attenuating effect of the wetland on the hydrographs routed through the wetland and the fact that the design flood hydrographs for all the inflow points start at the same time step, the routed hydrographs from the upper subcatchments A to E were found to pass points on the Mogalakwena River reach after the hydrographs of subcatchments F and G. Hydrographs F and G were attenuated less than hydrographs A to E, due to the fact that they did not travel through the wetland, and therefore they had higher peak flows than hydrographs A to E. These higher peak flows were found to dominate the stages downstream and therefore when the inflows from catchments F and G were included in the simulations, little difference was found between the flood lines for the with- and without- wetland scenarios.

To single out the impact of the wetland on the river hydraulics, two flow 'situations' were therefore developed for both scenarios. In one flow situation, which is hereafter referred to as 'inflow situation A-G', all the subcatchment (A-G) hydrographs were simulated and in the other flow situation hereafter referred to as 'inflow situation A-E', only the hydrographs from subcatchments A to E were simulated.

Figure 3.11 shows typical flood flow hydrographs and Figure 3.12 shows typical flood stage hydrographs corresponding to the two flow situations for the with-wetland scenario at the first cross-section downstream of the wetland outflow point (XS 43159.55). The remainder of the flood hydrographs downstream of the wetland reach displayed similar characteristics.

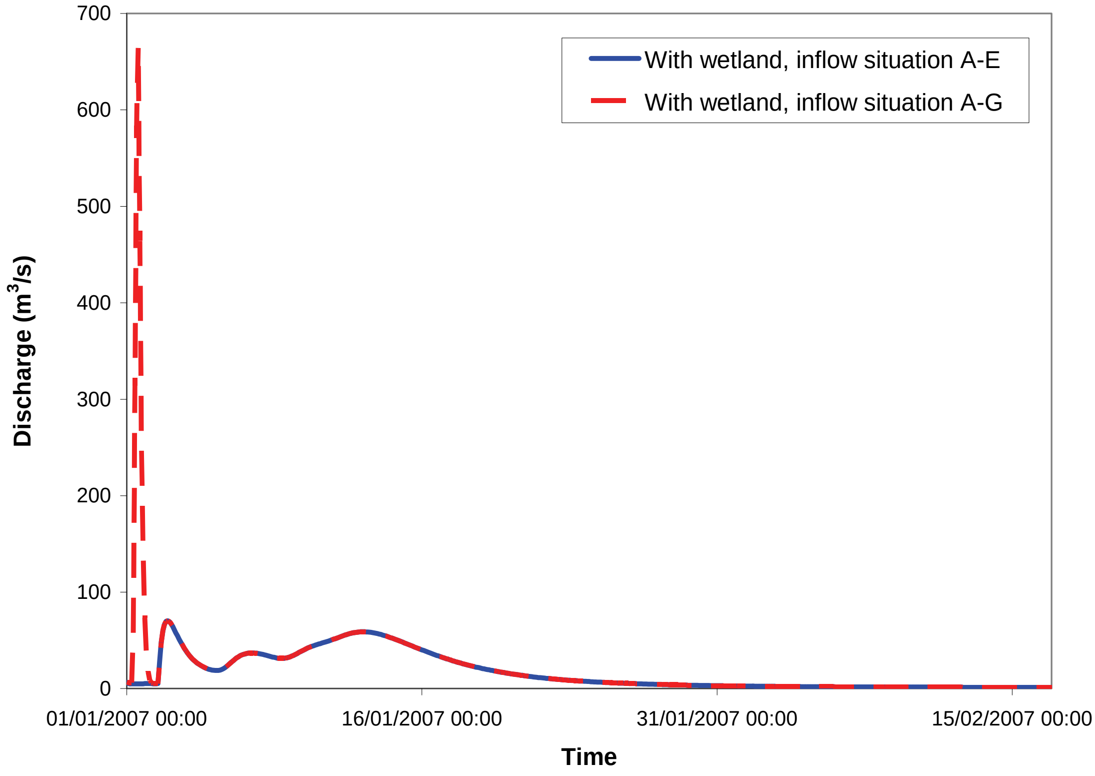

Figure 3.11: Flows simulated at the wetland outflow point for the with-wetland scenario: inflow situations A-E and A-G.

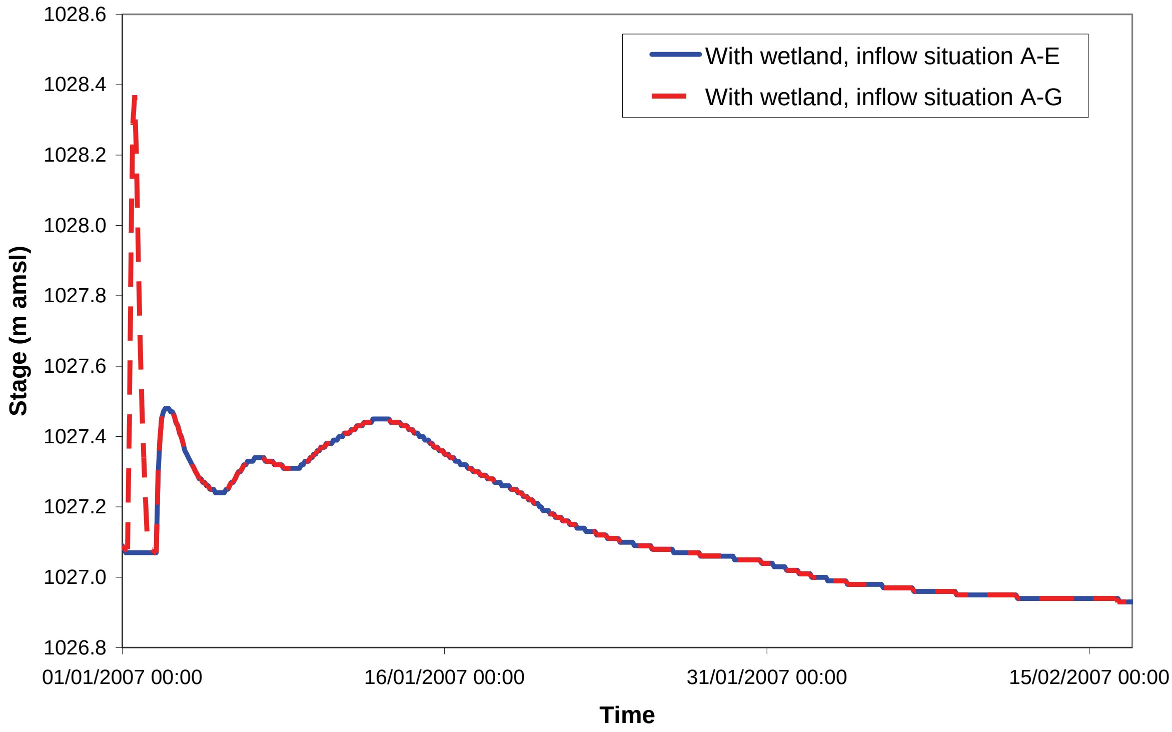

Figure 3.12: Stages simulated at the wetland outflow point for the with-wetland scenario: inflow situations A-E and A-G.

The flood hydrographs routed through the wetland for inflow situation A-E and inflow situation A-G show how the contribution of subcatchment F, the inflow hydrograph with a peak at time T = 1.5 days and which lasted only a few hours, caused the highest flow rate and hence highest peak stage at the site. The flood hydrographs from the more distant subcatchments were well attenuated.

The flood peaks at XS 43159.55 (just downstream of the wetland outflow point) for the with-wetland scenario was 665 m^3/s on 1 January at 14:00 for flow situation A-G and 70 m^3/s on 3 January at 02:00 for flow situation A-E. The peak flow under flow situation A-G is a factor of nearly 10 times higher than that for flow situation A-E, demonstrating the impact that the inflows downstream of the wetland have on peak flows in the downstream reach.

Figures 3.11 and 3.12 also indicate the degree of attenuation of the inflows from the more distant upstream quaternaries. The flows at the wetland outflow point only return to base flow levels approximately 70 days after the inflows have returned to base flow levels at all the model inflow boundaries.

Figure 3.11 indicates that the Nylsvley floodplain provides a large volume of storage during wet periods and that it prolongs the duration of flows that are above base flow levels in the reach downstream. This has been observed by Tarboton (Kleynhans, 2005) and is also evident in the stage gauge records in the floodplain.

3.4.1.2 Without-wetland scenario

The same comparison between flow situations A-E and A-G was carried out for the without-wetland scenario, the scenario including the canal. Figures 3.13 and 3.14 show the flows and stages simulated at the wetland outflow point. Again flow situation A-G results in higher flows and stages at this cross-section than flow situation A-E, but the difference in peak flows and stages is much smaller in this scenario. The peak flow under flow situation A-G is a factor of about 1.4 times higher than that for flow situation A-E, due to the low level of flow attenuation in a canalised channel. The remainder of the flood hydrographs downstream of the wetland reach displayed similar characteristics.

The flood peak at XS 43159.55 (just downstream of the wetland outflow point) for the without-wetland scenario was 819 m^3/s on 1 January at 16:00 for flow situation A-G and 596 m^3/s on 2 January at 08:00 for flow situation A-E.

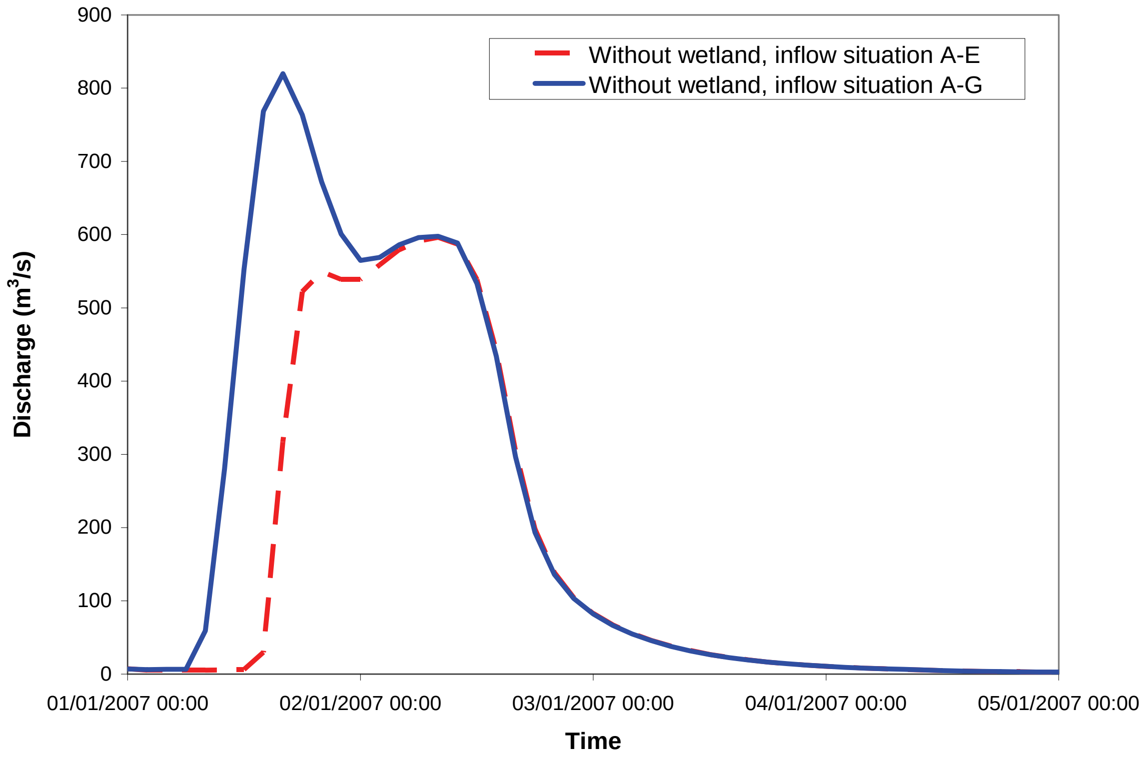

Figure 3.13: Flows simulated at the wetland outflow point for the without-wetland scenario: inflow situations A-E and A-G.

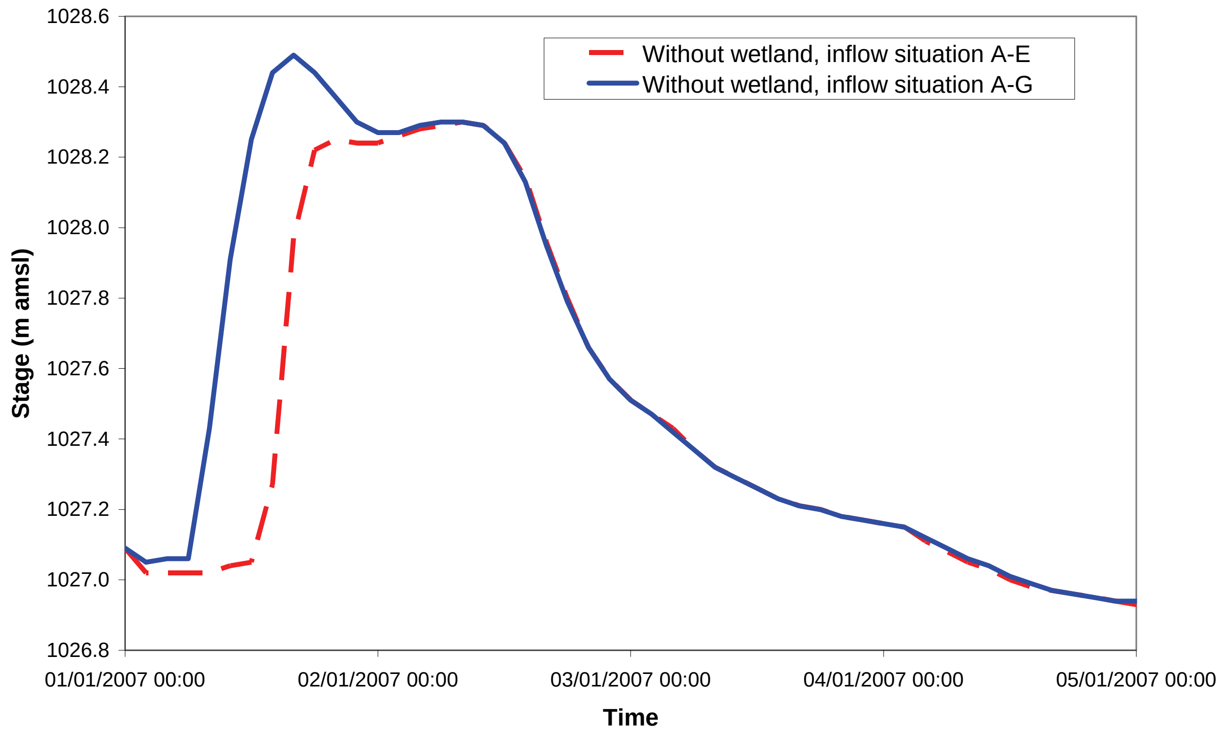

Figure 3.14: Stages simulated at the wetland outflow point for the without-wetland scenario: inflow situations A-E and A-G.

3.4.1.3 Effects of both scenarios on stages and flows in the downstream reach.

Figure 3.15 shows the effects of the with- and without-wetland scenarios on flows at the wetland outflow point for inflow situation A-G.

The effect of the wetland upstream on flows at the site is very clear, when comparing the two scenarios for both flow situations. The Nylsvley floodplain attenuates flow very effectively, with flows at the site as mentioned previously, only returning to base flow levels approximately 70 days after the inflow hydrographs returned to base flow levels. By comparison, flows for the without-wetland scenario, with the canal, returned to base flow levels only 4 days after the inflow hydrographs returned to base flows.

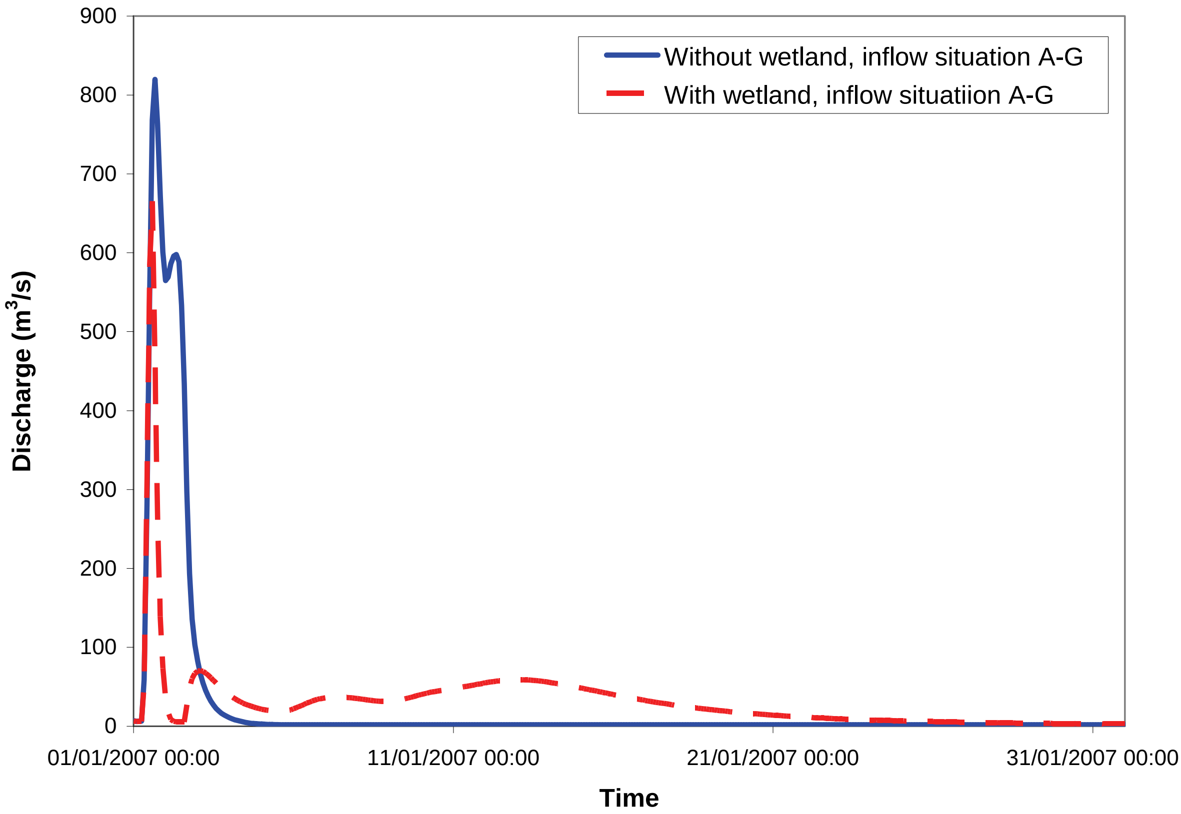

Figure 3.15: Flows simulated at the wetland outflow point for the with- and without-wetland scenarios: inflow situation A-G.

Figure 3.16 shows the flows for the two scenarios for the cross-section at the outflow point from the study area (XS 3206.099). The flows return to base flow levels about a day later at this point compared to at the wetland outflow point.

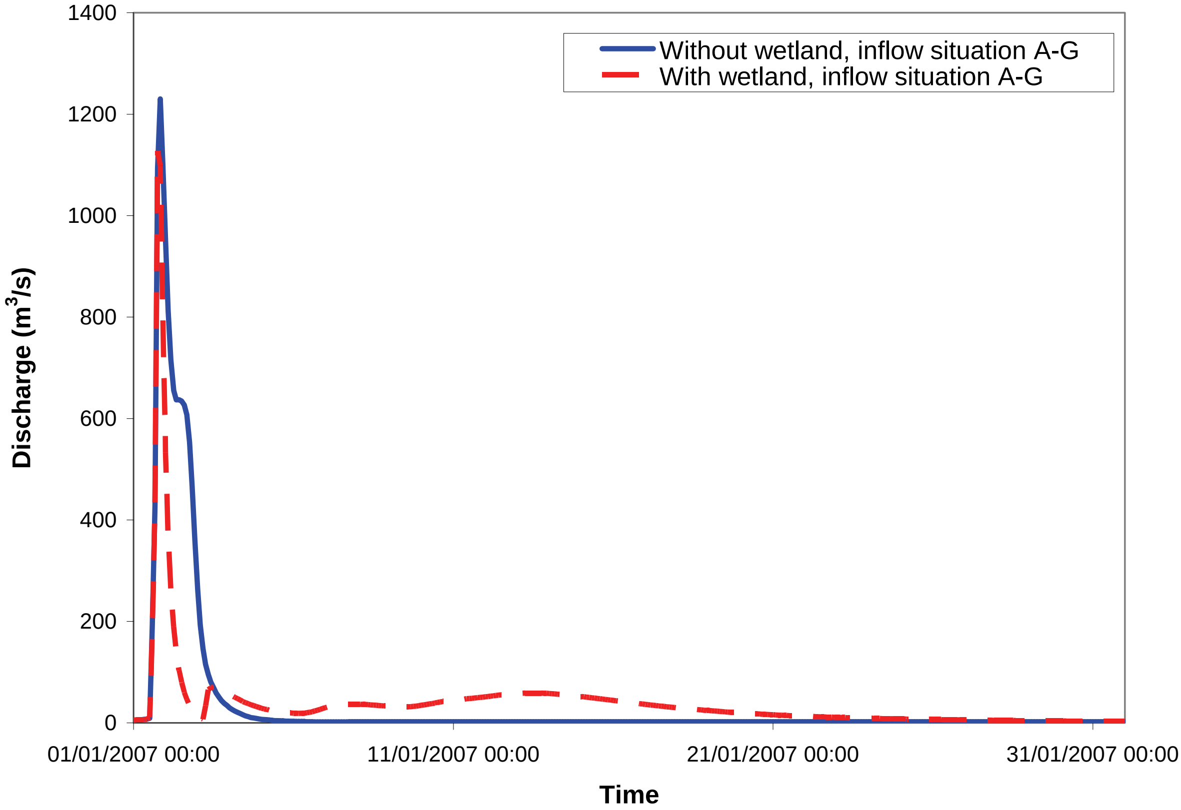

Figure 3.16: Flows simulated at the outflow point of the study area (XS 3206.099) for the with- and without-wetland scenarios: inflow situation A-G.

3.4.1.4 Mapping of inundation areas in the downstream river reach

Figure 3.17 shows inundated areas in the Mogalakwena River reach, downstream of the wetland outflow point for the with- and without-wetland scenarios for flow situation A-E.

The inundated areas for the two scenarios along the Mogalakwena River reach in flow situation A-G were very similar to each other and hence are not plotted on a map: the with-wetland scenario had an inundated area of 19.5 km^2 and the without-wetland scenario had an inundated area of 20.6 km^2, a mere 5% increase on the with-wetland scenario. This was due to the dominance of the inflows from the quaternary catchments downstream of the Nylsvley floodplain outflow point.

The inundation areas along the Mogalakwena River reach for flow situation A-E were 10.2 km^2 for the with-wetland scenario and 18.1 km^2 for the without-wetland scenario, a 78% increase on the with-wetland scenario.

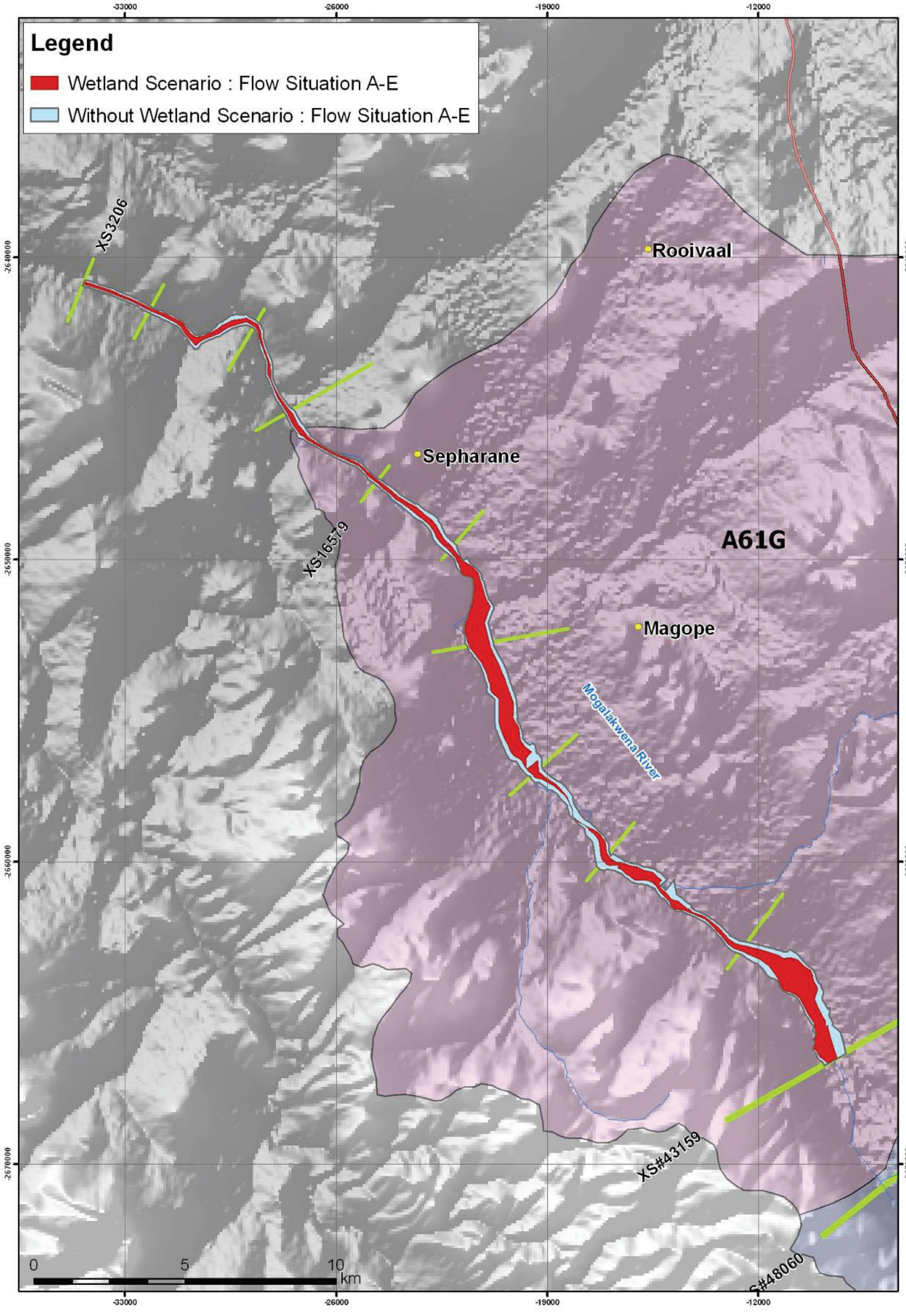

Figure 3.17: Inundation areas for the with- and without-wetland scenarios for flow situation A-E.

3.4.2 Maintenance of base flows

3.4.2.1 Time series

The daily time series of flows are shown at the wetland outflow point (Figure 3.18) with all the quaternary catchments contributing flow. A non-zero minimum flow of 0.2 m^3/s was maintained at all times in the model to enable solution of the hydraulic computations, and therefore although the inflows for the with-wetland scenario were calculated to be zero for quite a large proportion of the simulation period, these zero flows were simulated hydraulically at 0.2 m^3/s.

It is clear from the figure that the removal of the wetland would result in an increase in low-flows and an increase in high flows. The time series shown in the figure is analysed using flow-duration curves in the next section.

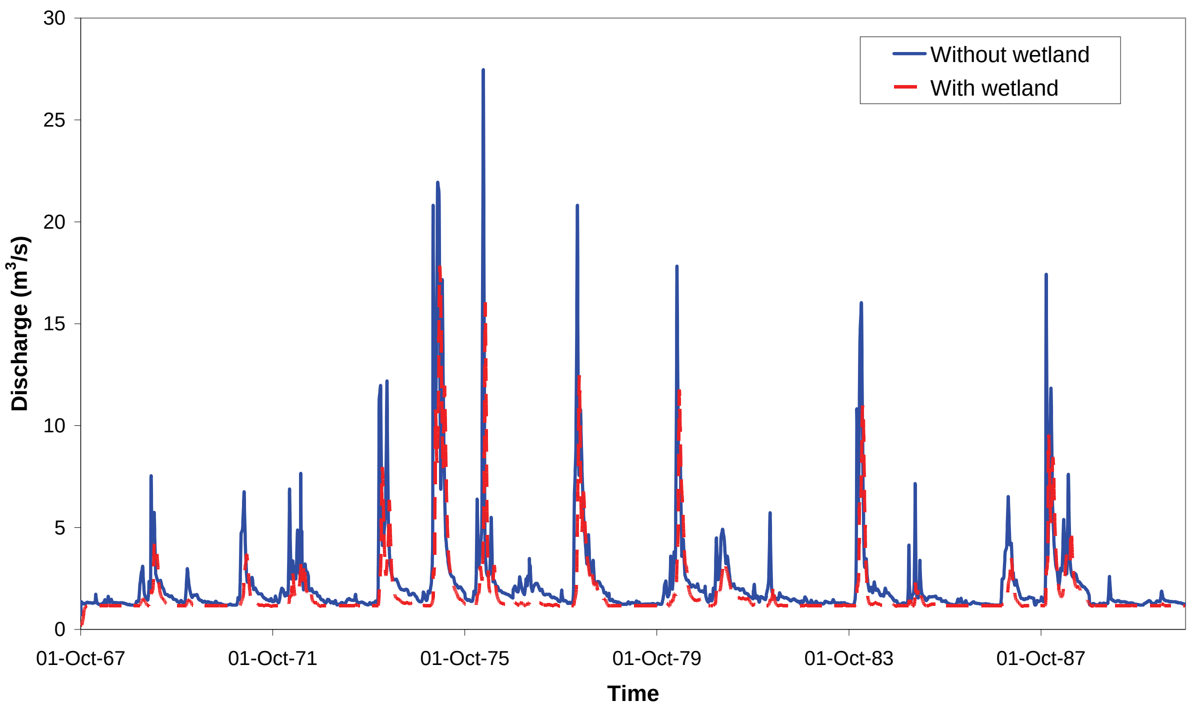

Figure 3.18: Flow time series at the outflow of the wetland, showing flows for the with- and without-wetland scenarios.

3.4.2.2 Flow-duration curves

Figure 3.19 and Figure 3.20 give flow duration curves for the with- and without-wetland scenarios at the wetland outflow point and the outflow point for the study area, respectively.

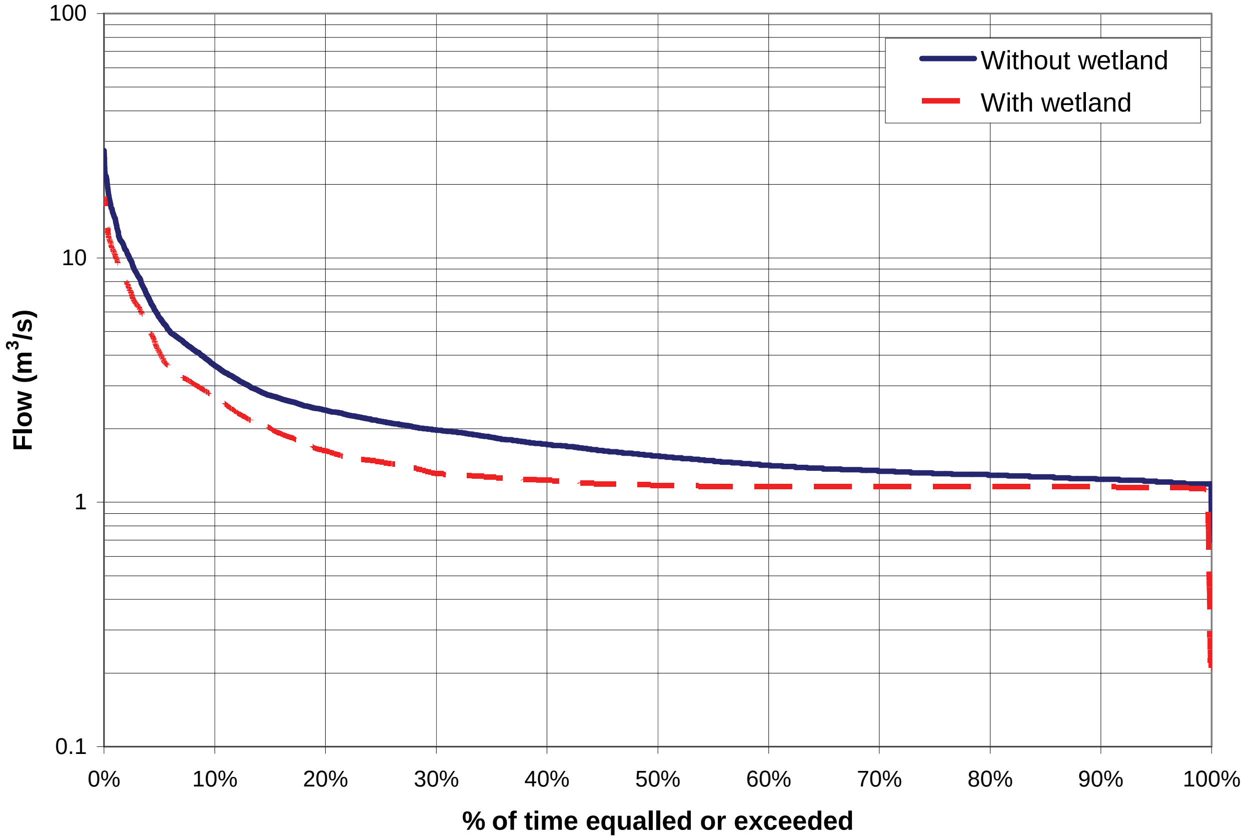

Figure 3.19: Flow-duration curve for flows at cross-section 48 060.48 at the wetland outflow point.

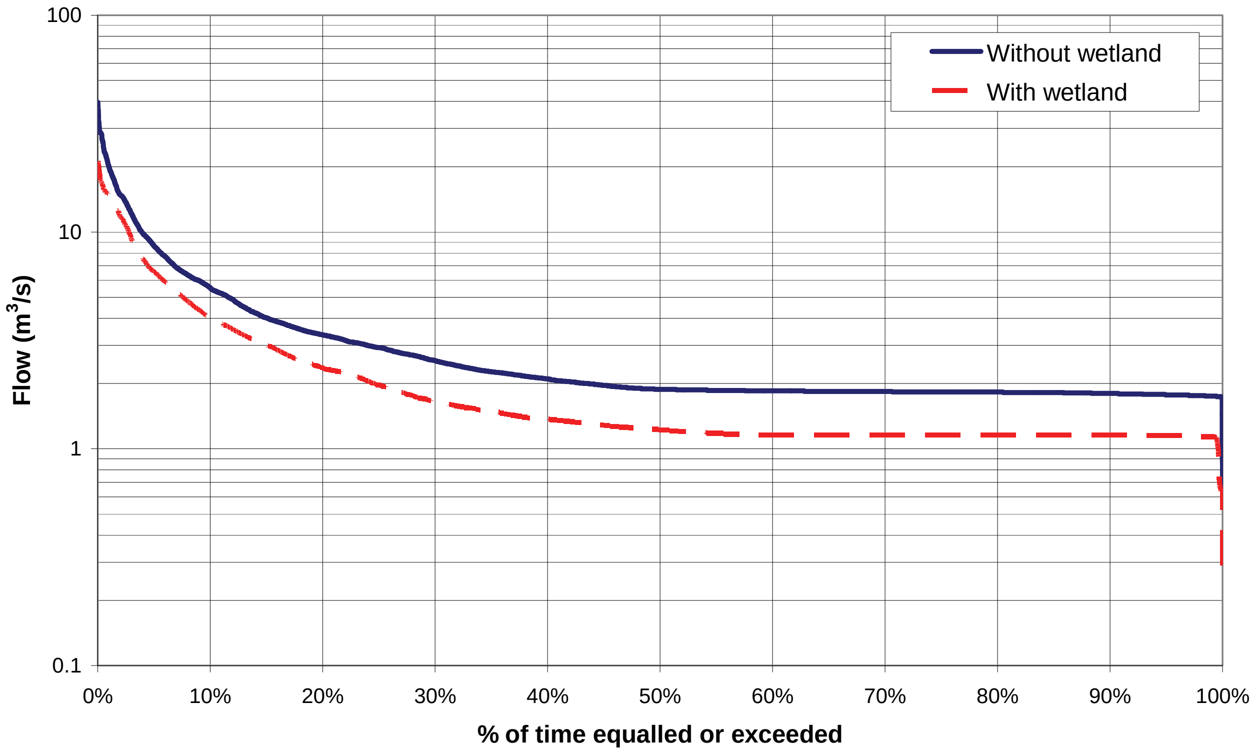

Figure 3.20: Flow-duration curve for flows at cross-section 3206.099 at the outflow point from the study area.

At the wetland outflow point (XS 48060.48), for example, a flow of 5 m^3/s is equalled or exceeded for approximately 4.2% of the time in the with-wetland scenario and 6.0% of the time in the without-wetland scenario. These differences become larger at lower flows. For example, a flow of 1.5 m^3/s, at the wetland outflow point, which roughly represents the upper limit of low flows (Figure 3.18) is equalled or exceeded for approximately 23.3% of the time in the with-wetland scenario while the same flow rate is equalled or exceeded for approximately 53.3% of the time in the without-wetland scenario. At the outflow point of the study area (XS 3206.099), a flow of 2 m^3/s, is equalled or exceeded for approximately 24.6% of the time in the with-wetland scenario and 43.4% of the time in the without-wetland scenario.

From the flow duration curves, it is clear that the presence of the Nylsvley floodplain upstream of the cross-section sites has a negative impact on the flows, in particular on base flows. Flows are reduced at all magnitudes, which can be beneficial to users downstream for high flows through reduced flood risk, but not at low flows. It has been observed that Nylsvley does reduce flows downstream and in many years, no outflows occur from the floodplain due to the high losses that are experienced (Higgins *et al., 1*996).

3.4.3 Value of flow regulating services

The modelled 1:50 year flood for flow situation A-G (the real situation) was estimated to inundate a total area of 1955 ha in the modelled reach of the Mogalakwena River downstream of Nylsvley. Without the wetland, this area increased by only 5% to 2059ha. The additional area that would be inundated if the wetland were removed under flow situation A-G would be 104 ha..

The modelled reach of the Mogalakwena River downstream of Nylsvley forms the border with a former homeland area (Lebowa) to the east that is managed as communal land and is used for agricultural production. The western bank of the river is agricultural along its margin, but above this, is untransformed vegetation, probably used primarily as rangelands (cattle and/or game). Grazing capacity in this area is approximately 8 LSU/ha. Based on agricultural census data, the average income generated by cattle per year is in the order of R925/LSU. Thus the area in question contributes in the order of R770 000 from livestock, but probably less in a subsistence farming situation. Google Earth images of the study area suggest there is no significant infrastructure. Thus in this case the total cost savings in terms of “insurance savings” would be less than R10 000 per annum. In other words, the service performed by the wetland is small, and the demand for the service is not high, resulting in a low overall value of the flood attenuation service.

3.5 Discussion

Relatively simple hydrological and hydraulic modelling techniques were able to determine the flood attenuation services that a wetland provides to areas downstream. Although shortcuts were taken that reduced confidence, the results of the study suggest that low-confidence estimates may be adequate to identify whether the flow regulation services of a wetland are potentially valuable.

During a flood event, and with the wetland intact, once the river stage reaches the bankfull condition of the channel (where the channel exists) along the wetland reach, the cross-sectional area available for storage increases dramatically due to the cross-sectional area provided by the wide and vegetated floodplain. In the process, the floodplain stores floodwater temporarily, through inundation and later releases it slowly back into the main river channel thereby supplementing the flow passing downstream. The net hydraulic effect of the wetland or floodplain is to reduce the flood peak discharge and stage, prolong the hydrograph and reduce the speed of travel of the flood peak. By prolonging the flood hydrographs through the reach, the period of inundation of the downstream reach is extended in the with-wetland compared to the without-wetland scenario, where the flood is essentially instantaneous or flash.

This study indicated that a large wetland such as the Nylsvley can have a significant attenuation effect on flows, but that this effect can be quickly negated by the presence of downstream tributaries. Moreover, the impact of the flow attenuation on downstream inundation areas is also dependent on valley shape. In this case, the Mogalakwena River downstream of the Nylsvley wetland had a relatively steep sided valley, which meant that increase in flood impacts without the wetland were relatively minor, even when the downstream tributary inflows were included.

In the case of Nylsvley, the productive value of the land under the threat of flooding was relatively low and contained little or no infrastructure of significant value. Combined with the relatively small flood attenuation effect, the estimated value of the service turned out to be negligible when compared with the size of the wetland. Thus it is important to realize that even for a large floodplain wetland, the value of the flood attenuation function can be small. The nature and context of the downstream area plays an important role in determining value.

This study suggests that the ability of wetlands similar to Nylsvley to perform a base flow maintenance function through regulation of surface flows alone may not be significant, due to the losses (evaporative + recharge) in the wetland itself. The tools used in this relatively rapid assessment did not estimate recharge effects. Various previous studies at Nylsvley have concluded that the aquifer below the floodplain surface is generally separated from the floodplain by clay lenses and that very little recharge occurs (Porszasz and Bredenkamp, 1973; Scott and Wijers, 1992; Morgan, 1996).

Although this study has found Nylsvley to be relatively unimportant in terms of flow regulation functions, it is important to remember that it provides other services that might be more valuable. For example, the productivity of the floodplain contributes to its importance as a conservation area, as well as farming and tourism activities in the area. It is also important to note that these findings cannot be generalised to other wetlands, as they are highly context-specific.

3.6 Acknowledgements

The research presented in this report was undertaken as part of a project funded by the Water Research Commission and their support is gratefully acknowledged. Hans Beuster contributed ideas of how to answer the question of quantifying the flow regulation wetland functions at the inception of the project. Ivy Masinga and Frank Denys carried out the work required to derive the Unitgraphs for the flood attenuation investigation. Frank Denys also derived the long-term daily flow sequences required for the maintenance of low-flows investigation. Ben Abban contributed ideas on alternative methods to calculate the inundated areas of a wetland. Cheryl Beuster, Sheena Swartz and Peter Wilson helped with the GIS aspect of the work. All their contributions are greatly appreciated.

3.7 References

Adamus PR, Clairain EJ, Smith RD and Young RE. 1987. Wetland Evaluation Technique (WET), Volume II: Methodology. Department of the Army, Waterways Experiment Station, Vicksburg, MS. NTIS No. ADA 189968.

Alexander WJR. 1990. Flood hydrology in southern Africa. South African Committee on Large Dams (SANCOLD), Pretoria.

Birkhead AL, James CS and Kleynhans MT. 2004. The Hydrologic and Hydraulic Study of the Behaviour of the Nyl River Floodplain: Hydraulic Modelling. DWAF Report No. P WMA 01/A61/00/0503. Department of Water Affairs and Forestry, Pretoria, South Africa.

Birkhead AL, James CS and Kleynhans MT. 2007. Hydrological and hydraulic modelling of the Nyl River floodplain. Part 2: Modelling hydraulic behaviour, Water SA Vol. 33 No. 1. January 2007.

Cullis J, Görgens A and Lyons S. 2007. Review of the selection of acceptable flood capacity for dams in South Africa in the context of dam safety. WRC Report No. 1420/1/07. Water Research Commission, Pretoria.

Higgins SI and Rogers KH. 1993. The Nyl River Floodplain: Situation Report and Preliminary Statement of Impacts of the Proposed Olifantspruit Dam, Report No. 3/93. Centre for Water in the Environment, University of the Witwatersrand, Johannesburg.

Higgins SI, Coetzee MAS, Marneweck GC and Rogers KH. 1996. The Nyl River floodplain, South Africa, as a functional unit of the landscape: A review of current information, East African Wild Life Society. African Journal of Ecology 34: 131-145.

Hydrological Research Unit (HRU). 1973. Flood hydrograph synthesization program (Unigraph method). Hydrological Research Unit, University of the Witwatersrand, Johannesburg.

Kleynhans MT. 2005. Hydraulic and Hydrological Modelling of the Nyl River Floodplain for Environmental Impact Assessment. Unpublished M.Sc. (Eng.) Dissertation. University of the Witwatersrand, Johannesburg, South Africa.

Kleynhans MT, James CS and Birkhead AL. 2007. Hydrological and hydraulic modelling of the Nyl River floodplain. Part 3: Applications to assess ecological impact. Water SA 33 (1) 21-26.

Kotze DC, Marneweck GC, Batchelor AL, Lindley DS and Collins NB. 2008. WET-EcoServices: A technique for rapidly assessing ecosystem services supplied by wetlands. WRC Report No. TT 339/08. Water Research Commission, Pretoria.

Kusler J. 2006. Recommendations for reconciling wetland assessment techniques. Final report – April 2006. Association of State Wetland Managers, New York.

Midgley DC. 1972. Design flood determination in South Africa, Report No. 1/72. Hydrological Research Unit, University of the Witwatersrand, Johannesburg.

Midgley DC, Pitman WV and Middleton BJ. 1994. Surface Water Resources of South Africa 1990. WRC Report No. 298/2/94. Water Research Commission, Pretoria.

Morgan, C S. 1996. The Application of Digital Terrain Models and a Geographic Information System in the Modelling of Flooding in the Nyl River Floodplain, MSc dissertation. University of the Witwatersrand, Johannesburg.

Ogawa H and Male JW. 1986. Simulating the flood mitigation role of wetlands. Journal of Water Resources Planning and Management 112: 114-128.

Porszasz K and Bredenkamp DB. 1973. An investigation of the groundwater potential of the Nyl River valley. Division of Hydrology, Hydrological Research Institute, Department of Water Affairs.

Rogers KH and Higgins SI. 1993. The Nyl Floodplain as a Functional Unit of the Landscape, Preliminary Synthesis and Future Research, Report No. 1/93. Centre for Water in the Environment, University of the Witwatersrand, Johannesburg.

Scott P and Wijers BEW. 1992. Hydrogeology: groundwater resources, Annexure 3.5, Water resources planning of the Mogalakwena River Basin, situation assessment and development potential. Steffen, Robertson and Kirsten Consulting Engineers.

Smakhtin VU and Batchelor AL. 2005. Evaluating wetland flow regulating functions using discharge time series. Hydrological Process 19: 1293-1305.

Smithers JC and Schulze RE. 1993. The influence of wetland on streamflow regulation and flood attenuation: a modelling approach. In: Wang SSY (ed.) Advances in Hydro-Sciences and Engineering, Vol. 1. University of Mississippi, Jackson. pp. 329-334.

Tarboton WR. 1987. The Nyl Floodplain: Its significance, phenology and conservation status. In: Walmsley RD and Botten ML (eds.) The ecology and conservation of wetlands in South African Ecosystems Programme. Occasional Report No. 28, Foundation for Research and Development, Pretoria.

Tarboton WR. 1991. Flooding and the avifauna of the Nyl Floodplain. *Referaat aan die Nylstroom Beraad, Sessie 2.*

Thiesing MA. 2001. An evaluation of wetland assessment techniques and their applications to decision making. In: Finlayson CM, Davidson NC and Stevenson NJ (eds.) Wetland inventory, assessment and monitoring: Practical techniques and identification of major issues. Proceedings of Workshop 4, 2nd International Conference on Wetlands and Development, Dakar, Senegal, 8-14 November 1998, Supervising Scientist Report 161, Supervising Scientist, Darwin.

Thompson JR and Hollis GE. 1995. Hydrological modelling and the sustainable development of the Hadejia Nguru wetlands, Nigeria. Hydrological Sciences 40: 97-108.

4. ESTIMATION OF THE WATER QUALITY AMELIORATION FUNCTION AND VALUE OF WETLANDS: A CASE STUDY OF THE WESTERN CAPE, SOUTH AFRICA

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Abstract

Wetlands are commonly understood to have the capacity to reduce the loads of excess nutrients, pathogens, sediments and other contaminants generated by various activities in their catchments. However, the quantification of these services is difficult, and most research in this field has concentrated on artificial treatment wetlands. Understanding the value of their water treatment services, as well as the other services they provide, is increasingly recognised as being essential to achieve a balance between conservation and the activities that degrade or replace wetlands. The aim of this study was to estimate the water quality amelioration ("water treatment") capacity of wetlands at a landscape scale in the southwestern Cape, and estimate the economic value of the service performed. The outflow points of 100 subcatchments were sampled, and the measured loads of nitrogen, dissolved phosphorous and suspended solids were analysed in respect of detailed spatial data on land cover and wetland area. Wetlands were found to play a significant role in the reduction of nitrates, nitrites and ammonium, but not dissolved phosphorous or suspended solids. Estimated removal rates ranged from 307 to 9505 kg N/ha/y, with an average of 1594 ± 1375 kg N/ha/y. Data from a number of water treatment works suggested that the cost of removal of ammonium-N was in the order of R26/kg. Applied to the wetlands in the study area, and assuming that wetlands do play a role in total phosphorus removal, this suggested that the average value of the water treatment service provided by wetlands in the study area was about R14 350 ± 12 385/ha/y. There was no broad-scale pattern in the average value of wetlands per catchment.

4.1 Introduction

Wetlands are among the most threatened habitats globally, and it is estimated that since 1900, more than half of the world's wetlands have been destroyed and lost to other land-uses (Barbier, 1993). Indeed, despite various forms of international and national legislation ratifying their protection (Bergstrom and Stoll, 1993), wetlands continue to be impacted by human activities, including channelization and drainage, crop production, effluent disposal and water abstraction. This occurs both internationally and in South Africa (Walmsley, 1991; Barbier *et al., 1*997; Turner *et al., 2*000; Bowers, 1983).

A major factor contributing to this international trend is the fact that the value of wetlands is poorly understood. In addition to the provision of habitat to often rare or endangered plants and animals, wetlands provide a range of "ecosystem services" which provide direct and indirect benefits to surrounding and downstream communities (Barbier *et al., 1*997). These include (Barbier *et al., 1*997): *provisioning services* (the supply of goods such as reeds and fish), *regulating services* (such as the attenuation of floods, treatment of water quality by the sequestration or uptake of pollutants including nutrients and heavy metals, and effective trapping of suspended sediments) and *cultural services* (such as opportunities for recreation, scientific research and spiritual fulfillment). The economic benefits and services provided by wetland ecosystems such as these are frequently overlooked by governments, developers, private industry and other land users (Emerton, 1998), resulting at times in distorted decision-making. Estimation of the economic value of wetlands is thus seen as a potentially important means of correcting these distortions and achieving a better balance between conservation and the activities that degrade or replace wetlands.

The global value of wetlands and their associated ecosystem services has been estimated at US$14 trillion annually (Costanza *et al., 1*997). However, the estimation of wetland values at a local scale requires a more accurate understanding of their capacity to deliver services and the demand for those services. While provisioning and cultural services, such as the provision of harvested natural resources and tourism value are relatively straightforward to quantify using survey-based valuation techniques, valuing the regulating services of wetlands is particularly challenging because it requires in-depth understanding of biophysical processes. In the case of wetlands, the biophysical functioning of wetlands is often complex, varies dramatically between wetlands of different types and in different ecoregions and may be difficult to measure and conceptualise. As a result, some of the kinds of services performed by wetlands are difficult to quantify, and past valuation studies have relied on high levels of assumption.

The ability of wetlands to ameliorate the quality of water passing into downstream systems is one regulating service that is commonly attributed to wetlands. This study focuses on quantification in biophysical and economic terms of the water quality amelioration (or "water treatment") services provided by wetlands.

The main water quality constituents over which wetlands are known to assert influence, include the loading and/or concentrations, of phosphorus and nitrogen nutrients, and various heavy metals, as well as suspended solids and their load of sorbed compounds. As streamflows enter wetlands they slow down, with the result that suspended sediments settle out of the water column. Since many pollutants (e.g. metals and organic chemicals) attach strongly to suspended matter, this process is also important for the reduction of these materials in downstream systems. While uptake by plants and epiphytes and sorption to soil surfaces are primary processes that change wetland water phosphorus concentrations in the short term, plants and their epiphyton release up to 75% of this phosphorus back into the water column, and long term storage relies primarily on sediment and peat accumulation (Kadlec and Knight, 1996; Cooke *et al., 2*005). Removal of heavy metals is also by way of short term uptake into plant structures, but longer term storage is achieved in sedimentation. Wetlands are also known to be effective in terms of processing nitrates (Cooke *et al., 2*005). Wetlands are also attributed with the capacity to effect removal of various pathogens from water passing through them. While this is true of many wetlands when pathogen (e.g. coliform bacteria) are present in high loads, it should be noted that wetlands themselves include active populations of many bacteria, and wetlands with large populations of birds or other wildlife may well contribute larger numbers of faecal bacteria to through-flowing water than are removed (Kadlec and Knight, 1996).

Seasonality is also important. Wetlands are thought to be better at removing total suspended solids, phosphorus and ammonia during high flow periods (when sediment loads entering the wetland increase), but better at removing nitrates during low flow periods (Johnston *et al., 1*990). During extreme flow events, the sediments and nutrients that have accumulated in wetlands may be flushed out, leading to temporary elevation of downstream loads. This may be at lower cost to the downstream environment than if they were released during lower flow periods – but where downstream systems include areas of permanent sediment entrapment (e.g. basins and lakes), the same net loading may occur after receipt of a large dilute load of sediments or a smaller but continual supply of sediment.

A number of studies have been carried out on the function of wetlands in the treatment of waste water (e.g. Peltier *et al., 2*003; Thullen *et al., 2*005; Batty *et al., 2*005), but most of this research has been carried out in artificial, or dedicated treatment wetlands, and few studies have used a landscape approach. In treatment wetlands, absolute removal rates of nutrients such as N and P are often proportional to the concentration of inflowing water, and the proportion removed tends to increase as water detention time increases (Jordan *et al., 2*003). In such wetlands, inflowing water quality, loading rates and detention time are usually known, along with outflowing quality and loading, making quantification of internal wetland services to a relatively high level of accuracy, possible. Comparatively little research has been carried out on quantifying the water treatment capacity of natural wetlands (Verhoeven *et al., 2*006), and research that has been carried out suggests that it is critical to take landscape-level processes into account. Because of the common perception that wetlands act as pollution filters in a catchment, some authors have likened wetlands to a point source equivalent in a landscape dominated by non-point source pollution. However, uptake of pollutants does not only occur within aquatic ecosystems, but also occurs during the drainage process, as surface and sometimes groundwater flows pass through various environments *en route* to streams and rivers. In Florida it was estimated that 9.3% of total nitrogen inputs of a catchment reached surface water and 19.6% reached the groundwater, with the contribution varying for different types of inputs (Young *et al., 2*008). The balance was attributed to the assimilation capacity of the soil. Measurement at the landscape scale allows the assessment of the integrated effect of wetlands on downstream water quality as well as the effect on suspended solids, which cannot be easily measured at the individual wetland scale.

The water quality amelioration functions of wetlands benefit both ecological and human users in downstream systems. For example, prevention of contamination of downstream areas may protect fisheries from harmful pollutants or reduce the human health and other impacts associated with extensive growth of algae or aquatic macrophytes in response to nutrient loading. Reduced sediment loads may reduce the costs of management of downstream impoundments, by reducing the frequency of dredging needed to prolong the lifespan of the impoundment. Once such services have been quantified, they can be valued using a damage costs avoided or a replacement cost approach (Pearce and Turner, 1990; James, 1991; Barbier, 1993; Emerton *et al., 1*999).

The aim of the present study was to estimate the water treatment capacity of wetlands in the Fynbos Biome of the Western Cape, South Africa, using a novel landscape scale approach, and to estimate the economic value of the service performed. The study focused on the removal of nitrogen, phosphorous and suspended solids only.

4.2 Methods

4.2.1 Overall approach

The water treatment capacity of wetlands was valued using a replacement cost approach which entailed quantifying the removal of pollutants by wetlands in the study area and then estimating the equivalent cost of performing this service through engineering solutions in the form of water treatment works. Because of the difficulties of measuring flows through individual wetlands, a landscape approach was taken to estimating the service performed by wetlands, in which water quality at catchment outflow points was related to the prevalence of wetlands as well as other land-uses, using multivariate statistical analysis.

4.2.2 Study area

The study was carried out in the Fynbos Biome within the Western Cape Province, South Africa. The study area was chosen due to the fact that accurate and recent fine-scale spatial data on land cover was available, which had been collected as part of the CAPE Fine Scale Planning project (Job *et al., 2*008). Samples were collected from the outflow points of 100 subcatchments (Figure 4.1), which collectively covered an area of 797 000ha. Of these, 75% were fed only by the immediate subcatchment and the remainder were at the outflow points of subcatchments fed by other subcatchments. In the latter case, it was assumed that the influence of land cover in the distal subcatchments would be negligible compared with land cover in the immediate subcatchment, and only land cover in the immediate subcatchment was taken into account.

The study area falls within the winter rainfall area of South Africa, and receives most of its rainfall between June and September. Towards the east of the study area, rainfall distribution becomes more bimodal (Figure 4.2). Most of the smaller tributaries within these areas flow as seasonal rather than perennial systems. All of the sampled nodes fell within the seasonal rather than the perennial portion of the catchment areas.

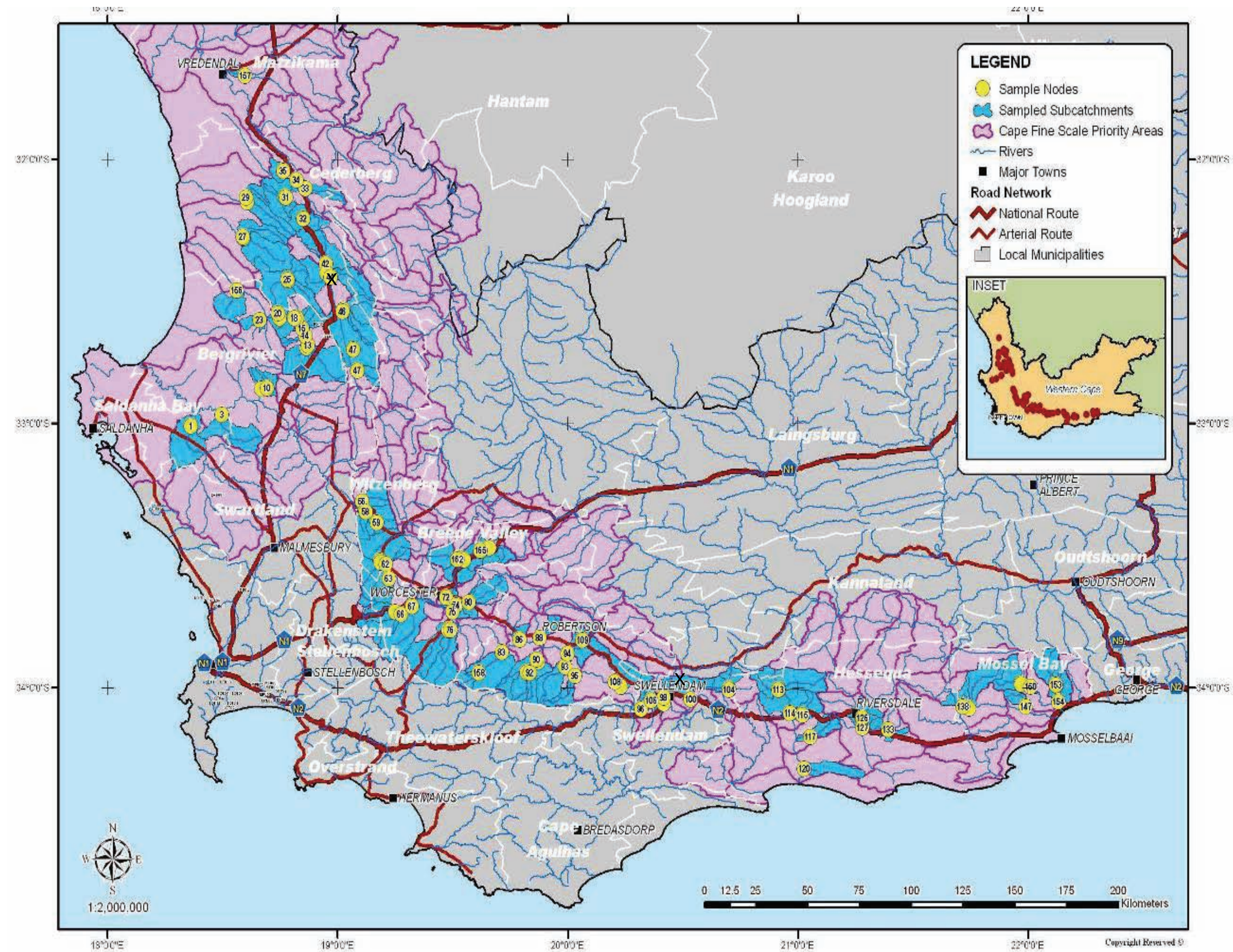

Figure 4.1: Map of the southwestern Cape, showing location of the sampling points and their associated subcatchment areas. X marks points from which rainfall data were taken for Figure 4.2.

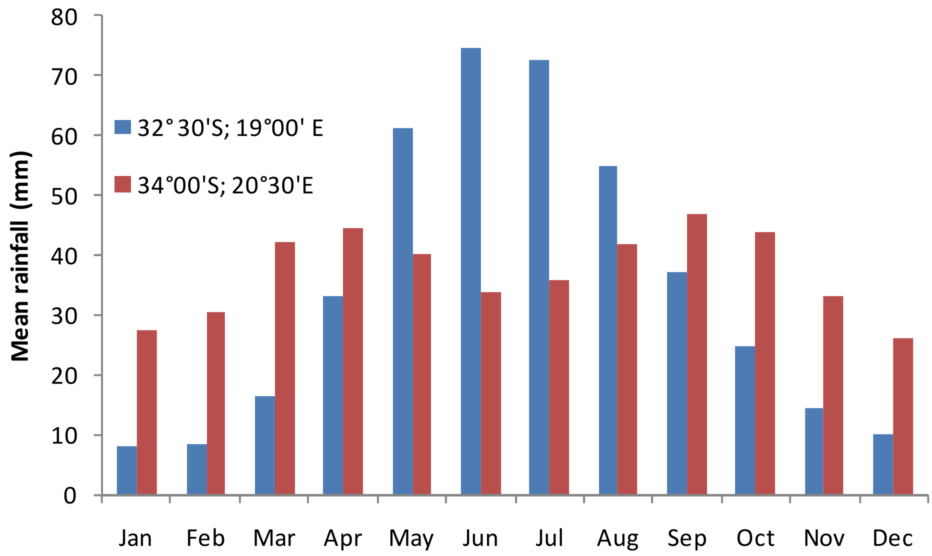

Figure 4.2: Average monthly rainfall from a point in the north of the study area and a point in the east (see Figure 4.1). Source Zucchini *et al.* (2009).

Falling within the fynbos biome, the natural vegetation is dominated by low shrublands associated with fynbos and renosterveld vegetation types. Most renosterveld, which occurs on richer soils, has been converted to croplands, and the natural grazing capacity of the remaining fynbos areas is relatively low. Agriculture is dominated by winter wheat dryland cropping, and there are significant areas of irrigated orchards and vineyards. Livestock operations tend to be intensive. Urban settlements are concentrated at the coast, and settlements within the sampled area tend to be small. Natural vegetation dominates the sampled landscape, although much of it is degraded, and dryland agriculture makes up a significant proportion of the remaining area.

The majority of wetlands in the study area are channelled and unchannelled valley bottom wetlands. Hillslope and valley head seeps are also well-represented, although these two categories were potentially underrepresented as a consequence of poor visibility in the aerial photography that informed much of the Fine Scale Planning Wetland Layer (Job *et al., 2*008).

4.2.3 Land-use data

Detailed land-use data from the CAPE Fine Scale Planning project were grouped together in the present project into13 land-use categories (Figure 4.3).

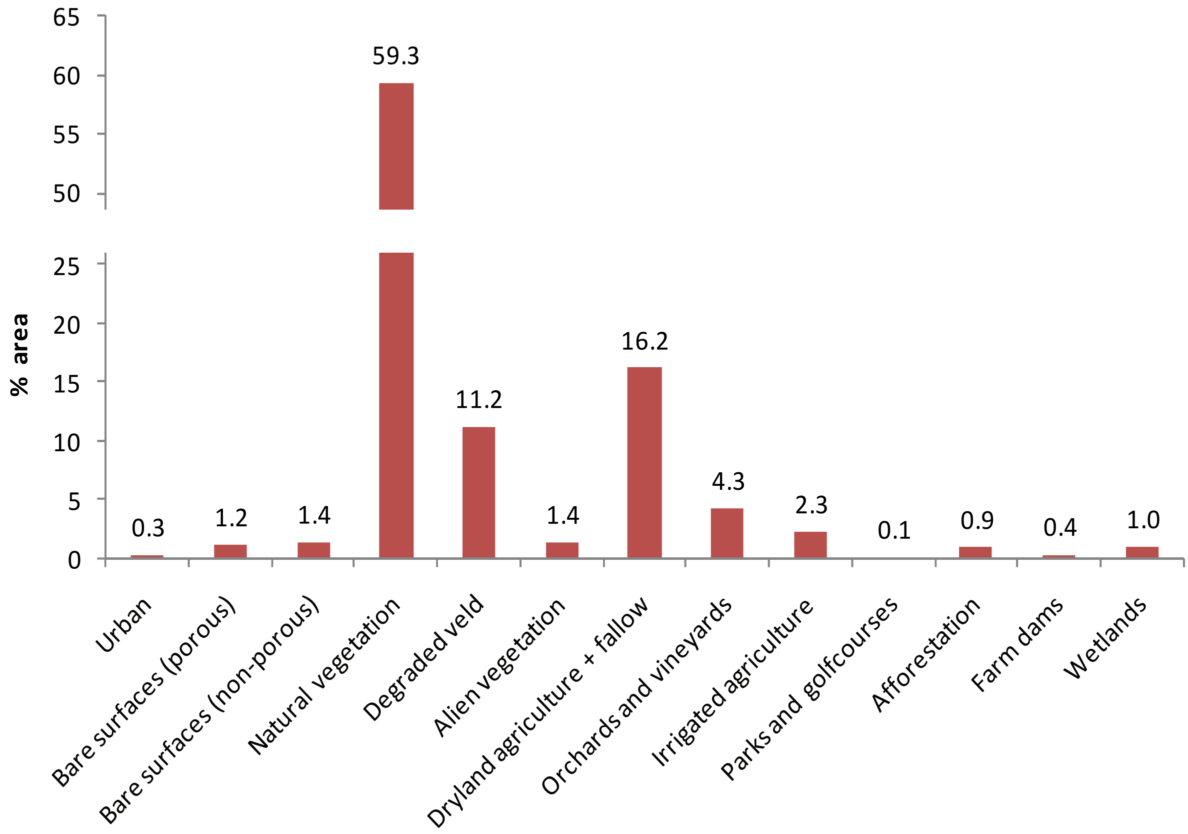

Figure 4.3: Overall percentage of different land cover categories in the sampled catchments.

4.2.4 Timing of the study

Data used in this study were collected between late August and mid September 2008. The timing of field measurements was chosen as the last quarter of the rainy season, i.e. after the main spates had past and assumes uniform wet season flushing of the catchments. This was done to avoid problems associated with inadvertent sampling of certain wetlands during 'first flush" rainfall events, and sampling of others after more extensive periods of catchment flow, when water quality might have lower concentrations of nutrients and other dissolved contaminants. Thus, all catchments were sampled towards the end of the wet season, in August. At this time, events such as first-flush concentrations would not be expected in any of the systems. From this perspective, it is recognised that the estimates of loading based on this research are likely to under-represent contributions made by wetlands to catchment level water quality, since the wetlands were sampled at a period usually associated with the most dilute runoff conditions, and before the application of fertilizers for summer crops. .

4.2.5 Field data collection and analysis

Positions of the outflow "nodes" from each subcatchment were identified using GIS data, and located in the field using a hand-held global positioning system (GPS). Once located, a sampling site was chosen up to a maximum of 200 m upstream of the nodal point, where flow could be calculated with relative accuracy (i.e. ideal sites had a simple cross-sectional profile). At each site, photographs were taken of the site, a cross-sectional profile of the river and surrounding area was sketched, and within the channel, depth and flow were measured along a transect at 0.5 m intervals. *In situ* measurements were taken of pH, dissolved oxygen concentration, oxygen saturation, temperature and electrical conductivity (EC). Total suspended solid (TSS) concentrations were calculated by filtering known volumes of water *en site* through pre-weighed filter papers, which were subsequently dried, weighed and ashed in a muffle furnace at 450ºC to allow calculation of both organic and inorganic suspended sediment components. Water samples of 50 ml volume were collected at each site, frozen and later analysed at the University of Cape Town for concentrations of the following variables: nitrate and nitrite ((NO_3+NO_2)-N), ammonium (NH_4-N) and orthophosphate (PO_4-P). Downstream loading was calculated, using instantaneous flow data and the concentrations of selected water quality variables as follows:

Loading (mg/s) = concentration (mg/L) x flow (L/s).

It was hypothesized that nutrient and sediment loads in the water flowing from each subcatchment would be a function of the relative area of different land cover types, as follows:

Loading (mg/s) = $f(A_w, A_1, A_2 \ldots . A_n)$,

Where: A_w = % area of wetlands and A_1-A_n = % area of other land cover types 1 to n.

The sign of each influencing land cover type would depend on whether it represents a land cover that is associated with nutrient or sediment input (e.g. irrigated fields) or removal (e.g., as hypothesized here, wetlands).

Since all variables were continuous, linear stepwise multiple regression analysis was used (in Statistica 8 ®). For each of (NO_3+NO_2)-N, NH_4-N, PO_4-P and total suspended solids, instantaneous load at the sampling point (quantity per unit time) was regressed against the percentage area of grouped land cover categories of the catchment (apart from bare surfaces). Data were not transformed in any way.

In those cases where wetlands were found to have a significant impact on load, the equation was used to predict what the load would be for each subcatchment if the % area of wetlands was changed to zero. The difference between measured value and the latter value was taken to be the amount removed by the wetlands. This amount, expressed as a quantity per second, was converted to an absolute amount removed per year, by estimating the total time of flow. In the absence of time series data, it was conservatively estimated that this level of service would only be performed during the main rainfall months, and that the elevated loads that would be expected at the onset of the rainy season when catchments are 'flushed' would largely go untreated due to the high flows during these flushing events. The estimated amount removed annually was then divided by the actual area of wetlands to determine the average rate of removal per hectare of wetland per year in each subcatchment.

4.2.6 Valuation

The water treatment function was valued using the replacement cost method, based on the cost of treatment in a water treatment plant. Data were collected from 24 water treatment plants. These included the total amount of water treated, the concentration of N and P before and after treatment, and the capital and operating costs of the plants. Multiple regression analysis was used in order to estimate the marginal cost of treatment per unit mass of N and P. It was assumed that any treatment service provided by the wetlands was fully demanded. This is reasonable given the scarcity of water in general in South Africa, due to low rainfall, and of clean water in particular, due to government failure to provide adequate treatment services (Turton, 2008).

4.3 Results

4.3.1 Removal of nutrients and sediments by wetlands

Both irrigated lands and wetlands were found to significantly influence both (NO_3+NO_2)-N and NH_4-N loads, with irrigated lands having a positive influence and wetlands having a negative influence (Table 4.1; Table 4.2). In the case of NH_4-N, degraded veld was also found to have a positive influence (Table 4.2). Although highly significant, the regressions had a poor fit, which suggests that not all important factors were taken into account.

Table 4.1: Regression summary for Load (NO3 + NO2)-N mg/s (n = 93, $F(2,92)=4.9106$, Adj. $R^2 = 0.077$, $P< 0.001$)

	Beta	Std.Err. – of Beta	B	Std.Err. – of B	t(92)	p-level
Intercept			**334.8203**	126.9991	2.63640	0.009835
% Irrigated lands	0.218609	0.099158	**18.4488**	8.3681	2.20465	0.029972
%Wetlands	-0.213352	0.099158	**-43.7603**	20.3381	-2.15164	0.034045

Table 4.2: Regression summary for Load NH4-N mg/s (R^2= .27407242 Adjusted R^2= .250 $F(3,91)=11.452$, $P<0.001$)

	Beta	Std.Err. – of Beta	B	Std.Err. – of B	t(91)	p-level
Intercept			**74.95**	42.59	1.76	<0.10
% Degraded veld	0.562359	0.097672	**9.52**	1.65	5.76	<0.001
%Wetlands	-0.293469	0.096943	**-22.13**	7.31	-3.03	<0.01
%Dryland agriculture	-0.153267	0.090831	**-1.89**	1.12	-1.69	<0.10

The above results yielded the following equations:

$$N\ (NO_3 + NO_2)\ (mg/s) = 334.82 + 18.45{*}\%\ I - 43.76{*}\%\ W \qquad \text{..................Eqn 1}$$

$$N\ (NH_4)\ (mg./s) = 74.95 + 9.52{*}\%\ DV - 22.13{*}\%\ W - 1.89 * \%\ DA \qquad \text{.....Eqn 2}$$

Where: **$N(NO_3 + NO_2)$** = the load of N leaving a particular subcatchment, **% I** = percentage area of irrigated lands (including orchards, vineyards, pastures, parks and golf courses) in the subcatchment, **%W** = percentage area of wetlands in the subcatchment, **%DV** = percentage area of degraded veld in the subcatchment and **%DA** = percentage area of dryland agriculture in the subcatchment.

Orthophosphate loading was not significantly correlated with any form of land cover. The results for TSS suggest that sediment loads were driven predominantly by the presence of dryland agriculture, which have a positive impact on sediment loads, while wetlands did not have a significant impact on downstream sediment loads (Table 4.3).

Table 4.3: Regression summary for TSS load g/h (Adjusted R^2= .064, $F(1,96)=7.6306$ $p<0.05$)

	Beta	**Std.Err. – of Beta**	**B**	**Std.Err. – of B**	**t(96)**	**p-level**
Intercept			-0.028551	0.335998	-0.084974	0.932459
% Dryland agriculture	0.271353	0.098233	0.033448	0.012109	2.762353	0.006878

Equations 1 and 2 above were used to estimate the removal of N per unit area per year in each catchment by applying the equation with and without the wetland area. Estimated removal rates ranged from 307 to 9505 kg N/ha/y, with an average of 1594 ± 1375 kg N/ha/y.

4.3.2 Valuation of the water treatment service

Costs of water treatment vary according to the quantity treated due to economies of scale (Figure 4.4). The weighted average treatment cost of the 19 plants for which detailed data were available was R0.83/m^3. About R0.63/m^3 of this is the annual operating cost, and the balance is depreciation and maintenance of capital. According to engineers (Du Toit, 2008, pers. comm.), construction costs for treatment works have shown a marked rise recently. Explanations for the increase are likely to result from the sudden escalation in demand for new works after a prolonged period of stagnation, coupled with the soaring cost of materials due to booming foreign demand. Current construction costs were estimated to be in the range of R7 million per mega litre (ML) for a large works and up to R10 million for smaller works (Du Toit, 2008, pers. comm.).

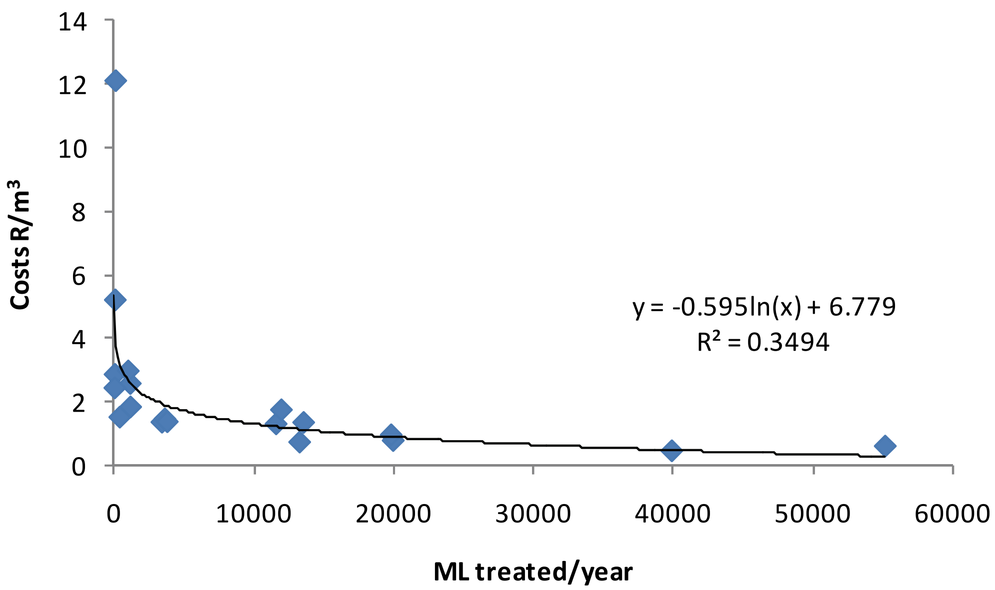

Figure 4.4: Variation of total costs of water treatment (capital depreciation, maintenance and operating costs) per unit and the quantity of effluent treated annually (n = 19 treatment works).

The amounts of TSS, N and P removed were highly correlated (Table 4.4). Thus it was not possible to perform multiple regression analysis in order to isolate marginal costs of removal of any single constituent.

Table 4.4: Correlation matrix between average daily cost of treatment (including cost of capital) and removal of total suspended solids (TSS), NH_3-N and PO_4-P. All correlations are highly significant (P<0.001)

	Cost R/day	*TSS kg*	N kg	P kg
Cost R/day	1.00			
TSS kg	0.76	1.00		
N kg	0.74	0.97	1.00	
P kg	0.75	0.97	0.96	1.00

In other words, while treatment works are designed primarily with the removal of P in mind (thus driven by the average cost per kg P removed), if N was the targeted nutrient, the costs of treatment would not differ significantly from the average cost per kg N removed that is achieved while P is being targeted. Thus, the value of treatment by wetlands can theoretically be determined as follows:

Value (R/y) = Max (kg TSS removed x C_{TSS}, kg N removed x C_N, kg P removed x C_P)

Where: C_i = total cost of treatment / total kg of substance *i* removed.

The rates of removal of different substances from water treatment works in the Western Cape suggested that an average of at least 33 mg N is removed per litre of effluent, which translates to 0.033 kg/m^3. Based on the above, the average cost of treatment was about R26/kg of N removed (from total ammonium). The analysis was limited by lack of data on the rate of removal of total P, with PO_4-P only accounting for 67% of influent total P. If removal of total P was also correlated with cost of treatment and removal rates of the other elements, then it could be assumed that the cost of treatment in terms of P removal was in the order of R71/kg P. Similar estimates could not be made for total N due to lack of data on influent concentrations of NO_3-N. These values are not additive and are merely calculated for application in the above equations.

Table 4.5: Estimated average removal rates in water treatment works

	TSS	**NO_3**	**NH_3**	**PO_4-P**	**Total P**
	mg/L	**mgN/L**	**mgN/L**	**mgP/L**	**mgP/L**
Sample size (treatment works)	20	20	24	24	19
Average influent concentration	475.5	No data	37.7	8.2	14.4
Average effluent concentration	24.8	3.4	4.7	3.3	No data
Difference (mg)	450.8		33.0	5.0	
Removal rate (kg/m^3)	0.451		0.033	0.005	0.009*****
Average cost per substance (R/kg) (not additive among substances)	R2.17		R26.16		R71.15

***** Assuming similar rates of removal as for PO_4-P.

On this basis, and using only the removal of NH_3-N to avoid double-counting, and assuming that removal of total P is correlated to that of N, the value of wetlands in the different subcatchments was estimated to have an average value of R14 350 ± 12 385/ha/y, and the total value of wetlands in the study area was estimated to be R328 million. There was no spatial pattern in the average value of wetlands in different subcatchments, but higher values tended to be associated with smaller subcatchments (Figure 4.5).

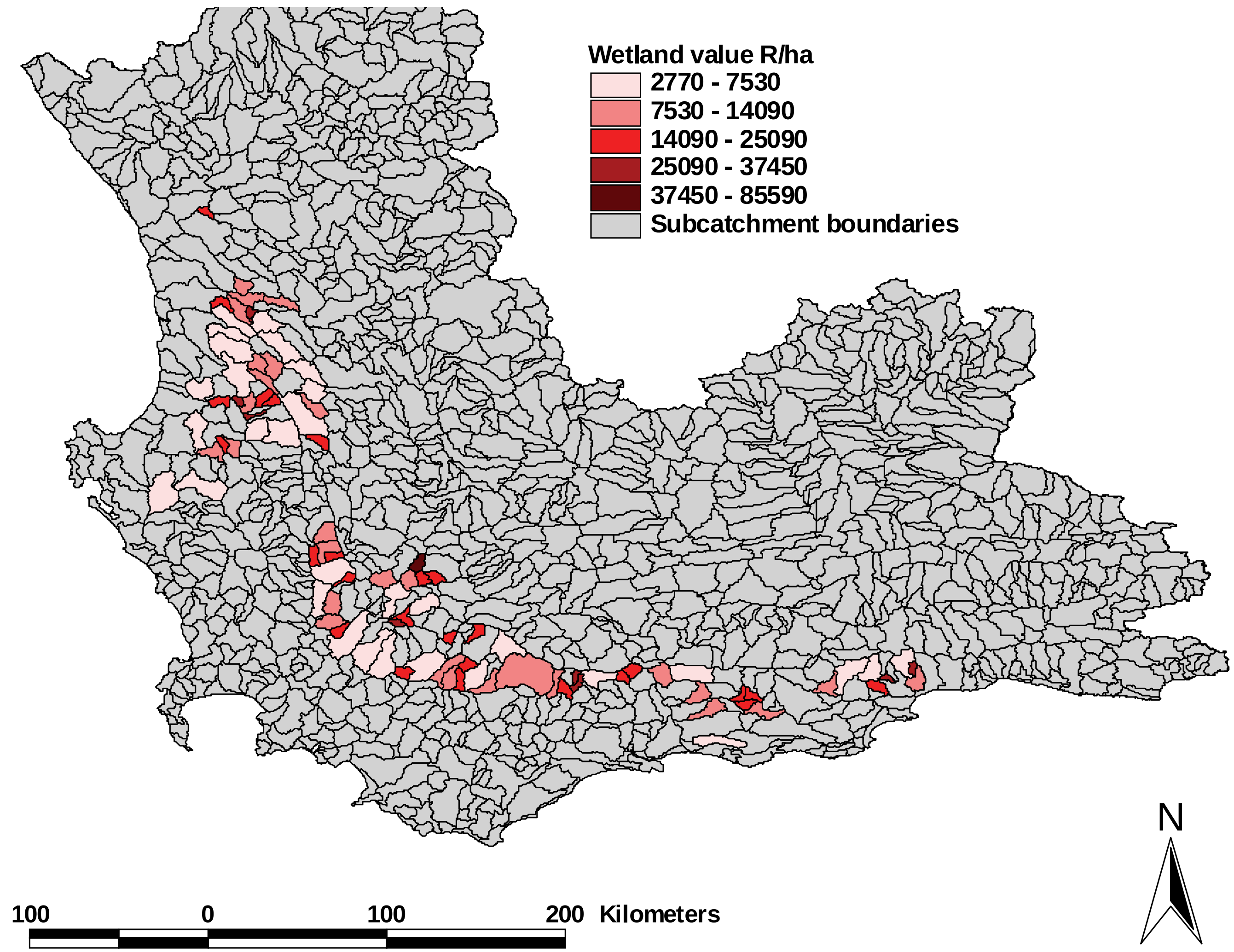

Figure 4.5: Variation in the average value of wetlands in the sampled subcatchments.

4.4 Discussion

4.4.1 Factors influencing water quality at a landscape scale

The results of this study suggest that, as expected, both wetland area and land-use do play a role in determining water quality, although the regression models were weak, suggesting that not all factors had been considered. The results suggested that irrigated lands (including orchards, vineyards, pastures, parks and golf courses) and dryland agriculture increase the concentrations of nitrogen (in ammonium, nitrates and nitrites) (probably due to the application of fertilizers in these areas) while wetlands have the opposite effect. There were no significant correlations between land cover and dissolved phosphorus concentrations. This was probably due to the fact that much of the total phosphorous load is bound to particles (DWAF, 1996). Nevertheless, effects on total phosphorus would be expected to be similar to the effects on TSS. Dryland agriculture had a weakly positive influence on TSS, but wetlands were not found to play a role. The influence of dryland agriculture probably relates to the high potential for erosion of these disturbed areas, and the prevalence of drainage channels across them, which convey water to downstream drainage systems, potentially bypassing remnant wetland areas which might have had an ameliorative impact. Data on wetland condition would potentially have shed some light on this aspect – channelisation of naturally unchannelled valley bottom wetlands is a common impact to this wetland type, and likely to dramatically affect the efficacy of wetland functions such as sediment trapping and associated phosphorus removal (see Ellery *et al., 2*010).

Surprisingly, farm dams were not found to have a significant influence on any of the water quality parameters considered. Indeed, trapping of TSS in farm dams has been hypothesized as a primary mechanism for reducing downstream phosphorus loading in agricultural areas. The lack of correlation may be linked to the timing of the water quality study in late winter, when small farm dams were likely to be full and have the capacity only for reduced rates of sediment retention.

The analysis was limited in that it did not take wetland type and condition into account (due to a lack of data), nor other factors that might be expected to have an influence on water quality, including antecedent runoff events, natural hydrology and geology.

Wetland type and condition are both likely to play an important role in determining the efficacy with which different wetlands are able to ameliorate water quality. Job *et al.*

(2008) outlined the likely roles of different wetlands at a catchment scale, noting that only those wetlands that are directly linked to surface and/or groundwater flows through a catchment are likely to exert a measurable impact on water quality. Hence channelled and unchannelled valley bottom wetlands (in terms of wetland types specified by SANBI, 2009), river channels and hillslope and valley head wetlands would be the main wetland types expected to play a role in catchment level impacts on water quality, whereas depressional wetlands and flats that are not linked to directional flow are unlikely to affect water quality at this scale.

Kotze *et al.* (2008) postulated probable levels of delivery of ecosystem services from different types of wetlands. In terms of sediment trapping and phosphate and nitrate removal, valley bottom wetlands (which dominate the wetlands of the study area) were attributed low to moderate levels of function (with unchannelled valley bottom wetlands accruing a higher rating in terms of sediment trapping than channelled valley bottom systems), hillslope seeps (which are also well represented) were attributed higher levels of ecosystem service in terms of nitrate removal, but were considered to play no role in phosphorus removal, and floodplain wetlands (rare, if not absent, in the study area) were assumed to play an important role in phosphorus removal.

Ideally, the approach should have included multiple site visits, carried out over a full annual flow cycle. The timing of the study in late winter attempted to standardize the effects of antecedent rainfall effects to a degree, by allowing for data collection at a time when dry season accumulations of nutrients and other pollutants in the catchments were likely to have been flushed out of the catchment by rainfall during the early and peak wet season. Although the impact of abstraction on the efficacy of wetland function was not specifically measured, it was accounted for indirectly in terms of the presence of farm dams. Accurate present day mean annual runoff (MAR) data were not available for the mapped subcatchment areas. However, real-time data measured at each sampling “node” allowed at least comparison of estimated loading between catchments.

Geology was not considered as a variable, and might indeed play a role in the discrimination of water quality characteristics between different portions of the study area. Since the study area comprised three broad vegetation zones, mapped for the Fine Scale Planning study by Job *et al.* (2008), it is likely that these botanical zones respond at least in part to changes in geology. Future work on this project should include testing for differences in water quality between catchments in different botanical zones. Budget and logistical constraints in the present study limited the extent to which such question could be explored, given the limited number of sites sampled across the three broad botanical areas included in the Fine Scale Planning Study.

4.4.2 Capacity of wetlands for water quality treatment

Estimates of the rates of removal of nitrogen by wetlands in the study area were higher than expected, and fell within the broad ranges for nitrogen removal observed in artificial wetlands (300-9000 kg/ha/y; Verhoeven *et al., 2*006).

The high levels of variability in removal rates estimated in this study are likely to reflect differences in land-use, but to some extent may also reflect the un-assessed variability in wetland type and condition, as well as regional variation in precipitation, evaporation and vegetation type. Variability in wetland characteristics may be associated with greater or lesser efficacy in terms of facilitating pollutant sequestration (Kadlec and Knight, 1996), especially differences in the degree to which flows are spread through a wetland and affect aquatic contact with microbial communities. Wetland condition, as noted earlier, is also likely to be a primary determinant of wetland function at a landscape level, and this in turn is likely to be tied into land-use and the existence of an ecological buffer area or “setback” between wetlands and their surrounding land-use. These uncertainties highlight the importance of providing a measure of wetland condition and type, if greater levels of confidence are to be attached to modelled valuations of wetland ecosystem services.

Kadlec and Knight (1996) also found seasonal differences in nitrogen uptake by aquatic macrophytes, with uptake in temperate climates being at a maximum during spring and summer, and die-back (associated with the release of nitrogen nutrients back into wetland soils and waters) often occurring in autumn and early winter. Seasonal variation in nitrogen uptake was not investigated in the present study, but should be considered in efforts to fine-tune modelled wetland loading rates.

4.4.3 Valuation

The valuation of the water quality amelioration service was carried out using a replacement cost technique. However, it is difficult to isolate the cost of removal of different water quality variables in the treatment process. The main costs entailed in design and management of water treatment works are usually associated with the reduction of phosphorus and total ammonia concentrations, to levels that concur with licensing requirements. These in turn are often dictated by ecological concerns, with phosphorus often being a limiting nutrient in natural inland aquatic ecosystems. Elevated phosphorus concentrations are usually associated with increased productivity, often including increases in algal and/or cyanobacterial blooms, and increased invasion by (often alien) aquatic macrophytes. Management of ammonium concentrations is also accorded high priority. Although the total nitrogen loading associated with ammonium is usually lower than that associated with nitrates and nitrites, the un-ionised form of ammonium nitrogen (ammonia – NH_3) is associated with high levels of toxicity to many aquatic organisms, even at very low concentrations (DWAF, 1996). It might be argued that a plant designed purely for the removal of sediment and nitrogen might be less costly, and the values applied in this study could thus be an overestimate. Furthermore, most of the waste-water treatment works analysed in this study are currently operating over-capacity, with the result that they might not be as efficient as they were designed to be. These are areas that deserve further study. Nevertheless, conservative assumptions were applied, and we are confident that the estimates are in the right order of magnitude.

Because of the economy of scale and the lack of data on the removal of N in the form of nitrates and nitrites, it was not possible to derive the marginal cost of removal of different substances. The assumption that the average cost of treatment can be attributed to N might produce an overestimate of value. This is particularly the case if the assumption that total phosphorus removal is correlated with nitrogen removal is relaxed. If wetlands do not remove phosphorous, then water treatment would still be necessary and the wetlands would not perform a cost-saving service. Thus the value estimates in this study must be viewed with caution, and taken only to be potential values of the service.

4.4.4 Scale of the study

This study allowed wetlands to be valued at the subcatchment level i.e. assigning an average value per ha to all wetlands in a particular subcatchment. In reality the service performed will vary among the wetlands depending on their position in the landscape, type and condition. Nevertheless, understanding value at this scale may be useful in prioritising conservation and restoration action or in analysing broad scale conservation trade-offs. In order to estimate value at a more local scale, it would be necessary to assess the relative value of different types of wetlands, the influence of their position in the landscape and the influence of their condition (Kotze *et al., 2*008, Turpie *et al., 2*009).

4.5 Acknowledgements

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4.6 References

Barbier EB. 1993. Sustainable use of wetlands – Valuing tropical wetland benefits: economic methodologies and applications. The Geographical Journal 159: 22-32.

Barbier E, Acreman MC and Knowler D. 1997. Economic valuation of wetlands: a guide for policy makers and planners. Ramsar Convention Bureau, Switzerland. 127pp.

Batty LC, Atkin L and Manning DAC. 2005. Assessment of the ecological potential of mine-water treatment wetlands using a baseline survey of macroinvertebrate communities. Environmental Pollution 138: 412-419.

Bergstrom JC and Stoll JR. 1993. Value estimator models for wetlands-based recreational use values. Land Economics 69: 132-137.

Bowers J. 1983. Economics and conservation: the case of land drainage. In: Warren A and Goldsmith FB. Conservation in perspective. John Wiley and Sons Ltd. pp 375-389.

Cooke CD, Welch E, Peterson S and Nichols S. 2005. Restoration and management of lakes and reservoirs. Taylor and Francis. London.

Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P and van den Belt M. 1997. The value of the world's ecosystem services and natural capital. Nature 387:253-259.

Department of Water Affairs and Forestry. 1996. Water Quality Guidelines. Vols. 1-7. DWAF, Pretoria.

Ellery WN, Grenfell SE, Grenfell MC, Jaganath C, Malan H and Kotze DC. 2010. A method for assessing cumulative impacts on wetland functions at the catchment or landscape scale. Report emanating from WRC project K5/1584; Wetlands Health and Importance Research Programme. Water Research Commission, Pretoria.

Emerton L. 1998. Economic Tools for Valuing Wetlands in Eastern Africa. Biodiversity Economics Manual: IUCN Eastern Africa Regional Office, Nairobi.

Emerton L, Iyango L, Luwum P and Malinga A. 1999. The present economic value of Nakivubo urban wetland, Uganda. IUCN, Kampala.

James RF. 1991. Wetland valuation: guidelines and techniques. Asian Wetland Bureau – Indonesia.

Job N, Snaddon K, Day E, Nel J and Smith-Adoa L. 2008. C.A.P.E. Fine-scale Biodiversity Planning Project: Freshwater Ecosystems of the North-west Sandveld and Saldanha Peninsula planning domain. Produced for CapeNature. Cape Town, South Africa.

Johnston CA, Detenbeck NE and Niemi GJ. 1990. The cumultative effect of wetlands on stream water quality and quantity. A landscape approach. Biogeochemistry 10: 105-141.

Jordan TE, Whigham DF, Hofmockel KH and Pittek MA. 2003. Nutrient and sediment removal by a restored wetland receiving agricultural runoff. Journal of Environmental Quality 32: 1534-1547.

Kadlec RH and Knight RL. 1996. Treatment Wetlands. CRC Press. Florida.

Kotze DC, Marneweck GG, Batchelor AL, Lindley DS and Collins NB. 2008. WET-EcoServices: A technique for rapidly assessing ecosystem services supplied by wetlands. WRC Report no. TT 339/08. Water Research Commission, Pretoria, South Africa.

Pearce DW and Turner RK. 1990. Economics of Natural Resources and the Environment. Harvester Wheatsheaf, Hertfordshire.

Peltier EF, Webb SM and Gaillard JF. 2003. Zinc and lead sequestration in an impacted wetland system. Advances in Environmental Research 8: 103-112.

SANBI. 2009. Proposed National Wetland Classification System for South Africa. Final Project Report. Prepared by the Freshwater Consulting Group (FCG) for the South African National Biodiversity Institute (SANBI).

Thullen JS, Sartoris JJ and Nelson SM. 2005. Managing vegetation in surface-flow wastewater-treatment wetlands for optimal treatment performance Ecological Engineering 25: 583-593.

Turner RK, van den Bergh JCJM, Söderqvist T, Barendregt A, van der Straaten J, Maltby E and van Ierland EC. 2000. Special issue: The values of wetlands: landscape and institutional perspectives. Ecological-economic analysis of wetlands: scientific integration for management and policy. Ecological Economics 35: 7-23.

Turpie JK, Menayas A, Dures S, Shaw JM, Meek C, Cordingley J, Hamann M, Mzumara T, Musvuugwa T, Louw A, Bewana A, Quayle T and Ditlhobolo T. 2009. The nature, distribution and value of ecosystem services in South Africa. Unpublished report (paper in prep). Percy FitzPatrick Institute, University of Cape Town.

Turton A. 2008. Three Strategic Water Quality Challenges that Decision-Makers Need to Know About and How the CSIR Should Respond. Unpublished manuscript.

Verhoeven JTA, Arheimer B, Yin C and Hefting MM. 2006. Regional and global concerns over wetlands and water quality. Trends in Ecology and Evolution 21: 96-103.

Walmsley RD. 1991. Stream environments and catchment processes – a South African perspective. In: JJ Pigram and BP Hooper (eds.) Water Allocation to the Environment – Proceedings of an International Seminar and Workshop. The Centre for Water Policy Research, University of New England, Armidale. pp. 45-57.

Young LJ, Roeder E and Ursin E. 2008. Nitrogen input assessment for the Wekiva Study Area. An educational poster for: The Florida Department of Health by: University of Florida, Institute for Food and Agricultural Sciences.

Zucchini W, Nenadi´c O and Kratz G. 2009. A Web-based Rainfall Atlas for Southern Africa. Accessed online at [http://134.76.173.220/rainfall/index.html].

5. THE TOURISM VALUE OF NYLSVLEY FLOODPLAIN

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Abstract

A brief study was carried out to assess the tourism value of the Nylsvley floodplain in Northern Province, based on discussions with key informants and a small survey of visitors. Most recreational use occurs within the Nylsvley Nature Reserve, which protects about 1000 ha of the 16 000 ha wetland. Some 9-10 000 people visit the reserve annually, mainly for birdwatching. About 85% of visitors surveyed were domestic visitors, the majority from within a few hours' drive of the study area. South Africans tended to be on short visits specifically to the site, whereas overseas visitors tended to be visiting as part of a multi-destination trip. Based on the average on-site expenditure and off-site travel expenditure attributed to visiting the nature reserve, the tourism value of the Nylsvley floodplain was estimated to be in the order of at least R9-10 million per annum. Because of the small sample size obtained, the estimate is only rough, but this is likely to be the case when estimating the recreational value of small or isolated wetlands.

5.1 Introduction

Many wetlands have features that make them attractive places for recreation and tourism, or that contribute to the attractiveness of a broader area. These features include scenic beauty as well as the presence of wildlife and rare species, and they attract visitors for relaxation and walking, and game viewing, as well as more specialised interest activities such as birdwatching and frogging. Although many such studies have been carried out internationally (e.g. Bergstrom *et al., 1*990), there are few studies that have investigated the aesthetic, recreational or tourism value of inland wetlands in southern Africa. The studies that have been carried out, have considered urban wetlands, which impart amenity values that are reflected in the premiums paid for surrounding properties (van Zyl and Leiman, 2002), and the Okavango Delta in Botswana, a very extensive systems which supports a large tourism industry contributing some 6% to Botswana's economy (Turpie *et al., 2*006). Outside of urban areas, wetlands that are likely to be particularly attractive for tourism are those that contain significant birdlife and that are accessible to visitors. The Nylsvley floodplain wetland in Northern Province, South Africa, is one such example. The aim of this study was to investigate the use of the Nylsvley floodplain and estimate its total tourism value.

5.2 Study area

The Nyl floodplain is located in the Waterberg District of Limpopo (Figure 5.1), between Pretoria and Pietersburg. The floodplain is approximately 70 km long with an average width of 2 km and covers an area of 16 000ha, making it the largest floodplain of its type in South Africa. The flooding regime of the Nyl river determines the extent and duration of inundation of the floodplain; certain areas are permanently inundated while a substantial proportion only inundates seasonally or every few years. Full flooding is impressive, but requires sustained rains. There is substantial detailed biophysical information available for the wetland (e.g. Scholes and Walker, 1993; Barnes and Tarboton, 1998; DEAT, 1998; Malan and Day, 2005).

The primary land-uses on the floodplain are agriculture (mostly livestock with some cropping), game farming and tourism. Tourism in the study area primarily revolves around the Nylsvley Nature Reserve, a provincial reserve that covers approximately one-quarter of the wetland area and also encompasses some of the surrounding savanna and grassland. The Nylsvley Nature Reserve is a birdwatcher's paradise and also has a wide variety of mammals and other animals. The land within the reserve is relatively pristine and well protected (DEAT 1998).

Figure 5.1: Wetlands in South Africa (blue) and the location of the Nyl floodplain (red) in the Northern Province, South Africa. Source: SANBI National Wetlands Map III.

Approximately 600 plant species have been recorded on the reserve (Scholes and Walker, 1993). The stands of wild rice *Oryza longistaminata* that dominate some of the wetland areas are unusual in South Africa, as the Nyl floodplain is the southernmost extent of its range and its only locality in South Africa (Gibbs-Russel *et al., 1*989). The tropical grass *Paspalidium germinatum* is also found nowhere else in South Africa (Barnes and Tarboton, 1998) and *Ceropegia steniae* is a rare plant endemic to the old Transvaal (DEAT, 1998).

The Nyl floodplain is renowned for its avifauna. The site is designated as one of the Important Bird Area's of Southern Africa (IBA) (Barnes, 1998) and also a Ramsar

Wetland of International Importance. Barnes and Tarboton (1998) describe both the huge abundance of birdlife (estimated up to 80 000 individuals during floods) and exceptional diversity (426 species are recorded on the floodplain, approximately 46% of all species found in Southern Africa). Many of the birds utilizing the floodplain's habitat are threatened species. Over a hundred species of waterfowl alone are recorded on the floodplain, 58 of which are known to breed there and 23 are Red Data listed (eight of which breed on the floodplain) (DEAT, 1998). Nylsvley is the only site in South Africa where the Rufousbellied Heron *Butroides rufiventris* has been known to breed and is the only place in the country with a record of the Striped Crake *Aenigmatolimnas marginalis* and Streakybreasted Flufftail (DEAT, 1998).

Sixteen species of fish are known to occur in the Nyl system. The fish in the Nyl system proliferate to an estimated 300-600 tons during floods (DEAT, 1998) while the frogs multiply almost as astoundingly. A total of 75 species of herpetofauna and 62 mammal species have been recorded in the Nylsvley Nature Reserve alone (Jacobson, 1977), but additional species are found outside of the reserve. A number of the mammal and herpetofauna species are also threatened species.

The scenery and natural heritage of the region around the Nyl floodplain (the Waterberg) and its proximity to the large population centres in Gauteng have stimulated a considerable tourism industry. Stretches of intact bushveld, the Waterberg Mountains and high-quality game viewing opportunities attract visitors to the plentiful game farms and guest lodges in the area.

5.3 Methods

Information on tourist facilities and visitor numbers were collected from key informants and from the internet. Quantifying the extent that the wetlands contribute to tourism value includes direct expenditures and also money spent accessing the floodplain (e.g. petrol, accommodation) as well as multiplier effects. A questionnaire survey of visitors was conducted between September and December 2007, in which 95 visitors were asked about their reasons for visiting the wetland and the travel costs incurred in visiting the site.

5.4 Results

5.4.1 Visitor facilities and numbers

On the Nyl floodplain specifically, the Nylsvley Nature Reserve provides the main facility for visitors. Nylsvley is a provincial 4 000 ha reserve, about a quarter of which is floodplain. The reserve itself has limited infrastructure and accommodation options.

Nylsvley receives an estimated 9 000 to 10 000 visitors annually (Matatji, 2007, pers. comm., Nylsvley Nature Reserve; DEAT, 1998) depending partially on the quality of the rains (good years attract many more visitors to see the explosion of life during floods). In addition to the Nylsvley Nature Reserve itself, there are numerous and diverse accommodation options surrounding the floodplain.

In addition to tourism, the Nylsvley Nature Reserve provides a venue for educational instruction and scientific research. According to the reserve manager, the majority of the research and educational value is derived from three groups of students (Matatji, 2007, pers. comm., Nylsvley Nature Reserve). The first and most regular group is from the Organization for Tropical Studies (OTS), made up of undergraduate American and South African students on a semester-long ecology field course, the first two weeks of which is spent in Nylsvley. The second group is comprised of veterinary students that visit approximately twice per month for short periods. And the last group is composed of microbiology students from the University of Venda who visit sporadically, but just for the day. Occasionally school groups visit, but it is rarely more than once per year. There is also periodic research by university faculties, but no researchers are full time at Nylsvley and the amount of research is much smaller than at certain periods in the past when Nylsvley was one of the most intensively studied areas of the country.

Expenditures for the second semester of 2007 were obtained from OTS. At a total of R80 340.00 for 31 individuals over 10 days, expenditures averaged approximately R259 per person per day.

Table 5.1: Expenditures by the Organization for Tropical Studies for 31 personnel on their most recent 10 day trip to Nylsvley

Item	Amount (R)
Food	33 465
Accommodation	17 460
Transport	9 415
Visiting lecturers	20 000

5.4.2 Visitor origins and characteristics

The majority (85%) of the visitors surveyed were from South Africa, and all but 2 South African respondents from close by. The remaining 15% are from abroad. Of the South African visitors there were a total of 213 visitors from a total of 80 groups surveyed. The international component comprised of 34 visitors from 15 groups surveyed.

Nearly a third of respondents were day trippers to the Nylsvley Nature Reserve. Respondents who stayed longer were mostly international visitors. Domestic visitors were usually on a short trip of one or two days (average 2.8 days) and the wetland was often their sole purpose for the trip (average 72% of reason). Of the 75 respondents who dated their forms, 45 were there over weekends. Sixty-two percent of domestic visitors had been before. International travelers were typically on trips of up to a few weeks (average 22.1 days), of which Nylsvley was only one of a number of destinations visited, and made up 29% of the reason for their trip on average (possibly overstated). More than a quarter (27%) of international visitors had been to Nylsvley before. Overall approximately 22% of visitors visited more than once a year, 16% visit annually, 18% visit every few years, and the rest were newcomers.

5.4.3 Wetland features and their attraction for tourists

As expected, the majority of respondents cited birdwatching as the most important reason for visiting Nyslvley. Thirty-two percent of respondents felt there was no comparable site at which they could obtain a similar quality experience, 43% felt there were a few alternatives, and 25% claimed there were several alternatives they could have chosen.

5.4.4 Expenditure on visiting Nylsvley

Domestic and international visitors spent an average of R590 and R3100 per person on visiting Nyslvley, respectively. In the case of international visitors, most of this expenditure was off-site (Table 5.2). For a visitation rate of 9-10 000 people per year, and assuming that the proportion of international visitors in our sample (15%) was representative, the total annual expenditure on visiting Nylsvley was estimated to be in the order of R8.7-9.7 million.

Table 5.2: Average expenditure per person by respondents on visiting Nylsvley Nature Reserve (note sample sizes are small). Amounts given in Rands (2007)

	South African	**International**
Average on-site expenditure (Nylslvey)	419	368
Average total trip expenditure	573	12 118
Average: % expenditure in Nylsvley	73%	3%
Average: % of Nylsvley as reason for trip	72%	29%
Offsite expenditure on Nylsvley (% of reason for trip x travel expenditure)	174	2 729
Total off-site + on-site expenditure for Nylsvley	594	3 097

5.5 Discussion

Nylsvley Nature Reserve is a relatively small nature reserve, but is a well known attraction in South Africa, particularly among the birdwatching community. Being relatively close to Pretoria, it is also within range of a major population centre, and thus attracts reasonable numbers of visitors for a small nature reserve. Indeed, the numbers of people visiting Nylsvley Nature Reserve are in a similar order to those recorded at the 36 000 ha coastal De Hoop Nature Reserve, the flagship park of CapeNature in the Western Cape. The overall recreational value of the Nature Reserve was estimated to be at least R8.7-9.7 million. This is a minimum estimate as it does not include consumer's surplus (the amount over and above actual expenditure which visitors would have been prepared to pay in order to visit the area).

The nature reserve provides accessibility to only a part of the much larger Nylsvley floodplain, the remainder of which is on private land. Recreational value on the remainder is probably negligible at present. The value of the accessible portion is undoubtedly linked to its connectivity with the whole, and should probably be attributed to the whole wetland rather than the portion in the nature reserve. In other words, the value cited above is really the recreational value of Nylsvley floodplain itself.

The study was somewhat limited by the small sample size, which meant that estimates made in this study were rough, and there were insufficient data to undertake a travel cost analysis to estimate consumer surplus. The small sample size was attributed to a low response rate – only 95 questionnaires were obtained over a three month period. The low response rate was probably due to the method of leaving questionnaires on site to be filled in voluntarily by visitors and lack of follow-up by reserve staff. However, wherever daily visitor numbers are relatively low, there will be a trade-off between choosing to conduct face-to-face interviews and using a self-fill option, in that the cost of the former may not be justifiable for the return rate. The Nyslvlei floodplain is one of South Africa's larger inland wetlands, and part of it lies within a managed nature reserve, which made the estimation of visitor numbers relatively easy. For smaller and more isolated rural wetlands which do not fall within protected areas, estimation of recreational value will be more difficult to obtain because of a lack of information or even expert opinion on visitor numbers as well as a lack of visitors to interview.

5.6 References

Barnes KN and Tarboton WR. 1998. Important Bird Areas of the Northern Province. In: Barnes KN (ed.) The Important Bird Areas of Southern Africa. BirdLife South Africa. Johannesburg. pp.60-62.

Bergstrom JC, Stoll JR, Titre JP and Wright VL. 1990. Economic value of wetlands-based recreation. Ecological Economics 2: 129-147.

DEAT. 1998. Nylsvley Nature Reserve: Information sheet for the site designated to the List of Wetlands of International Importance in terms of the Convention on Wetlands of International Importance especially as Waterfowl Habitat. South African Wetlands Conservation Programme Document No. 24/21/3/3/17. Pretoria.

Gibbs-Russel GE, Watson L, Koekemoer M, Smook L, Barker NP, Anderson HM, Dallwitz MJ. 1989. Grasses of southern Afrca. Memoirs of the Botanical Survey of South Africa. No. 58. National Botanical Institute, Pretoria.

Jacobson NHG. 1977. An annotated checklist of the amphibians, reptiles and mammals of the Nylsvley Nature Reserve. South African National Scientific Programmes Report No. 21. Pretoria.

Malan HL and Day JA. 2005. Wetland water quality and the Ecological Reserve. WRC report no. 1311/1/05. Water Research Commission, Pretoria, South Africa.

Scholes RJ and Walker BH. 1993. An African Savanna: Synthesis of the Nylsvley Study.

Turpie JK, Barnes J, Arntzen J, Nherera B, Lange G-M and Buzwani B. 2006. Economic value of the Okavango Delta, Botswana, and implications for management. Report to the Okavango Delta Management Plan project, Government of Botswana.

Van Zyl H and Leiman A. 2002. Hedonic approaches to estimating the impacts of open spaces: a case study in the Cape. South African Journal of Economics and Management Science 5: 379-394.

APPENDIX 1. DESIGN RAINFALLS FOR NYLSVLEY CATCHMENTS FOR CALCULATION OF THE INFLOW HYDROGRAPHS FOR FLOOD ATTENUATION INVESTIGATION

Table A1. 1: Design rainfalls for Nylsvley catchments for calculation of the inflow hydrographs for flood attenuation investigation

QUART	AREA	MAP	RI	7 hrs	8 hrs	9 hrs	10 hrs	11 hrs	12 hrs	13 hrs	14 hrs	15 hrs	16 hrs	24 hrs
			1;2	45.96	47.73	48.91	50.08	51.26	52.44	53.13	53.82	54.50	55.19	58.92
			1;5	62.41	64.81	66.41	68.01	69.61	71.21	72.15	73.08	74.01	74.95	80.02
			1;10	74.26	77.12	79.02	80.93	82.83	84.73	85.84	86.96	88.07	89.18	95.21
			1;20	86.81	90.15	92.37	94.60	96.82	99.05	100.35	101.65	102.95	104.24	111.29
			1;50	103.51	107.50	110.15	112.80	115.46	118.11	119.66	121.21	122.76	124.31	132.71
			1;100	117.04	121.55	124.55	127.55	130.55	133.55	135.30	137.05	138.80	140.55	150.06
A61A	381	629	1;200	131.82	136.89	140.27	143.65	147.02	150.40	152.38	154.35	156.32	158.29	168.99
			1;2	45.16	46.89	48.05	49.21	50.37	51.52	52.20	52.88	53.55	54.23	57.89
			1;5	61.32	63.68	65.25	66.82	68.40	69.97	70.89	71.80	72.72	73.64	78.62
			1;10	72.96	75.77	77.64	79.51	81.38	83.25	84.34	85.43	86.53	87.62	93.54
			1;20	85.29	88.57	90.76	92.94	95.13	97.32	98.59	99.87	101.15	102.42	109.35
			1;50	101.70	105.62	108.22	110.83	113.44	116.05	117.57	119.09	120.61	122.13	130.39
			1;100	115.00	119.42	122.37	125.32	128.27	131.21	132.93	134.65	136.37	138.09	147.43
A61B	362	618	1;200	129.51	134.49	137.81	141.13	144.45	147.77	149.71	151.65	153.59	155.52	166.04
			1;2	44.43	46.13	47.27	48.41	49.55	50.69	51.36	52.02	52.68	53.35	56.96
			1;5	60.33	62.65	64.20	65.74	67.29	68.84	69.74	70.64	71.54	72.45	77.34
			1;10	71.78	74.54	76.38	78.22	80.06	81.90	82.98	84.05	85.13	86.20	92.03
A61C	362	608	1;20	83.91	87.14	89.29	91.44	93.59	95.74	97.00	98.25	99.51	100.76	107.58

			1;50	100.06	103.91	106.47	109.04	111.60	114.17	115.67	117.16	118.66	120.16	128.28
			1;100	113.14	117.49	120.39	123.29	126.19	129.09	130.78	132.48	134.17	135.86	145.05
			1;200	127.41	132.32	135.58	138.85	142.12	145.38	147.29	149.19	151.10	153.01	163.35
			1;2	44.72	46.44	47.58	48.73	49.88	51.02	51.69	52.36	53.03	53.70	57.33
			1;5	60.73	63.06	64.62	66.18	67.73	69.29	70.20	71.11	72.01	72.92	77.85
			1;10	72.25	75.03	76.89	78.74	80.59	82.44	83.52	84.61	85.69	86.77	92.63
			1;20	84.46	87.71	89.88	92.04	94.21	96.37	97.64	98.90	100.16	101.43	108.28
			1;50	100.72	104.59	107.17	109.76	112.34	114.92	116.43	117.93	119.44	120.95	129.12
			1;100	113.88	118.26	121.18	124.10	127.02	129.94	131.64	133.35	135.05	136.75	146.00
A61D	456	612	1;200	128.25	133.19	136.47	139.76	143.05	146.34	148.26	150.18	152.09	154.01	164.43

APPENDIX 2. DESIGN INFLOW HYDROGRAPHS FOR NYLSVLEY CATCHMENTS FOR FLOOD ATTENUATION INVESTIGATION

Table A2. 1: 1:50 year return period design flood hydrographs (m^3/s) for each quaternary catchment inflow for the Nylsvley investigation

Time (hours)	A61A	A61B	A61C	A61D	A61E	A61F	A61G
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	5.4	2.3	1.3	2.1	5.4	114.3	4.7
10	78.3	15.3	5.7	12.2	74.6	442.0	28.8
12	200.8	95.6	18.7	84.1	229.2	667.4	193.3
14	287.3	189.5	80.5	192.0	353.9	659.9	411.3
16	254.9	249.4	178.7	277.4	354.7	335.4	567.3
18	153.3	200.7	273.2	255.4	226.7	180.2	485.4
20	96.2	133.0	283.0	178.4	142.1	90.2	325.4
22	63.4	89.3	232.0	120.0	95.4	41.7	217.9
24	43.6	63.5	169.3	85.3	67.9	15.3	155.5
26	29.6	47.7	124.3	64.2	48.9	3.1	117.3
28	19.3	36.6	95.2	50.2	34.5	0.5	91.2
30	11.5	28.0	76.0	39.6	23.6	0.0	71.0
32	5.8	21.1	62.3	31.2	15.1	0.0	54.8
34	2.1	15.6	52.1	24.2	8.5	0.0	41.6
36	0.4	11.1	44.2	18.5	3.7	0.0	30.8
38	0.1	7.5	37.6	13.8	1.0	0.0	22.1
40	0.0	4.5	31.8	9.9	0.2	0.0	14.9
42	0.0	2.1	26.7	6.7	0.0	0.0	8.9
44	0.0	0.7	22.2	3.9	0.0	0.0	4.1
46	0.0	0.1	18.5	1.8	0.0	0.0	1.2
48	0.0	0.0	15.2	0.5	0.0	0.0	0.2
50	0.0	0.0	12.3	0.1	0.0	0.0	0.0
52	0.0	0.0	9.7	0.0	0.0	0.0	0.0
54	0.0	0.0	7.5	0.0	0.0	0.0	0.0
56	0.0	0.0	5.7	0.0	0.0	0.0	0.0
58	0.0	0.0	3.9	0.0	0.0	0.0	0.0
60	0.0	0.0	2.2	0.0	0.0	0.0	0.0
62	0.0	0.0	0.9	0.0	0.0	0.0	0.0
64	0.0	0.0	0.2	0.0	0.0	0.0	0.0
66	0.0	0.0	0.0	0.0	0.0	0.0	0.0
68	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70	0.0	0.0	0.0	0.0	0.0	0.0	0.0
72	0.0	0.0	0.0	0.0	0.0	0.0	0.0