LINKING THE HYDROLOGICAL, GEOMORPHOLOGICAL AND SOCIOLOGICAL ASPECTS OF WETLANDS IN RURAL AREAS. A CASE STUDY BASED IN THE CRAIGIEBURN WETLAND MICROCATCHMENT IN THE SAND RIVER CATCHMENT

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DECLARATION

I wish to certify that this study represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any University. Where use has been made of the work of others, it is duly acknowledged in the text.

Signed: ____________________
Karen King

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ABSTRACT

In many of the rural areas of South Africa local communities rely on wetland resources for daily living. For a symbiotic relationship to exist between these communities and the wetlands, the wetlands must be utilised in a manner sustainable to both parties. To prevent exploitation thereof, a comprehensive understanding of the processes and functions of wetlands, of the values and needs of rural community members, and of the interactions between these entities is essential.

This study focuses on research at three scales; the plot scale ($10m^2$), the microcatchment scale ($1km^2$), represented by the Craigieburn wetland and microcatchment, and the catchment area upstream of the gauging weir X3H008, all of which exist in the Sand River catchment in the Mpumalanga and Limpopo Provinces of South Africa. Relationships between the geomorphological properties of the Craigieburn microcatchment, the wetland management practices of the local communities, and the hydrological properties of the microcatchment have been investigated. Various hydrological models, but in the main the *ACRU* model, have been adopted as tools to facilitate this research. Possible scenarios of changes in land use, rainfall and soil texture were performed at the plot scale and at the scale of the microcatchment, and changes in wetland extent were simulated and analysed at the scale of the catchment.

Results of the modelling exercises simulating the effects of differences in soil texture highlight the positive effects of retention of fine particles within a wetland in a sandy environment. These results also depict greater rates of hydraulic conductivity, erosion and desiccation within coarse-textured soils than finer textured soils. Low levels of fertility can also be attributed to the lack of fine particles present in the soils of the Craigieburn microcatchment wetland.

Results of the modelling exercises that investigate the likely hydrological effects of a variety of land uses within the Craigieburn microcatchment verify accepted hydrological theory, as they highlight that more impervious areas produce more stormflow and lose more water to evaporation, and that the natural vegetation of the

area contributes to streamflow regulation more than other land uses do. The exercises performed at the scale of the Sand River catchment do not provide conclusive evidence of the effects of changes in wetland extent, as the hydrological effects that other land uses in the area have appear to override the effects of the simulated wetland areas.

Analysis of the sociological data captured highlights the great extent to which the local community depends on the Craigieburn wetland resources for a variety of livelihood strategies. Furthermore it illustrates the degree to which a reduction in wetland health negatively impacts upon the community.

Viewed in conjunction, the hydrological, biophysical and sociological results highlight the degree to which changes in one aspect of the environment affect other aspects thereof, thereby highlighting the degree to which these aspects of the Craigieburn microcatchment are inextricably linked.

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1. INTRODUCTION

Communities that adopt livelihood strategies that combine subsistence agriculture with utilisation of wetland resources make up a large proportion of those living in developing countries. These are vulnerable livelihood strategies, as the members of these communities are reliant on the productivity of the natural system. Although many of the functions that wetlands perform and the value they offer are crucial to communities, members of these communities are not often included in decision-making concerning development plans for the wetland area (Silvius *et al.*, 2000). The RAMSAR World Conservation Strategy for Wetlands (de Klemm and Creteaux, 1995) identified wetlands as one of the most important life support systems on this planet. Despite this, large proportions of South Africa's wetlands have been, and are being destroyed or damaged (Cowan, 1980; Kotze, 2002).

As some rivers in South Africa are seasonal, the social significance of the wetlands attached to these rivers varies temporally. In such cases the communities' reliance on these resources is even more precarious, as when resources become scarce, over-exploitation of the resource is likely. Using wetlands in a sustainable manner is of great importance in South Africa, especially where wetlands sustain and hold great value for local communities (Kotze, 2002). Wise use of wetlands implies sustainable use for the benefit of humankind in a manner that enables the wetland to maintain its natural functions (Blasco, 1997). For these reasons, wetland conservation in South Africa necessitates considerations that are specific to both the country and to individual wetlands.

Wetlands are important hydrologically and socially, and these aspects of wetlands are inextricably linked. Wetland functions essentially lead to the improvement of the quality of water passing through and retained in the wetland, and provide an aquatic habitat for many plants, animals and birds. Wetland functions directly affect the lives of local communities because of their storage capabilities, as they provide a water source during dry periods, and provide a habitat for plants that the community may harvest. The provision of alternative livelihood strategies, in the form of subsistence farming, or reed harvesting for household or commercial use, means that the functioning of the wetland has an impact on the economy of the area (Kotze, 2002), and because the trade of primary commodities is an important part of the South African national economy, natural resource bases, such as wetlands, also have larger scale economic effects (Rich, 1994).

1.1 The Sand River Catchment Wetlands Study

It has been suggested that the wetlands in the Sand River catchment in the Mpumalanga and Limpopo Provinces of South Africa play a vital role in the livelihoods of the members of local communities and are becoming degraded and progressively drier. This potentially poses a great threat to the community members who rely on the wetlands for cultivation in this low rainfall region (Pollard, 2002). The research reported in this thesis makes up a part of a larger project, titled, 'Wetlands and Rural Livelihoods' (WRL). Three sectors of this larger project exist, these are the geomorphological, hydrological and sociological aspects of the Sand River catchment wetlands, and the project explores the links between the sectors. This larger project is based on the recognition that both biophysical and socio-economic aspects need to be considered when studying the role of wetlands in rural livelihoods.

The research for this thesis is focussed on the hydrological aspects of the project, and the links between these and the geomorphological and sociological aspects thereof, and has thus been written adopting a multi-disciplinary approach. The geomorphological and sociological data collection and analysis were conceptualised and performed by Professor Fred Ellery (University of KwaZulu-Natal), and by Dr Sharon Pollard (AWARD), Ms Tessa Cousins (AWARD) and Dr Donovan Kotze (University of KwaZulu-Natal), respectively. The author has participated in the collection and analysis of both sociological and geomorphological data, but the hydrological data collection, analysis and links to the sociological and geomorphological aspects of this study make up the practical research component reported in this thesis.

The perceived problems that initiated the WRL research project in the Sand River catchment are a loss of wetland function and integrity. This indicates a lack in ability of the wetlands to perform the functions that characterise a wetland, and to sustain themselves as wetlands. This potentially leads to further problems, such as a lack of productivity of the wetlands and a consequent decrease in livelihood security for the communities that use the wetland, and a general decrease in catchment water security. Based on a broad overview of the catchment and some of the wetlands within it, and informal discussions with a few members of the community held in early 2003, preliminary assumptions made were that there has been an increase in desiccation and erosion, and a decrease in fertility of many of the wetlands in the Sand River catchment. Suggested reasons for these findings centred around the inherent properties of the soils of the catchment, a loss of on-site vegetation, a change in the flow regime of rivers in the catchment, poor management practices on plots within and outside of the wetlands, increased population pressure within the catchment, unregulated plot use and access, and a decline in governance in the area.

The hydrological research objectives of the WRL project and of the research reported herein, are to identify the role of the wetlands on the flow regime of the Sand River catchment, and to understand the related movement of water within the wetlands and the catchment in general. This follows a two-tiered approach of focussed study in a specific wetland, deemed to be typical of the wetlands of the catchment, as well as a broad catchment scale assessment of hydrological functions as explained more fully in Chapter 2. This knowledge will guide in the assessment of the likely effects of the management practices employed within wetland plots on the hydrology of the wetlands, and the potential effects that the hydrology of the wetlands has on the livelihoods of local community members.

1.2 Background to the Sand River Catchment Wetlands

The Sand River catchment lies in the northern part of the Sabie River catchment, and makes up a part of the Inkomati River System within the Mpumalanga and Limpopo Provinces, in the eastern Lowveld region of South Africa (see Figure 1.1). This area receives little, erratic rainfall of about 700mm annually, and is characterised by periodic droughts. It is thus an extremely vulnerable area in terms of water security. The catchment area spans 1910km^2, the central region of which is comprised of the former 'homelands' of the apartheid era (see Section 4.2), which includes Mhala

(Gazenkulu), and Mapulaneng (Lebowa) (Kotze, 2002). The upper reaches of the catchment include much degraded land and are becoming increasingly urbanised. This area also includes commercial and indigenous forestry (see Figure 1.2) and falls into a significantly higher rainfall area than the lower reaches do. The upper reaches thus contribute significantly to water production, but poor management practices have caused environmental degradation, highlighted by an invasion of riparian zones and wetlands by alien plants (Pollard, 2002). This catchment was selected as an area in which to implement the 'Wetland and Rural Livelihoods' project as a result of the perceived degradation of wetlands in the catchment, and the fact that this degradation potentially gives rise to socio-economic problems in the wetland areas, a large proportion of which occur within communal lands.

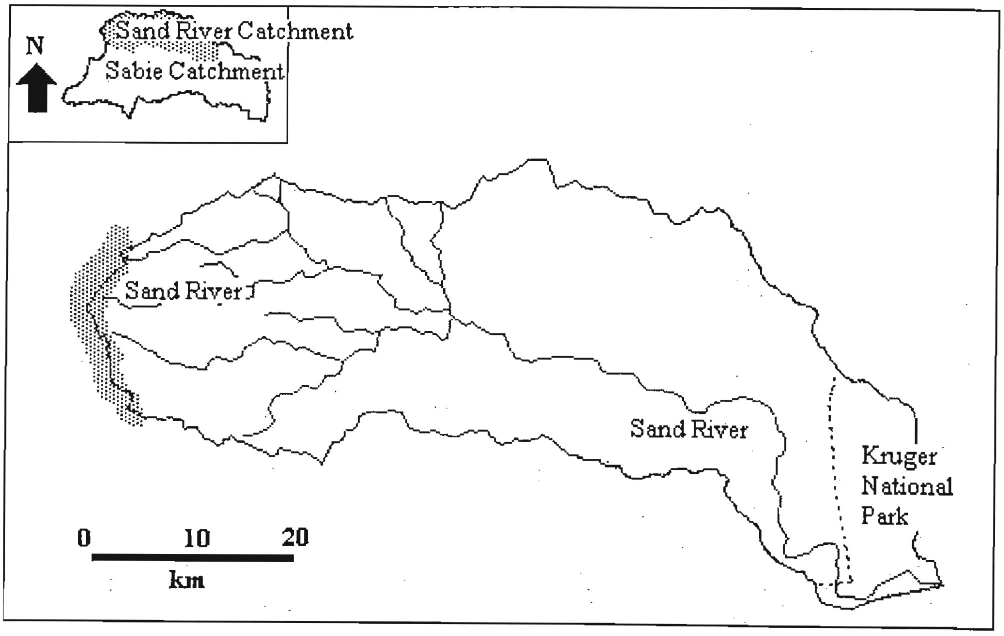


Figure 1.1 The location of the Sand River catchment (after Pollard, 2002)

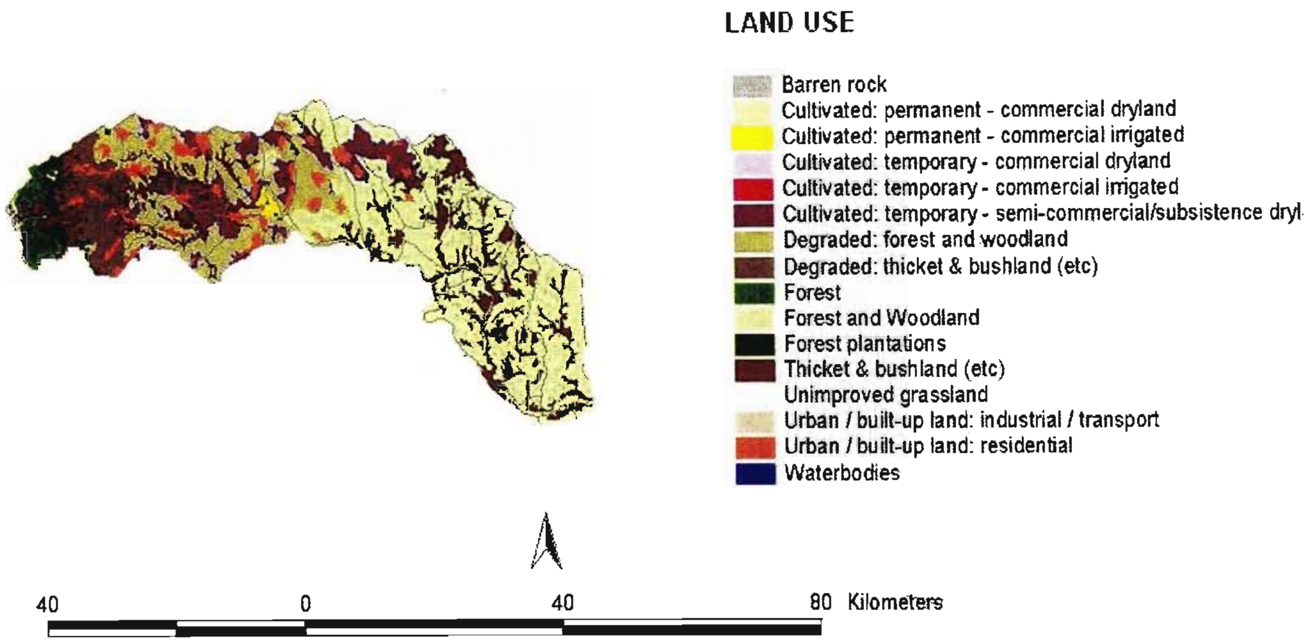


Figure 1.2 ISCW Sand River catchment land uses, as used by Schulze (1997)

A recent survey of the wetlands of the upper Sand and Klein Sand Rivers, undertaken by the Mondi Wetlands Project, indicated that they are far more extensive than previously estimated. The full extent of the wetlands was not identified previously, as a substantial area of these wetlands has been converted to subsistence agriculture (Pollard, 2002). Preliminary survey work performed in areas of the Sand River catchment by the WRL research team, centred on wetland users, indicated that the function and integrity of these wetlands are being progressively eroded, and it appeared that this can be attributed to a complex set of interrelated social and biophysical factors. Over and above the poor climatic and socio-economic conditions that typify the area, the catchment is dominated by granite-derived soils. The granitic rock forms part of the Archaean Basement Complex, upon which the sedimentary rocks of the Transvaal have been deposited. Soils produced by the granitic band of rocks are typically sodic, duplex soils that are prone to erosion. The preliminary overview of the wetlands of the area showed the soils to be coarse and sandy, indicating that they are easily drained and have low nutrient retention capabilities (see Figure 1.3). Continued erosion of the wetland soils could compromise local community water resources, thereby posing a threat to the livelihoods of local wetland users.

Figure 1.3 Headcut erosion in a wetland in the upper Sand River catchment, showing the sandy soil of the area

The overarching goal of the WRL research is to establish the links between wetland health, wetland hydrology and livelihood security for wetland users in the upper catchment of the Sand River, and provide recommendation for the maintenance and rehabilitation thereof. Preliminary work performed in the catchment has shown that over the past 15 years there have been significant reductions in baseflow of the Sand River. This is perceived to result from inappropriate forestry practices and wetland degradation as a result of their conversion to subsistence agriculture (Pollard, 2002). An investigation of this kind thus requires an understanding of the hydrological and biophysical characteristics of wetlands as well as an understanding of the importance of the wetlands in the lives of individual household members within the overall catchment.

The WRL project is loosely linked to a further, ongoing wetland rehabilitation project based in the Sand River catchment, under the auspices of Working for Wetlands. Working for Wetlands is a programme of the Department of Environmental Affairs and Tourism (DEAT) that has recently started to rehabilitate some of the wetlands in the Sand River catchment, but in a somewhat *ad hoc* manner. These projects could be of mutual benefit if project team members are able to capitalise on the research strengths of the WRL project, and the management and infrastructural implementation potential of the rehabilitation project. A broader and more integrated approach in which wetland rehabilitation is investigated in a broader catchment management context will benefit Working for Wetlands. In such a manner local understanding and management of resources and their rehabilitation can be improved, particularly in communal areas where land-use control is complex, institutions are weak and, in the case of the Sand River catchment, the lives of the local people are inextricably linked to the health of wetlands (Pollard *et al.*, 2002).

The objectives of this thesis, within the context of the 'Wetlands and Rural Livelihoods' research, include:

- understanding the biophysical role of the communal wetlands of the upper Sand River catchment, particularly in terms of water security;
- understanding the role of the communal wetlands of the upper Sand River catchment in the livelihoods of current wetland users, and most importantly,
- understanding the hydrological processes that occur within the wetlands of the Sand River catchment, and how these processes affect and are affected by the biophysiology of the catchment, and by the practices of the communities local to the wetlands.

1.3 Site Selection

In January 2003 a first visit to the Sand River catchment was made by those involved in the project, in order to establish a framework to guide the research, and to gain an initial understanding of the hydrological and geomorphological processes at play within the catchment, and within the wetlands specifically. Within this area a smaller section was identified as the area in which detailed geomorphological data collection could be performed, and within this area two small wetlands were identified in which detailed hydrological research was to be undertaken (see Figure 1.4). The Craigieburn microcatchment (see Figure 1.5), and the small, headwater wetland that makes up a large part thereof (see Figure 1.6), were identified as research areas that are both representative of the area, and of a size suitable to the WRL project, given the existing time and financial constraints. A small, riparian fringe wetland that has undergone considerably less degradation than the Craigieburn wetland was chosen as an appropriate wetland to study in order to compare its geomorphology and hydrology with those of the Craigieburn wetland, and is referred to as the 'control' wetland (see Figure 1.7).

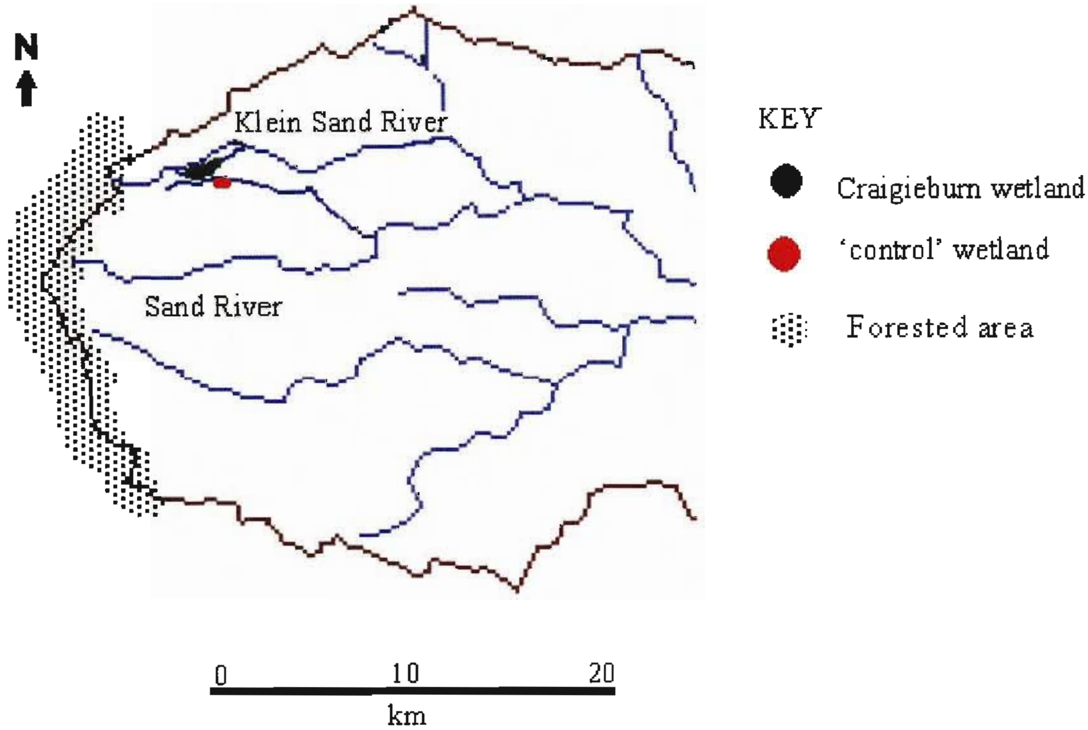


Figure 1.4 The respective positions of the Craigieburn and 'control' wetlands

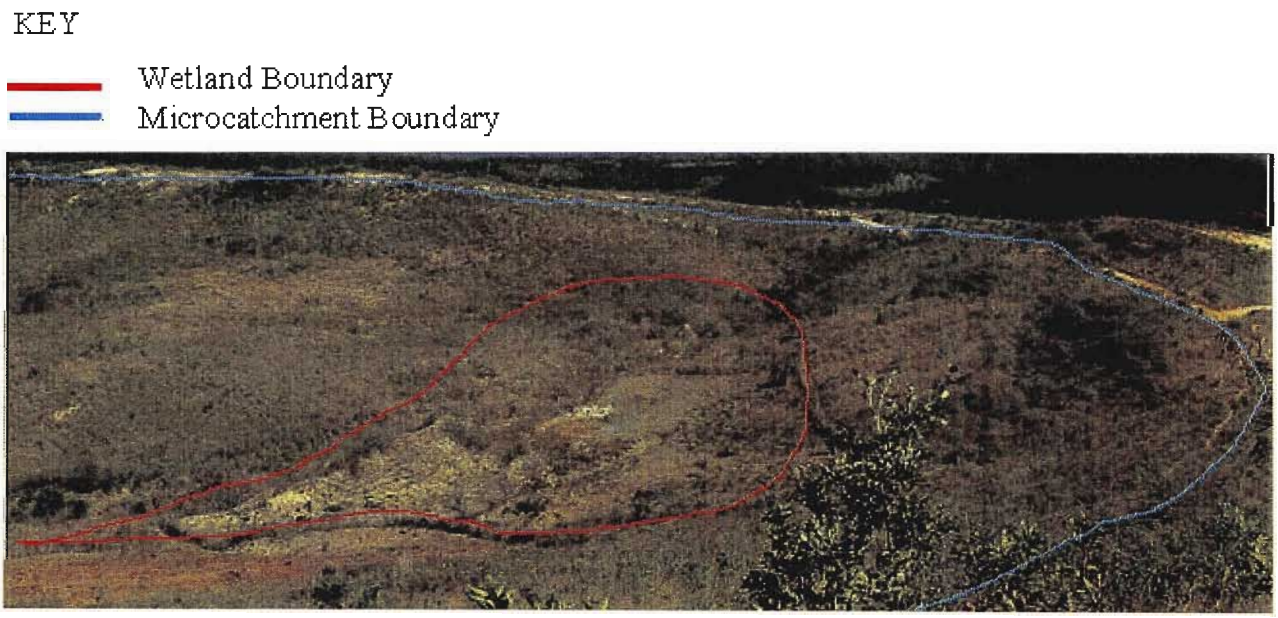


Figure 1.5 The Craigieburn microcatchment and wetland

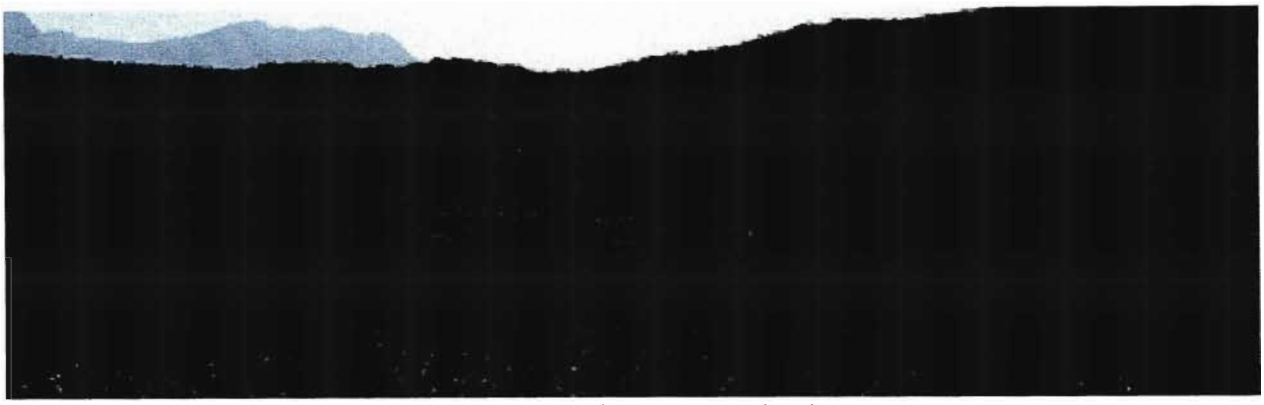


Figure 1.6 The Craigieburn wetland

Figure 1.7 The 'control' wetland

These small wetlands form the focus of the biophysical, sociological and hydrological research undertaken within the context of the WRL project. A further aspect was the consideration of the broader Sand River catchment scale role of such wetlands. A more detailed description of the methodology followed appears in Chapter 2. A review and description of the biophysical aspects of wetlands follows in Chapter 3, the sociological importance of wetlands are reviewed in Chapter 4, and Chapter 5 presents a detailed review of the uses of and background to hydrological and wetland modelling generally and in the context of this study. The results of the modelling exercises, and their significance in light of the geomorphological and sociological findings of this study are presented in Chapter 6, followed by conclusions drawn from these results and findings.

2. INTEGRATED WETLANDS RESEARCH METHODOLOGY AND DATA COLLECTION

As highlighted in Chapter 1, the perceived problem of a loss of integrity of the wetlands in the communal areas of the Sand River catchment is further perceived to lead to a lack of productivity and hydrological function of the wetlands. This, in turn, could lead to a decrease in catchment water security and livelihood sustainability. As highlighted in Section 1.2, the causative agents of these problems appear to be related to social problems, such as population pressure and the legacy of apartheid, as well as geomorphological problems, such as the inherent soil properties of the catchment. The methodology adopted in order to study the hydrological role of wetlands within this research project thus necessitated scope to incorporate the sociological and geomorphological aspects of the project, as these areas of research are inextricably linked in the context of the WRL project (see Figure 2.1). The hydrological, biophysical and sociological properties of the area surrounding a wetland greatly affect those of the wetland (Ellery, 2004), thus, although the focus of this study is the Craigieburn wetland, these aspects of the Craigieburn microcatchment have been investigated.

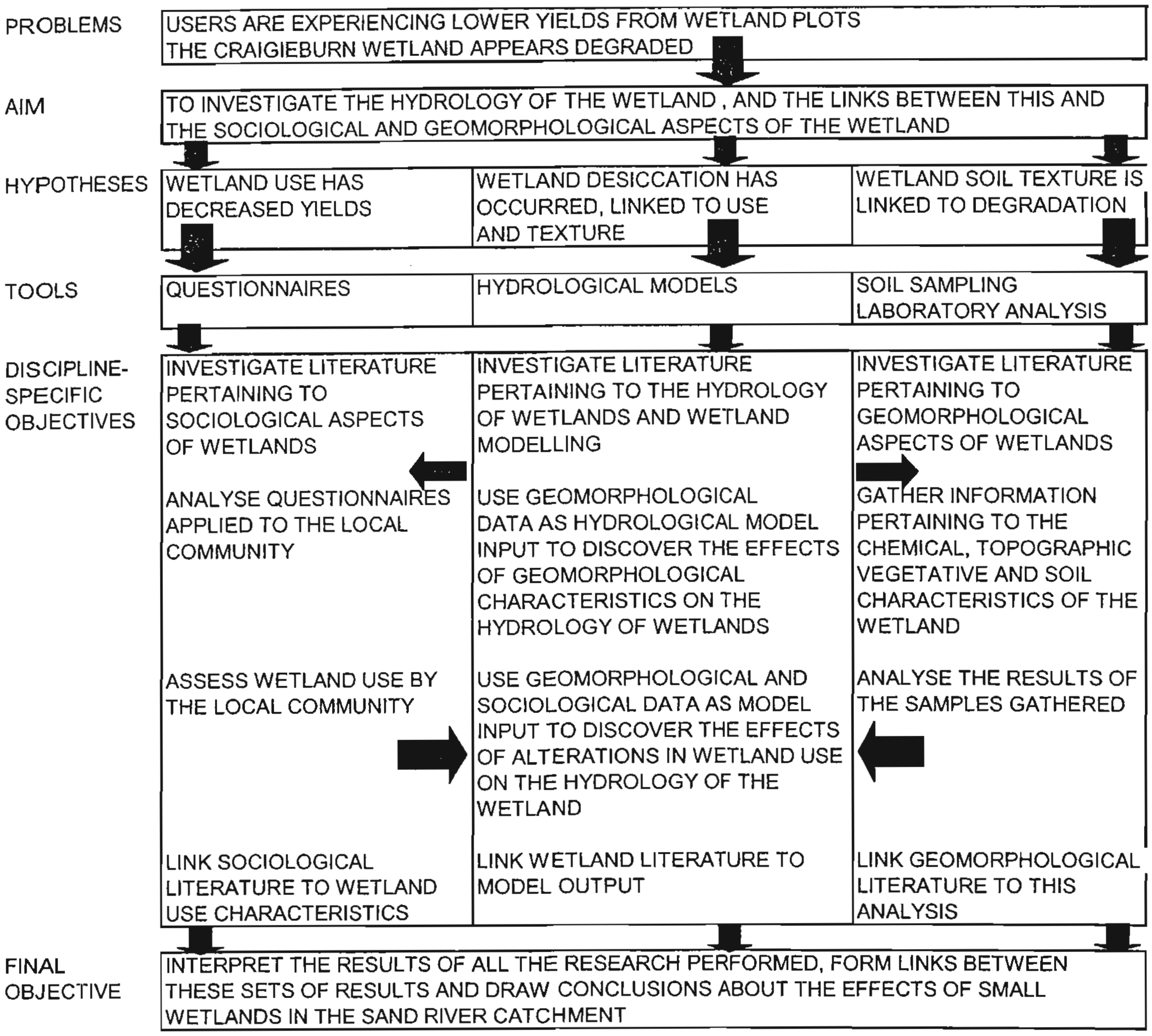


Figure 2.1 A diagrammatic representation of the methodology applied to this thesis

A broad, integrated and all-encompassing methodology that incorporates some features of Integrated Water Resource Management (IWRM) was adopted for the research reported in this thesis. This methodology remained flexible and adaptive throughout the research, data gathering and amalgamation processes, as new discoveries and links were made. The researchers involved in the WRL project adopted a range of research techniques, and the methodology for this study needed to encompass this range of techniques, such that the information gathered and approaches taken were applicable across all the disciplines. This was necessary in order that the data and information gathered in each area of the research could be used in all aspects of the research. In such a manner a truly integrated final product can be achieved.

Although data gathering could not be strictly discipline-specific, the gathering of sociological data was largely performed by qualitative means, including informal interviews and questionnaires (see Appendix 1). In order to make this data more applicable to the hydrological and biophysical aspects of the research, those more directly involved in these latter disciplines entered their own, specific questions into the questionnaires. These tended to pertain to notable trends in the wetness of the wetland soils.

Some of the biophysical information gathered in a quantitative manner, pertaining more directly to soil textures and signs of wetness in the soils, and rainfall and temperature records of the area, was relayed to members of the local communities, and in this way information pertaining to the separate sub-sections of the project fed into each other. Parallels were drawn between what these community members had observed in the past, and what characteristics of the soils, landforms and records indicated about the past. Ensuring a constant flow of information between the sub-sections, as depicted in Figure 2.1, and between the research team and the local community, proved important in order to clarify misunderstandings that arose and establish where differences in opinions lay. It was established early in the project that even the local community's definition of à wetland varied from that of the research team's, as elaborated upon in Section 3.1.

Difficulties likely to be incurred were identified through inspection of similar projects undertaken, and the lack of wetland-specific, small-scale hydrological models did pose problems. These are elaborated on later in this chapter.

2.1 Wetlands in the Context of Integrated Water Resource Management

Few guidelines are available for the management of wetlands in South Africa, although wetlands are recognised as being important and threatened habitats (Kotze *et al.*, 1994). IWRM is particularly applicable to wetland management, as it provides a broad framework for multi-disciplinary research (Dugan, 1990). IWRM is largely described as the coordinated and sustainable use and management of natural resources so as to balance resource utilisation and conservation, focussing primarily on the environmental aspects of sustainable development (de Souza *et al.*, 1995).

Many difficulties arise from research and management of wetlands and other water resources, as previous projects that adopt such an approach show. An IWRM approach has been adopted for research performed in the Mgeni catchment of KwaZulu-Natal, South Africa (Jewitt and Kotze, 1998), and provides lessons for the Sand River catchment study. The Mgeni project considered the principles of IWRM and stakeholder involvement, as well as those that guide the National Water Act (36 of 1998) (NWA, 1998), such as equity of resource distribution and redress of past inequities. Among the difficulties realised, and likely to be incurred in the Sand River catchment research, are those involving stakeholder participation when culture and value systems among stakeholders differ substantially. Even among those working in the Mgeni catchment that share similar cultural and value systems, differences in opinion hindered the research team's progress (Jewitt and Kotze, 1998).

An outcome of the Mgeni study that is also applicable to the Sand River catchment study is the realisation that local and regional wetland management initiatives need to be guided by national policies (Jewitt and Kotze, 1998). The researchers involved in the Mgeni project come from a variety of academic backgrounds, and are thus not accustomed to operating at the same research scales as one another. This potential problem is also applicable to the WRL project. Central to the findings of the Mgeni research is the impact of a policy or legislation on all aspects of the research (Jewitt and Kotze, 1998). This alerts one to the potential severity of the impact of environmental legislation on the members of the Sand River catchment community, and the effect that this may have on the use of the wetlands in the catchment.

A multi-disciplinary study based in the Mutshindudi River catchment in The Northern Province, South Africa (du Plessis, 2002) addresses similar issues to those of the Sand River catchment WRL Project. It comprised a sociological survey of the water needs and problems of a local community, and reviewed their use of riparian plants, agricultural demand, and the cultural importance of water. It also comprised a hydrological study of the area. The sociological study concluded that unsustainable rates of resource consumption have had a negative impact on the environment, and that this is threatening human survival in the area. The inhabitants of this catchment are impoverished, infrastructure in the region is very poor, water provision is unreliable and there is a general lack of sanitation. The survey shows that the riparian vegetation is overused, and that the community is aware of this. Such recognition can make implementation of rehabilitation programmes easier. The study as a whole emphasises the need for multi-disciplinary research in this field (du Plessis, 2002). Parallels can be drawn between this and the Sand River catchment study, as the wetlands in the Sand River catchment have been used in an unsustainable manner, inhabitants are poor, and there is again a need for research and rehabilitation plans that adopt a multi-disciplinary approach.

"The forces that oppose social change for sustainability ... are powerful, and isolated scientific disciplines will not suffice to change understanding and policy" (McMichael, 2003).

Projects elsewhere in the world that have adopted a multi-disciplinary approach to research are producing results that encourage such an approach. Five water supply projects undertaken by members of the Save the Sand project team were completed in 2001. The team adopted a multi-disciplinary approach to these developments, which have resulted in large-scale community involvement in the projects, increasing the sustainability of the projects (Pollard, 2002). A development project in the North-East of Brazil is causing water resources problems in this dry region. The climate, together with poor water resources management, has resulted in difficulties for the local population, not only owing to the water supply systems, but also to the agricultural practices in place. A research initiative has been implemented to analyse the vulnerability of this region to drought, in order to assess the potential of the area for a project based on the principles of sustainable development. In Brazil and other developing areas, politics plays a large role in the vulnerability of the area (de Souza *et al.*, 1995). The semiarid areas of Brazil are comparable with the Sand River catchment, as both are characterised by low rainfall and a poor local community with little infrastructure in the area, and are fraught by the political injustices of the past. The driest periods of the year in both cases increase the vulnerability of these regions to poor health. Previous studies in these semi-arid regions of Brazil have shown that it is necessary to apply policies of environmental protection in order to change the level of degradation in an area, and to increase the potential for sustainable development in the area (de Souza *et al.*, 1995).

Many development projects concentrate on one aspect of wetland value, while most wetlands supply a multitude thereof. Such projects can lead to a less integrated approach to developmental research, as such work requires a large amount of capital, manpower, technology and maintenance. Projects often require more sophisticated management than is available to local rural communities (Dugan, 1990). This is not to say that outsider intervention necessarily ensures sustainability, but this intervention is frequently a response to problems that have been unsuccessfully addressed from within the local community. The combined effort of researchers from a multitude of disciplines is therefore sometimes beneficial to project implementation. The Ramsar 'Wise Use of Wetlands' handbook identifies some steps toward wetland rehabilitation by project initiators external to the local community. These include supporting wetland conservation through capacity building and identifying and developing methodologies to address critical issues of the 21st century (Ramsar Convention Bureau, 2000). These needs are likely to be better met by a project team that integrates the wetland expertise from a number of disciplines.

An understanding of the social relations at play within the community in which research is based is paramount, as a lack of such understanding can precipitate the failure of a project. In rural areas of South Africa, in what are largely patriarchal communities, attempts to give rights to women will commonly oppose the inherent social norms of the communities, although such attempts may serve the needs of the project. 'Short-sightedness' on the part of the project implementers may lead to attempts to develop a rural area in the same manner in which urban areas are developed, as opposed to developing it in a manner that will complement the social practices at play in the area. Social relations need to be supported and members of a community need to feel in control of their environment, including the changes occurring. Thus a 'top-down' approach to project implementation cannot be adopted when addressing rural communities (Hall, 1998). The motivation to accomplish certain project objectives can take precedence over the aim to involve the local community in the project. Were community involvement to be achieved, a certain amount of monitoring of the project would need to be done after its implementation to ensure that structures put in place do fulfil the roles for which they were intended. This flies in the face of project objectives intended to support the nature of the society as it is at present. This provides a huge challenge, as policing of the community, even if the manpower and motivation to do so could be realised, is not in line with the intended objective of encouraging self-reliance (Hall, 1998).

Standard management models often prove inappropriate in underdeveloped, rural areas, owing to a lack of infrastructure, the traditional land tenure system, and difficulties in enforcing the legislation. A dependence on natural riparian vegetation for food, energy and medicinal purposes, shelter and other uses makes these areas unique, thus programmes implemented in underdeveloped, rural areas need to be unique. Appropriate water management policies for underdeveloped rural areas and for the development of local expertise are essential (du Plessis, 2002). Many factors reinforce each other to add to the degradation of the wetlands in the communal lands of the Sand River catchment. The sociological dimensions of these wetlands make them more complex systems than those on private lands or in protected areas, reinforcing the importance of understanding the sociological, economic, geomorphological and hydrological links between wetlands (Pollard, 2002). A shortage of experts in the field of wetland research, and shortages in the disciplines that link wetlands to their environments is a further problem (Dugan, 1990; Bergkamp, 1998; Swanson, 2004). Rural communities dependent on natural resources are often among the poorest members of society, thus despite an understanding of the resource and misuse thereof, incentives are necessary to encourage wiser use. Research and project implementation needs to be performed in conjunction with the local community (Silvius *et al.*, 2000).

Without an adequate legal system in place, community-based natural resource management is less likely to be successful. In South Africa an ongoing government initiative has been the provision of basic water supply services to ensure that all individuals have access to 25 litres of safe drinking water per day. Millions of rands have been committed to this initiative, yet in many areas the supply of the water has not been reliable. In such circumstances, many communities have withheld payment that had been negotiated when such projects were initiated (Mutume, 2004). Infrastructure maintenance and community education, management and participation need to become the focus of future water programmes in rural areas (Lubambo, 2001). According to the local community in the Sand River catchment, water is piped to most of the houses, but the pipes do dry up and water has to be extracted in buckets from the surrounding rivers. Many local Sand River catchment community members do not receive the legal minimum water and sanitation standards (Kotze, 2002).

A lack of understanding of the nature of local communities held by project implementers is not uncommon, as many communities in which attempts have been made to supply basic levels of water and sanitation have already had their basic needs met and require a higher level of service than these projects intended. The more successful projects are those implemented in areas in which there is the greatest need for water resources (du Plessis, 1998b), and the Sand River catchment can be categorised as such an area. An assumption made in many such cases that is usually proved inaccurate is that rural communities are homogenous, and that their needs are therefore similar. Suggested methods of combating this problem include attempts to perform more in-depth studies in the communities in question to better understand the dynamics of the specific community (du Plessis, 1998b). The research methodology behind the sociological data collection of the Sand River catchment community aims to do just this. It thus comprises in-depth interviews and meetings with local community members, and aims to successfully inform the local community of the presence and intentions of the research team.

Although there are many examples of studies of wetland degradation and potential rehabilitation, these tend to largely focus on the sociological, ecological and, to a lesser degree, geomorphological aspects of wetland research. Although the important hydrological buffering functions that wetlands play in the natural environment are widely recognised, deeming wetland hydrology essential to understanding the functions of and processes occurring in wetlands (Cater *et al.*, 1979; Bullock and Acreman, 2003), the lack of understanding of processes occurring in southern African wetlands is highlighted by contradictions in wetland-related literature (Smithers and Schulze, 1993; Maltby *et al.*, 2000). Wetland research has increased considerably internationally since the 1970s (Dugan, 1990; Silvius *et al.*, 2000), yet minimal literature that pertains explicitly to the hydrology of wetlands, and, more importantly to this project, to modelling of wetlands exists.

2.2 The Sand River Wetlands Project Research Methodology

Throughout every phase of research pertaining to the wetlands of the Sand River catchment for the purpose of this thesis, the overarching intention was to establish links between the functioning of the wetlands and the livelihoods of the local community members. A methodology that could encompass this aim was thus sought, as depicted in Figure 2.1. Each component of this study adopts both quantitative and qualitative research methods, although the sociological research is more qualitative, and the biophysical research is strongly quantitative. Besides research, the sociological component of the WRL project also plays a role as the means of interaction between the project team members and the community structures and wetland users.

Detailed data have been collected for the purpose of this study at the scale of the Craigieburn microcatchment. The hydrological modelling exercise performed at the scale of the Sand River catchment utilises data collected for a previous study. As the focus of this study is aimed at the scale of the microcatchment, the sociological and geomorphological data collected and information gathered at this scale can thus be directly compared to the hydrological data collected and findings made at this scale.

2.2.1 Linking the sociology and geomorphology to the hydrology of the microcatchment

As highlighted in Figure 2.1, one of the major aims of this study is to investigate the links between the hydrology and the sociology and geomorphology of the Craigieburn microcatchment and wetland. Implementation of a long-term rehabilitation and management plan involving communities, a long term aim of the WRL project, requires discipline-integrated research and an understanding of the links that exist between these social and institutional factors, and with the hydrological and biophysical characteristics.

As the hydrology of the Sand River catchment is inextricably linked to the geomorphology of the catchment and the sociological norms and practices of the local communities, alterations present in any of these spheres is likely to result in an alteration in the others. As the hydrology of the Craigieburn microcatchment is the major focus of this study, and detailed geomorphological and sociological data was collected for this study at the scale of the Craigieburn microcatchment, the likely effects of changes in the land use practices and geomorphological characteristics of the microcatchment on the hydrology of the microcatchment form the major part of the practical research undertaken for this study. As becomes more apparent in Chapter 6, a change in the geomorphology and sociology of the microcatchment is likely to precipitate a change in the hydrology of the microcatchment, which, in turn, is likely to precipitate further changes in the sociology and geomorphology of the microcatchment.

When making decisions pertaining to water resource development, particularly when there are substantial conflicts between interest groups, a scenario-based approach may be useful (du Plessis, 1998a). Scenario-based simulations using hydrological models were identified as a tool for the hydrological research component of this project, to gain insight into the effects that changes in land use may have on the hydrology of the wetlands. When adopting such an approach, the level of detail should be sufficient at each step of the process to allow those involved to compare and distinguish between the scenarios (du Plessis, 1998a), and for the purpose of this research, the procedure is also required to remain consistent with the concepts of IWRM at each step.

2.2.2 Investigating the hydrology of the microcatchment

As Figure 2.1 shows, the other major aim of this study is to investigate the hydrology of the Craigieburn microcatchment and wetland in depth. In order to address the hydrological concerns regarding wetland degradation, a number of hydrological and hillslope soil water models have been investigated for the purpose of simulating the functioning of the Sand River catchment wetlands. The methodology adopted for the hydrological modelling component of the study followed a three-tiered approach (see Figure 2.2) in order to meet the hydrological objectives outlined in Figure 2.1. This approach included;

1. A point-scale water balance study for different land uses on different soils
2. A microcatchment scale modelling exercise to investigate changes in land use and wetland degradation, and
3. A Sand River catchment scale modelling exercise to investigate the potential changes arising from wetland degradation in the upper reaches of the Sand River catchment.

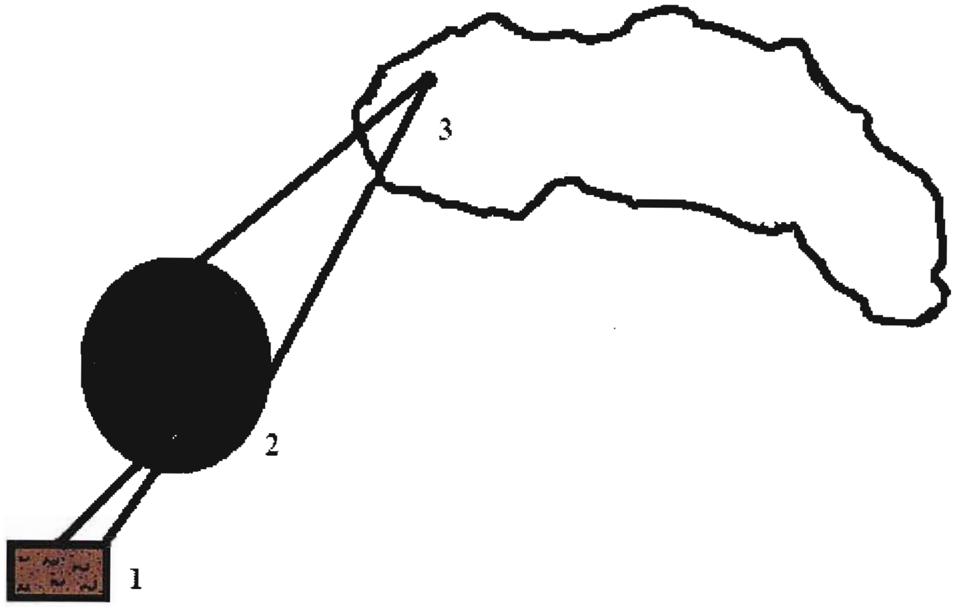


Figure 2.2 The scales at which the WRL hydrological modelling exercises focus

During the course of this study several hydrological models that contain a wetland component, and models designed for riparian areas have been investigated. Based on the processes represented in these models, an understanding of wetland hydrological functions gleaned from wetland literature, and a 'feeling' for the processes at play within the Craigieburn and surrounding wetlands specifically, these wetlands have been modelled. Possible effects of scenarios affecting the composition of these small wetlands, and the likely effects these differences will have on the local community have been investigated.

In order to establish the combined effect of all the small wetlands of the Sand River catchment on the hydrology of the catchment, an existing configuration of the Sand River catchment that does not include wetlands in its make up, made and used within the *ACRU* model, was adopted. This original scenario was run, and streamflow values were obtained from the outlet of the final subcatchment making up the Sand River catchment, as explained more fully in Section 5.2.

2.3 Craigieburn Microcatchment Data Collection

Although some of the data collection performed for the purpose of the 'Wetlands and Rural Livelihoods' project and for this thesis was straightforward and discipline-specific, much of it, more specifically the qualitative data, required carefully considered, flexible collection methods. Much of the qualitative data collected was useful from a sociological, a geomorphological and from a hydrological perspective, and was very useful in terms of establishing links between these aspects of the research.

2.3.1 Sociological data collection

Sociological data collection was performed through a series of group and household meetings with members of the WRL research team. Of the three categories of data collection, this was the category fraught with the most difficulties. This is typified by a meeting held between members of the WRL research team and a neighbourhood group from one of the local wetland communities in May 2003. A contact the project team had established from the Community Development Forum (CDF) enabled some members of the research team to meet some of the Craigieburn wetland users. The meeting began with the facilitators explaining the objectives of the overall project, the process followed thus far, and the purpose of the meeting. A community member questioned whether the project had proceeded through the correct structures, as the local people had not yet been informed by any local group of the wetland project. The facilitators informed the group that a meeting had been held with members of the CDF and other community organisations, and that the CDF had indicated that a general community meeting would be necessary to inform the community of the project, but that they were satisfied that informal interviews with farmers could proceed prior to this. It was further mentioned that the *induna* had been informed of the project, but was unable to attend owing to his ill health.

Some of the members of the group were still not satisfied that the meeting could proceed, and an individual mentioned that farmers cultivating in the wetland had not yet met as a group, thus he was anxious that farmers may sign agreements without the knowledge of the other farmers. It was emphasised that this was not the intention of the project, but some members of the group maintained that approval was required from the CDF. It was thus agreed that the meeting would not continue, but that informal discussion would. After an informal discussion the women in the group indicated that they were satisfied that the meeting could formally proceed. Following this, further questions were raised expressing concerns that an intention of the investigation was to fence off and make people move out of the wetlands. These suspicions were refuted, and the meeting proceeded successfully. Discussions centered on changes in the wetland noted by the local community, freedom of access to and use of wetland plots and resources, and crafts made from reeds collected from the wetland were held. It is not the intention of the research reported herein to fully investigate the livelihood strategies of these communities – this is the task of other members of the project team. Rather it is the goal of this study to highlight the linkages between these and the hydrological functioning of the wetlands. The outcomes of discussions held with community members that are applicable to this study are presented in Section 6.3.

In September 2003 further sociological data was collected (see Appendix 1). Wetland use mapping was performed in order to establish the demographics of the households present in the community, the degree to which the wetlands in the area are important to the community members' livelihoods, and at which places within the wetlands various wetland resources are being made use of. Initially a large map was constructed, upon which the community members indicated where their houses, wetland fields and non-wetlands fields could be located, and where else they collected reeds (see Figure 2.3). It was further established how large the households of the members present were, and into which wealth category they fell. These were designated according to amount and reliability of income sources. It was established who, among the community members present, harvest reeds and agricultural produce on their own plots, and how many plots each member or household has access to. The kinds of crops that are harvested, amounts of each type, and success of these crops over the years and seasons were also questioned in order to gain an idea of the more recent agricultural history of the area from the viewpoint of the wetland users (see Table 2.1). These responses generated a clearer understanding of the role of the wetland in these local community members' lives, and those applicable to this study have been captured in Section 6.3.

Table 2.1 An example of the sociological data collected pertaining to wetland use

Field Categories (FC)			**Wealth Category (WC)**	
1	Have fields and do no harvesting		1	Barely any income
2	Have fields and harvest for domestic purposes		2	Intermittent income
3	Have fields and sell the harvested material		3	Household receives a grant
4	Do not have fields, but sell reeds		4	Formal employment
5	Do not have fields and do not sell reeds			
			s= small	
Reed Harvest (RH)			m=medium	
1	Within own field		l=large	
2	In common property area			
No.= Number of members of household				

			Wetland Fields			Non-wetland Fields			RH	WC	Number of Animals		
ID	**No.**	**FC**	s	m	l	s	m	l			Cows	Goats	Pigs
1	8	1		1			1		0	3	3	2	
2	5	1		1			1		0	3			
3	10	1		1			1		0	3			
4	7	2	1					1	2	1	2	2	
5	2	2	1					1	1	2			
6	4	2						1	1 + 2	2	6	6	3
7	12	3	1	1				1	1	3			
8	5	1	1						0	4			
9	9	1						1	0	3	2		
10	10	1		1			1		0	1			

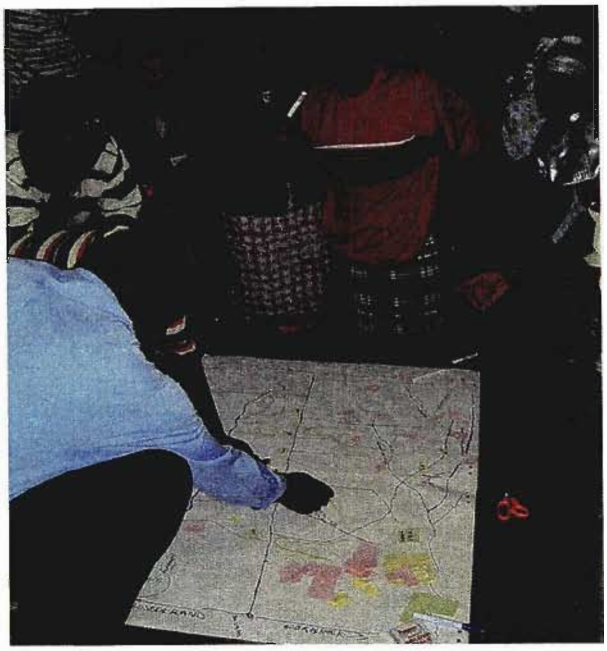


Figure 2.3 A group meeting centred on wetland use mapping

2.3.2 Geomorphological data collection

The majority of the geomorphological data was collected using conventional quantitative methods, however informal interviews with local community members pertaining to the current and previous functioning and health of the wetlands were also of value to the geomorphological assessment of the wetlands. These aided early formulation of geomorphological hypotheses, and gave an initial indication of how the geomorphology of the area influences the lives of the local community members. During a visit to the catchment in January of 2003, it became increasingly plausible that wetland degradation had occurred. The sandiness of the wetland soils and a large erosion donga (hollow) present at the outlet to the Craigieburn wetland stood out. The point at which the donga begins is referred to as the 'nick point' (see Figure 2.4). The extent of this donga emphasised the vulnerability of the wetlands of the catchment to erosion. Also evident was a lack of structures or projects in place to counteract this degradation. This indicated a lack of governmental and infrastructural resources in the area, and highlighted the financial impoverishment of the area. One community member pointed out that management decisions are made 'on the basis of starvation'.

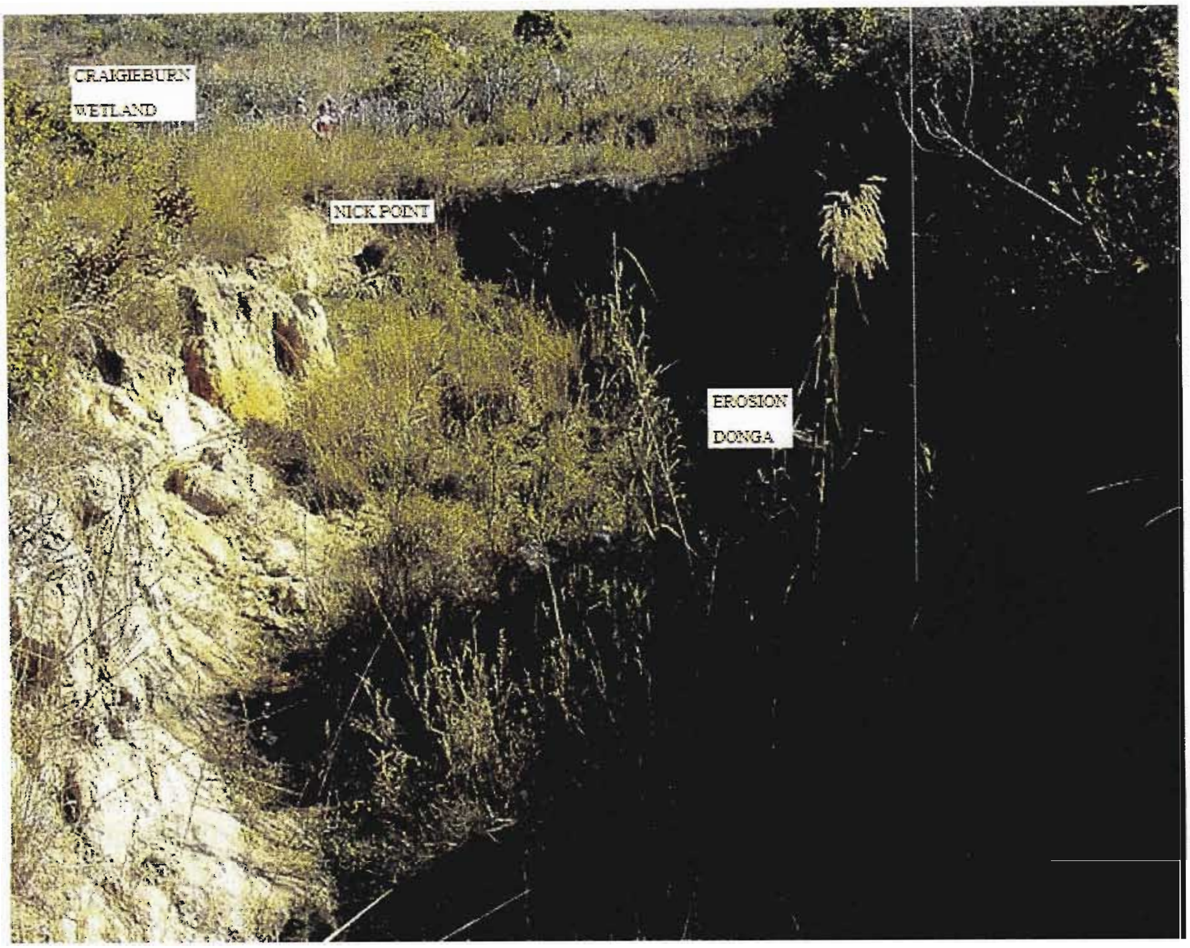


Figure 2.4 The erosion donga at the outlet of the Craigieburn wetland

In July 2003 the longest and most intense geomorphological data collection took place in conjunction with Geography Honours students from The University of KwaZulu-Natal. This included collection of topographic survey data for the Craigieburn microcatchment and the area downstream of the headwater wetland making up a large portion of the microcatchment. Vegetative analyses within the Craigieburn wetland (see Figure 2.5) provided an initial aboveground indication of where soil forms change, making establishment of the extent of the wetland on the basis of soil characteristics easier. A systematic sampling method was used for all the data collected, which involved locating sampling points at fixed, regular intervals. Lines perpendicular to the slope (transects) were plotted and surveyed (see Figure 2.6), along which samples of soil and vegetation composition were taken. These transects were evenly spaced through the wetland (see Figure 2.7). The main purpose of this method is for use in situations where change in vegetation, which commonly correlates with change in soil, is directional, such that maximum variation over the shortest distance can be described, and sampling can be performed in minimal time (Ellery, 2004).

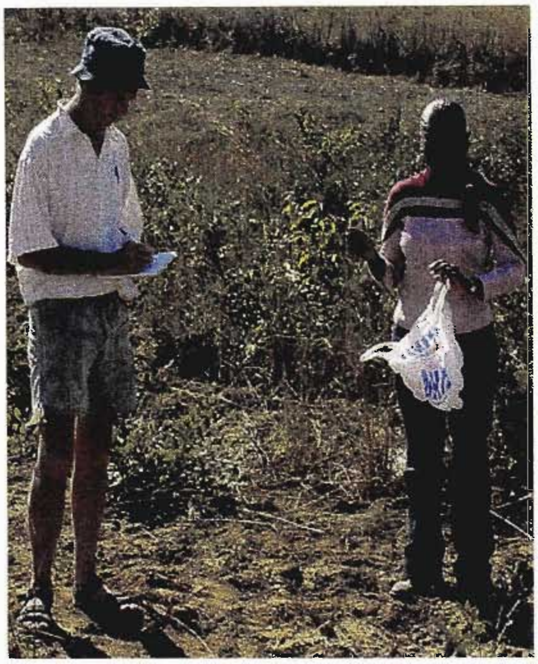


Figure 2.5 Craigieburn wetland vegetation collection

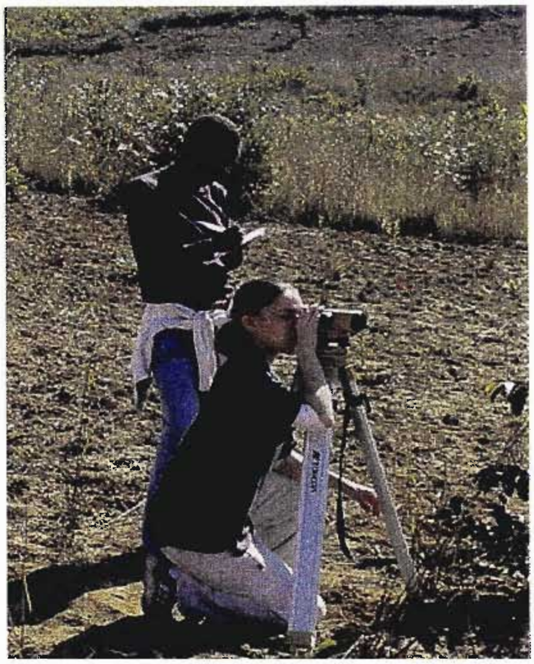


Figure 2.6 Craigieburn wetland topographic survey

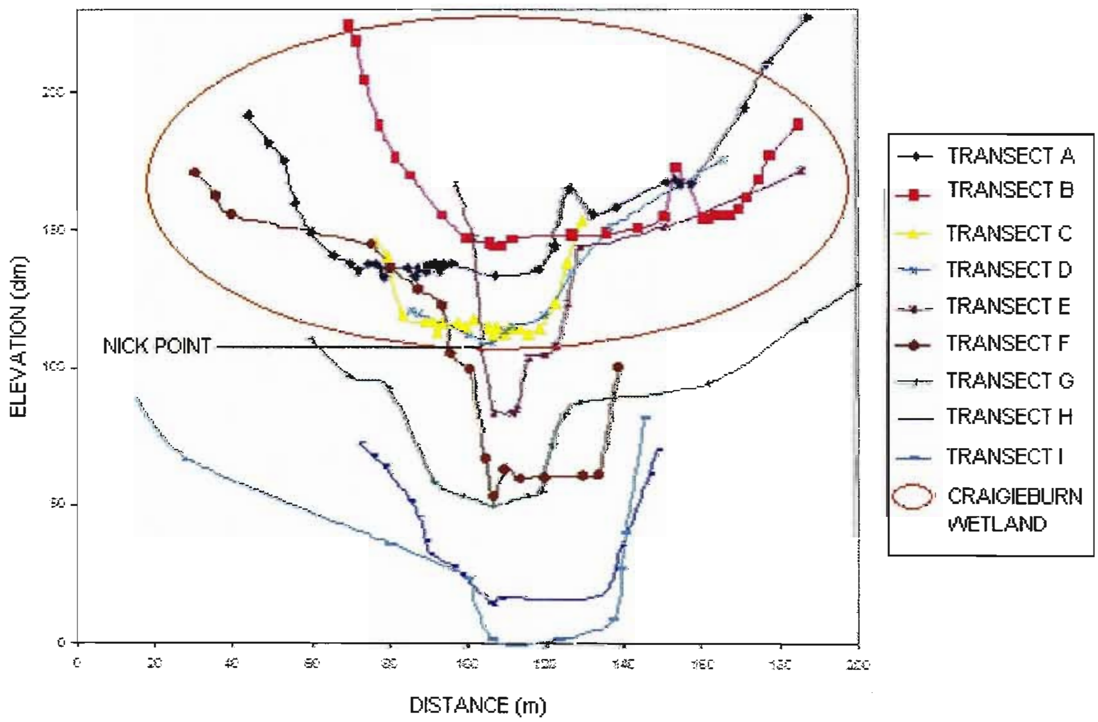


Figure 2.7 Cross sectional profiles of the Craigieburn wetland and downstream area

Sample plots along each transect line were surveyed, using a dumpy level and staff to measure the elevation of the plots along the transects, and each transect was surveyed relative to the other transects in order to obtain the relative elevations of the transect lines.

2.3.3 Hydrological data collection

Data collected pertaining to the hydrological aspects of the wetlands was both quantitative and qualitative. Climatic data was collected as input into the models selected to model the Craigieburn microcatchment and wetland and the 'control' wetland, and the views expressed by community members relating to the climatic history of the area was documented. Visits to the wetlands were made to confirm their current hydrological condition, and to generally gauge the wetness, textures and depths of the soils of the area. This information lead to initial assumptions made about the composition of these wetland areas. Evidence of previous hydrological conditions and occurrences was noted and initial hypotheses were formulated. Damage to the gauging network within the Sand River catchment, caused by the floods of February 2000, has prevented the extension of the existing rainfall records.

Quantitative data necessary to run the hydrological models include rainfall data. Nine rain gauges, set up by the South African Weather Bureau at various times in the past century, were identified in the vicinity of the Craigieburn wetland (see Appendix 2). The best rain gauge for use for the modelling component of this thesis was decided upon based on proximity to the Craigieburn wetland, and length and quality of the data set. Based on these criteria the 'Wales' rain gauge (0594819W) was chosen to run all the hydrological models investigated (see Figure 2.8). Good quality data was available from 1950 to mid-2000 at this site (see Appendix 3). This rainfall record shows that the Craigieburn microcatchment falls into a dry area that receives erratic rainfall. The Mean Annual Precipitation (MAP) received at the 'Wales' raingauge is 700mm. The total rainfall received for 1982, displayed in Figure 2.8, is 727.8mm. This microcatchment falls into a summer rainfall region of South Africa, in which the wettest month on average is January, but is not infrequently February. The driest month on average is June, in which very little rainfall is experienced, and no rainfall at all is not uncommon.

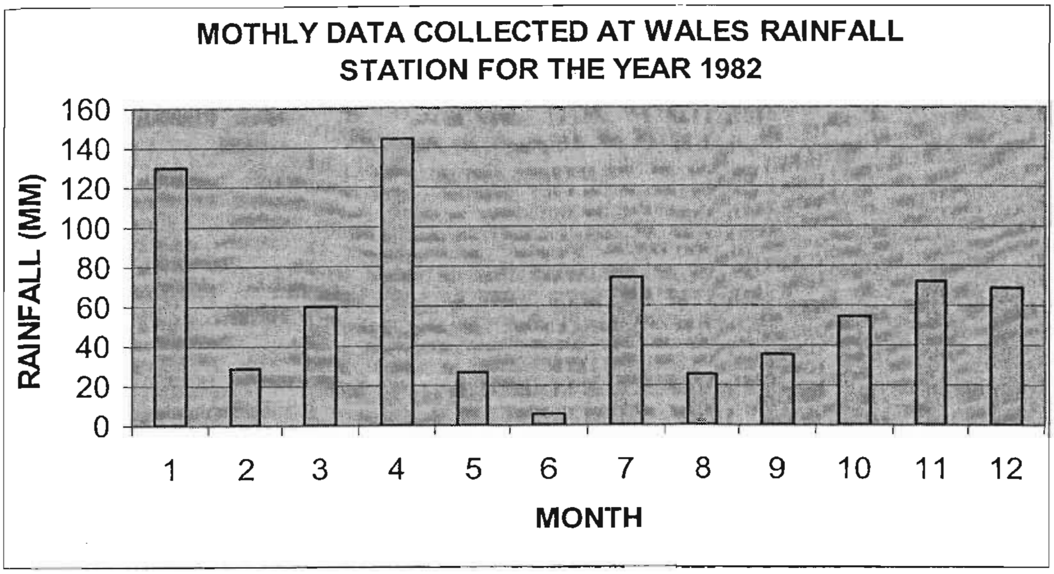


Figure 2.8 Values of monthly rainfall data collected at the 'Wales' rainfall station for the year 1982

Notable hydrological events considered significant by the Craigieburn micrcatchment wetland users include a drought in 1992 and a flood in February/March of 2000. The rainfall records collected at the 'Wales' rain gauge provide evidence of these events. The total rainfall received between January and May of 1992 was 208.5mm, and an average value for this time is about 400mm, yet rainfall increased in the latter months such that the annual total was a more representative 752.7mm. In February and March of 2000, 719.2mm and 512.9mm, respectively, fell in this area, highlighting the degree to which rainfall did deviate form the norm in these months.

Further climatic data for the same area, within the same time frame, were obtained using the 'Gridded Daily Temperatures for Southern Africa' database (Schulze and Maharaj, 2003). This programme requires the latitude and longitude values for the position of the area in question, and provides daily maximum and minimum temperature data records for stations close to these positional values. In such a manner the most applicable maximum and minimum temperature data for the period 1950 to 2000 was obtained close to the Craigieburn wetland (see Appendix 4). This data set shows that this area experiences typically hot summers in which mean annual Summer temperatures range between 26-31 degrees Celcius, and temperate winters that seldom fall below 10 degrees Celcius.

Further climatic data, such as evaporation and transpiration, are necessary inputs into models investigated within this research, such as the HYDRUS-2D model (Poeter, 2003). The *ACRU* model (Schulze, 1995) produces evaporation and transpiration values as output, using the input values of maximum and minimum temperature to calculate these values. Further data used as input into the *ACRU* model were obtained from the applicable sub-sections in the *ACRU* User Manual (Smithers and Schulze, 1995a), from the *ACRU* Theory Manual (Schulze, 1995), as elaborated on in Section 5.1.4, and from The South African Atlas of Agrohydrology and Climatology (Schulze, 1997).

Qualitative hydrologically related data were gathered from visits to the Craigieburn microcatchment, yet the comments, stories and opinions of the local community members served as input into all three major sections of this project.

2.3.4 Land use and soil data collection

Land use and soil data collected made up a large part of the hydrological, geomorphological and sociological data collected. The land use areas and the soil forms upon which they were simulated within various modelling exercises formed core input data into the *ACRU* model simulations, and the land use areas and soil forms are both influenced by and influence the geomorphology and sociology of the area, as highlighted in Chapter 6.

Soil texture information was gathered from lab analyses performed on the numerous soil samples collected from the microcatchment, from visits to the site, and from soil maps of the area (Schulze, 1997). Some information used to formulate initial hypotheses involving the soil properties was also gathered using 'at-site' soil texture testing methods, which have proven to be within a few percent of lab analysis data in past research (Bester, 2003). These included grinding the soil between ones front teeth, and rolling the soil samples into cylindrical segments, and bending these into rings (Hillel, 1998).

To gather soil samples from the microcatchment, soil sample plots were located along the established transect lines, and major divisions were made primarily on the basis of differences in soil colour and form, and structure of the vegetation. Soil samples were collected using an auger (see Figure 2.9), and taken at 0-10cm, 40-50cm and 70-80cm below the soil surface. For each sample, signs of wetness, such as the degree of mottling evident (see Section 3.3) were noted. A detailed laboratory soil texture analysis was later performed on each sample at 0-10cm and 40-50cm depths, and recorded according to the percentage composition of soil particle sizes found at each depth. Soil textures could thus be classified according to the respective percentages of sand, silt and clay present in each sample (see Appendix 5). The soil extracted at 70-80cm below the soil surface was examined for signs of wetness, in order to better gauge the movement of water through the profiles and down the slopes. Each sample was then sent to a laboratory for X-Ray Fluorescence (XRF) analysis, and this provided the elemental composition of the soil (see Appendix 6).

Figure 2.9 Soil sample collection, performed with an auger

The land use data selected to investigate the hydrological effects of the major land uses identified in the Craigieburn microcatchment at a point scale and at the scale of the microcatchment were obtained from the options specified within the *ACRU* model decision support tools. Data pertaining to the vegetative and hydrological properties of these land uses are contained within these tools.

As the WRL project is loosely linked to a 'Working for Wetlands' project based in the Sand River catchment wetlands, acquisition of some resources, including aerial photographs of the Craigieburn microcatchment taken in previous years, was made easier. Data collected and used for the WRL study thus included aerial photographs taken of the microcatchment in the years 1954, 1965, 1974, 1984 and 1997. These photographs were an essential part of the microcatchment scale modelling study, performed to investigate the potential effects of changes in land use on the hydrology of the microcatchment. From these photographs it was possible to determine the respective sizes of the land use areas present in the Craigieburn microcatchment in the past. Geographic Information System (GIS) images of these land use areas for the years mentioned are presented in Section 5.1.4.10, an example of which is presented below (see Figure 2.10)

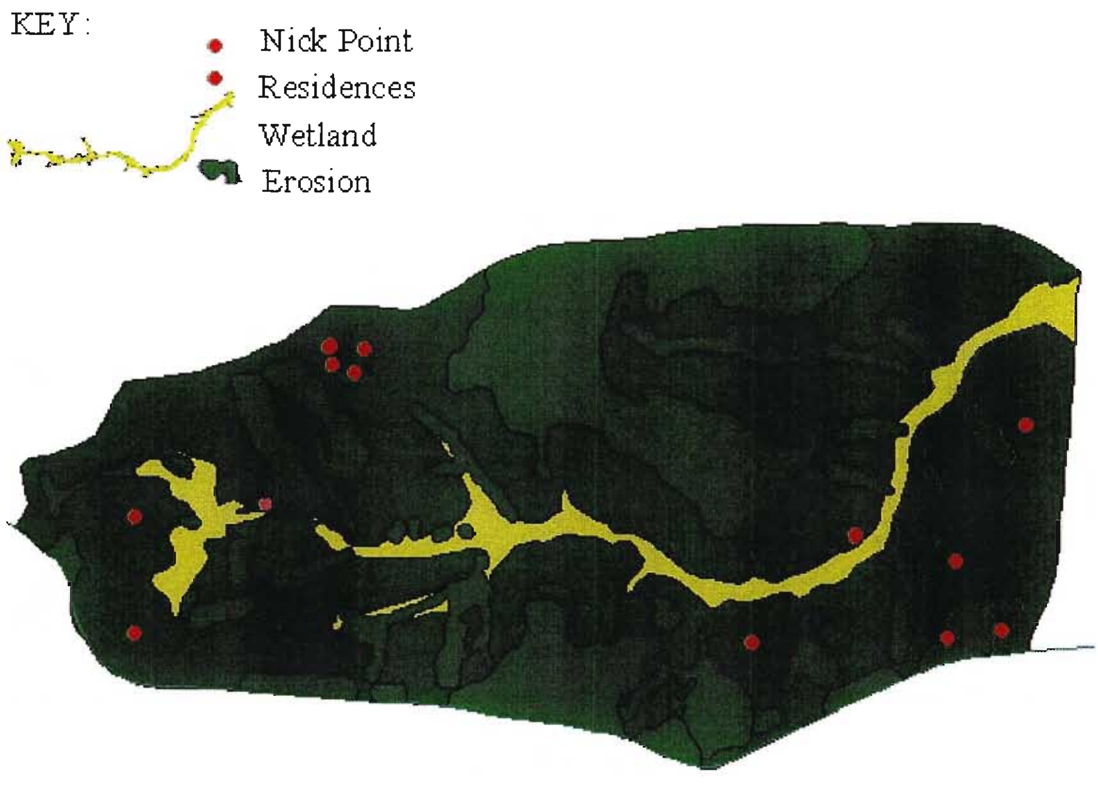


Figure 2.10 A GIS image of land use areas in the Craigieburn microcatchment in 1954

In order to comprehensively understand the simulated processes involved in the wetland modelling exercises, and thus make inferences about changes in hydrological output with varying geomorphological input variables, the composition, processes and functions associated with wetlands were first extensively researched.

3. THE BIOPHYSIOLOGY OF WETLANDS

The biophysiology of wetlands is complex, incorporating aspects of soil depth and texture, slope, vegetation and climate, as well as anthropogenic impacts. Wetlands are not homogenous, making the study thereof even more complex. This makes identifying and defining wetlands a very important initial step (Kence, 1995).

3.1 Wetland Definitions

'The word 'wetland' does not even appear in dictionaries' (Maltby, 1986).

In order to pool South Africa's human resources to conserve and better utilise its wetlands, it is important that those involved have a common understanding of what defines the resource under discussion. According to the Ramsar guidelines, 'a wetland' is a term for an ecosystem whose formation, processes and characteristics have been dominated by water (see Figure 3.1). A wetland area is an area wet enough to have specifically adapted vegetation, and characteristically waterlogged soils. The differences in opinion about what a wetland is have led to the degradation of some wetland areas. Wetlands are young, dynamic landscape forms, thus many are physically unstable, changing over seasons and even individual events as vegetation, sediments, and landforms change (Ramsar Convention Bureau, 2000). In 2003 most dictionaries did have at least a brief definition of a wetland. Sources do not provide the same definition, however, and many dictionaries simply describe a wetland as 'a low area where the land is saturated with water' (Encarta, 2003; Merriam-Webster, 2003; Wordsmyth, 2003; Cambridge, 2003). The South African National Water Act (NWA, 1998) defines wetlands as; 'land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil'.

A discussion held with local Sand River catchment community members based on their general understanding of the term 'wetland' showed that these members' understanding of what a wetland is varies from that defined in the South African National Water Act. The community concluded that what the research team had identified as the Craigieburn wetland was not, in fact, a wetland at all. The word used by the local farmers when describing a wetland is '*hlakaze*'. The community defined a wetland as an area that is permanently waterlogged, through which a river constantly flows, upon the banks of which reeds (*Leshago*) grow, where the vegetation looks different and continues to be green much later than in other areas, and where cattle often have difficultly walking. This description excludes the drier end of the continuum included in the RAMSAR scientifically defined wetland, which is an area wet enough to have specifically adapted vegetation, and characteristically waterlogged soils (Ramsar Convention Bureau, 2000).

As wetlands are by no means homogenous, wetland classification systems are necessary to simplify wetland management. For this reason, Kotze *et al.*, (1994) developed a classification system called WETLAND-USE for the KwaZulu-Natal Midlands to rationalise management and land-use allocations within wetlands. It uses information derived from previous management, land use and nature conservation practices. This classification system utilises hydrological data and soil maps in combination with vegetation maps of the area to identify wetlands. The wetland soil criteria used within this system are the identification of gleyed soils and soils of a low chroma, and the extent of mottling of the soils. These are the soil characteristics that the WRL researchers used to delineate the Craigieburn and 'control' wetlands. Further input required for the WETLAND-USE classification system is information pertaining to the surface flow characteristics of the wetland, and the potential downstream significance of the wetland. The ecological importance of the wetland is also accounted for (Kotze *et al.*, 1994).

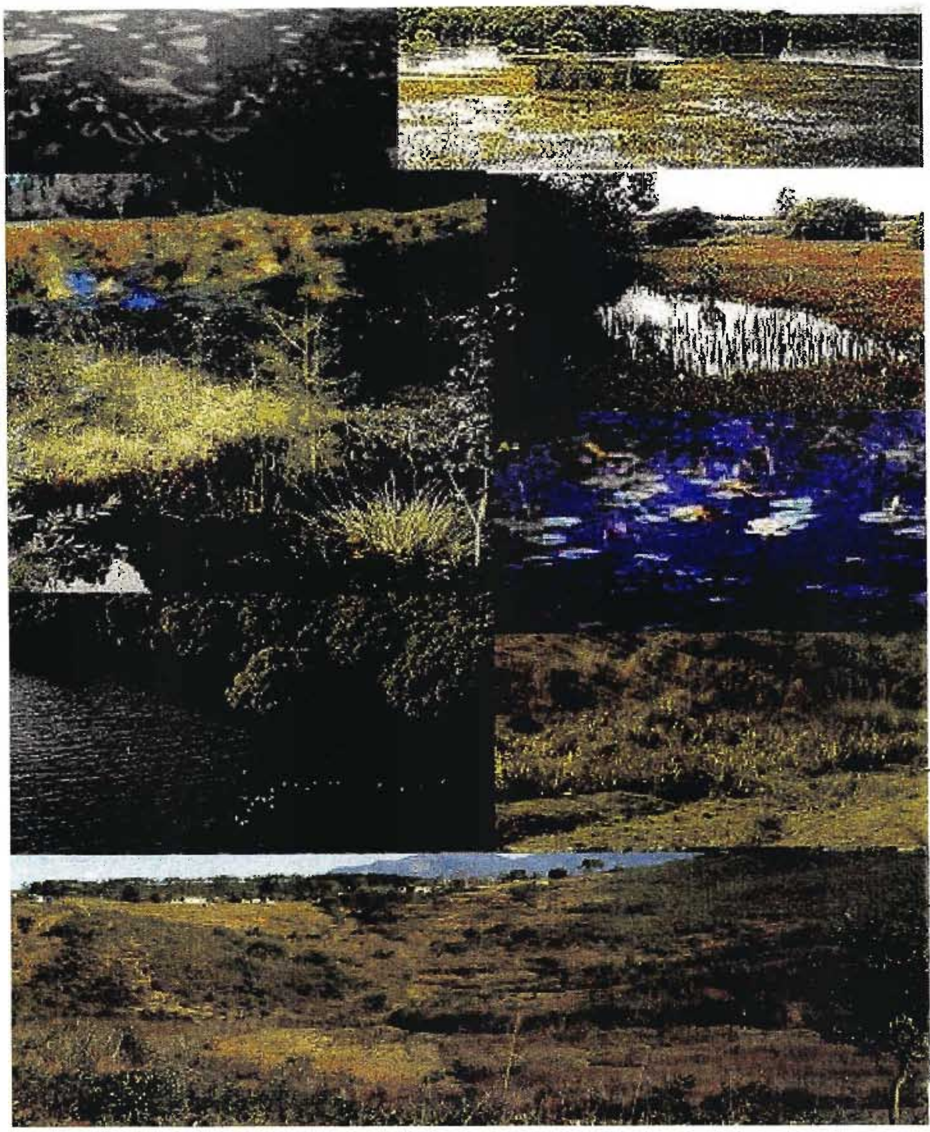


Figure 3.1. A variety of wetlands
(after Missouri Botanical Gardens website, 2002)

3.2 Wetland Hydrology

Hydrology is generally viewed as the driving force behind wetland creation and maintainence (Tiner 1993), largely because the hydrology of a wetland controls the characteristics of wetlands that are most evident, including wetland soil colours and textures, the water quality of a wetland and the abundance of plants, vertebrates, invertebrates and microbes existing within a wetland. Functions of wetlands that are important to their hydrological role are streamflow regulation, flood attenuation, water purification and sediment accretion (Begg, 1986). These are elaborated upon in Section 3.5.

Water is introduced to a wetland through direct rainfall, runoff from nearby areas, streamflow and groundwater discharge, and is stored in the wetland channel, soils and in the groundwater table. The final hydrological processes that occur within wetlands include the removal of the water through evaporation, plant transpiration, runoff and groundwater recharge. This process of water introduction, storage and removal is referred to as the water budget (Williams, 1991), and the development of wetland conditions depends on a long-term balance between water inflow to the wetland and outflow from the wetland (Brinson, 1993). Likely water budgets of the Craigieburn wetland under a variety of land uses can be seen in Section 6.2.1.2.

In wetlands the groundwater table lies close to the soil surface, the level of which changes with climatic and seasonal changes (Williams, 1991). As a result of the sandy soils and low rainfall experienced in the Craigieburn microcatchment, this is not always the case. Water losses through evapotranspiration can result in extreme declines in the water table and a de-saturation of the wetland (Brinson, 1993). Wetlands can thus be permanently saturated for the entire year, seasonally saturated for a period of 5–11 months or temporarily saturated for 1–4 months, as is the case in the Craigieburn wetland. In order to qualify as wetland soils, the soils must be saturated long enough for anaerobic conditions to develop, therefore the water regime is one of the most important factors affecting the functioning of a wetland. The surface water processes within a wetland are a result of local and regional rainfall patterns, which influence the wetland water budget directly through rainfall within the physical boundaries of the wetland and the associated runoff, and indirectly through inflows from upstream. Surface water lost through evaporation is determined by air temperature, humidity, wind speed, vegetative cover and soil moisture content, and water lost through transpiration results from root uptake by emergent plants and the loss through the surface area of the plants (Williams 1991). Examples of such water losses for various land use conditions in the Craigieburn wetland can be seen in Section 6.2.1.2.

The hydrology of different types of wetlands differs. Riparian fringe wetlands, found throughout the Sand River catchment, are found in low-lying regions adjacent to rivers and streams that are periodically subjected to overbank flooding, and are of major importance in regional hydrology, as they are hydrologically connected to both the river and surrounding catchment. Riparian fringe wetlands intercept surface and groundwater runoff from the upland regions of the catchment, and thus function as buffers for the river systems. These wetlands also interact periodically with floodwaters originating from rivers and streams, and these hydrologic interactions can have a significant effect on river water quality (DeBusk, 1999).

3.3 Wetland Soil and Geomorphology

Geomorphology plays a major role in wetland hydrology and ecology within a particular climatic region, and encompasses the shape, size and location of wetlands in the landscape. The morphology of individual microcatchments or wetlands influences flooding depth as well as the frequency and duration of flooding. Geomorphology of the surrounding landscape exerts a strong influence on surface and groundwater connections between the wetland and adjacent ecosystems. Another example of geomorphological influence on wetland function is the location of the wetland in the landscape, especially the landscape position relative to aquatic ecosystems such as rivers and lakes. Landscape position of a wetland may have a significant effect on regional water quality, by controlling the type and extent of wetland interaction with surface and groundwater flows in the catchment. Wetland classification is largely based upon wetland geomorphology, specifically the position of the wetland in the landscape (DeBusk, 1999).

Wetland conditions occur where topographic and hydrogeologic conditions are favorable and a sufficient, long-term source of water exists. Favorable topographic conditions refer to the presence of land-surface depressions in the catchment. These depressions may be located in upland areas, along hillsides where there may be a change in slope or geology, or in floodplains of streams or rivers (Brinson, 1993). As mentioned, riparian fringe wetlands are found in low-lying regions adjacent to rivers and streams, and throughout the Sand River catchment.

Geologic conditions frequently associated with wetland development include areas that have fine textured soils with low hydraulic conductivity and sufficient thickness to store water (Brinson, 1993). This makes the sandy nature of the soils of the Craigieburn microcatchment and other small wetlands throughout the Sand River catchment, and their associated high hydraulic conductivities unusual wetland soils. One of the major indicators of the existence of a wetland, and the indicator that best represents previous environmental conditions within a catchment, are the soils of the area. Wetland soil indicators include the soil colour and mottling, flood 'markings' on the soil surface and coatings of silt or clay particles on plants (Lyon 1993). Wetland soils have a characteristically dull grey background or 'matrix' colour, as the minerals once contained in this soil have dissolved into solution with the surrounding soil water. These minerals, especially irons, impart colour to soils, thus the background colour of wetland soils is largely a dull grey colour. Oxidation of iron minerals that precipitate out of solution when the wetland water table lowers causes the bright orange colour frequently associated with wetland soils. The existence of mottles is an indicator of wetland soils in which this orange colour can be seen, largely as a result of the fluctuating nature of wetland water tables. When the water table is high, anaerobic conditions occur, draining the soils of all their irons, but when the water table subsides, oxidation of the irons that precipitate out of solution occurs, leaving a bright orange colour where oxidation occurred. In this manner one can determine the heights of water tables in a specific wetland in previous years. Such characteristic markings enabled the delineation of the Craigieburn wetland within the microcatchment.

3.4 Wetland Vegetation

Although wetland functions are largely determined by geomorphological and climatic factors, in increasingly many cases these functions are being influenced by anthropogenic factors. These functions can be both determined by and determine the vegetation of the wetland, the occurrence of which is often due to limited water outflow. Wetland vegetation is commonly replaced by agricultural subsistence crops in impoverished rural areas of South Africa, but wetland vegetation has been replaced with agricultural crops worldwide in the past, as these crops are viewed as more financially productive. Because wetland vegetation is specifically adapted to wet conditions, it is also very productive. The functions and benefits of wetland vegetation are wide ranging and can include water and nutrient retention, improved wetland soil fertility and downstream flood prevention.

In the case of a wetland that comprises a densely vegetated water surface, water in a wetland behaves, in some respects, in a similar fashion to groundwater (Ellery, 2004). It follows that differences in wetland vegetation types and cover could result in different hydraulic conductivities, and high shoot densities will sustain a much higher hydraulic slope than a less dense vegetative growth under similar growth conditions. Openings in vegetation, caused by physical disturbances, commonly further open vegetation cells for colonisation by competitors (Rogers, 1997). In the Craigieburn wetland much of the natural wetland vegetation has been replaced by agricultural crops (see Figure 3.2), thus repeated disturbances have occurred, opening gaps for colonisation by competitors and creating a diversity of weed species. As a result of human intervention the potential colonisers are unlikely to fully colonise these gaps (Ellery, 2004).

Roughly 60% of the Craigieburn wetland area has been drained as a result of cultivation, thus typically anaerobic wetland soils no longer exist in many parts. Competitors that attempt to colonise the disturbed ground in these drier areas will not necessarily be a typical wetland species (Ellery, 2004). Such an occurrence will affect the hydrological regime of the wetland, and this hydrological regime is one of the important determinants of vegetation distribution within a wetland (Rogers, 1997).

Figure 3.2 Agricultural plots constructed within the Craigieburn wetland

Draining the Craigieburn wetland will potentially have further negative impacts, as wetland vegetation also acts as a filter for bacteria, thus the length of time that water remains in a wetland has a large effect on decomposition and nutrient cycling, which affect the productivity of the wetland (Davies and Day, 1998). Vegetative disturbance will thus exacerbate wetland degradation, and reduce its integrity (Rogers, 1997). It was established in 1986 that as much as 90% of the wetlands of part of the Thukela catchment had been destroyed as a result of a considerable loss of wetland vegetation, severely affecting the local communities. Here extensive areas of wetlands have been destroyed for agriculture, resulting in a loss of wetland capacity to store floodwaters and release them slowly (Begg, 1986).

Wetland plants are very efficient photosynthesisers, and are thus very productive. They can grow in highly waterlogged conditions under which few other plants can grow. Many have specialised tissue or organs through which oxygen can be moved quickly to the roots or large leaf areas. They also comprise little wood and thickened tissue material, thus more of the plant is devoted to photosynthesis. Water movement in wetlands removes dead tissue, keeping plant communities healthy. The determination of habitat types and community types rely on vegetative characteristics, but analysis of the health of a wetland and susceptibility to impact also reflects physical factors such as soils and hydrology. Wetland vegetation can provide early indications of wetland health, as it is the most visible of the indicators thereof. This is reflected in the types of vegetation, and the effectiveness with which this vegetation carries out its functions of stabilising soil and trapping sediments. The depth and texture of riparian soils influence the wetlands capacity to filter and slow water running through it, and to act as a 'sponge' to store water in order to support the riparian vegetation (Kence, 1995).

Wetland vegetation, soils and further geomorphological and anthropogenic factors that influence the composition, processes and functions associated with wetlands need to be accounted for and understood in order to understand the hydrology of wetlands.

3.5 Wetland Functions

River valleys and floodplains have been the centre of human settlement since early times. Many are still essential to the health of local communities, yet wetland services are commonly taken for granted. The physical, biological and chemical components of wetlands enable them to perform certain functions, including flood control and attenuation, and consequently some degree of erosion control; sediment and toxicant retention, thus providing an aquatic habitat encouraging biodiversity in an area; groundwater recharge; as well as acting as a source of water for local communities, for whom they may also provide the materials for a number of products (Dugan, 1990).

In some cases, more typically when an area is dominated by soils of low clay content, wetlands are able to attenuate floods. Precipitation and incoming streamflow are stored within the wetland, and runoff is regulated, diminishing the destructive power of the flood peak on downstream users. This can eliminate the need for dams for this purpose. In this way, wetlands also aid in erosion control, as wave energy is reduced when water passes slowly through the wetland and potentially erosive bottom sediment is held in place by roots.

Sediment and toxicant retention is achieved as wetlands serve as settling pools and the reeds present slow the flow of the river. Groundwater exchange and the quality of the ecosystem are maintained if sufficient sediment is retained in the headwaters. The ability of wetlands to retain sediment and nutrients enables many wetlands to support a wide variety of wildlife. Toxicants often adhere to sediment, and are thus immobilised in a wetland, and can change in chemical composition. The lifespan of channels is extended by such sediment retention. Nutrients such as phosphorus are retained in the sediment, preventing eutrophication of rivers and dams and improving water quality. When water flow is rapid, wetlands can act as a source of nutrients, affecting algal growth, fish production, and downstream recreation (Maltby, 2000). Most wetland soils are alternately wet and dry, increasing the release of nutrients and speeding up the turnover of organic matter (Dugan, 1990).

Wetlands are able to recharge the groundwater in the area in which they are located as a result of their retention capabilities. Rainwater and streamflow that enters and is stored in the wetland can percolate into the lower soil horizons, and into the groundwater store. The degree to which a wetland is capable of this function is dependant on the biophysiology and the hydrology of the wetland. The hydrology of a wetland is often considered to be its most important characteristic, and the characteristic that largely determines the functions it is capable of. Changes in hydrology may result in both long and short-term changes in the environment. These changes are evident in changes in flow volumes, water table heights, and the composition of the stream banks. These changes alter the vegetation and fauna of the wetland, thus directly and indirectly changing the functions and potential functions of the wetland (Thompson *et al.*, 1998).

Wetlands may also be used as a source of water for local communities, if the quality and quantity of the water supply are adequate, and the resource can be utilised in a sustainable manner (Kotze, 2002). Today there is a growing recognition of the potential of wetland ecosystems to meet development needs of local communities. Thus, if managed sensitively, wetlands can provide a wide range of products and services (Dugan, 1990). Although wetlands have been viewed as wastelands in the past, they are among the most fertile and productive ecosystems in the world (Maltby, 1998). In developing countries the urgent need to feed people serves as a convincing argument in favour of draining wetlands. Although this can provide food in the short term, it frequently has negative effects on the communities local to the wetland in the long term. Wetland drainage and conversion in the developing world are frequently carried out using foreign aid (Kence, 1995), thus many wetlands have been lost irretrievably, and others are under immediate threat. The most important use of wetlands in developing countries remains the provision of a sustainable yield of plants for human use (Dugan, 1990), yet wetland functions that benefit the greater society are largely ignored when decisions pertaining to the use thereof are made (Kotze *et al.*, 1994).

The health of a wetland site refers to its ability to perform the riparian wetland functions highlighted above. Members of the local communities of the Sand River catchment commented that the wetlands were in good health before 2001, in poor health thereafter, but are improving presently. Comparisons between the productivity of the plots next to the river and those in the upland regions are difficult to make, as a variety of crops are grown in these respective areas. Community members agree that the state of the wetlands is a direct reflection of local weather patterns, and a reflection of historical events to a lesser degree.

The functioning of a wetland is clearly influenced by the surrounding landscape and by anthropogenic factors, yet in South Africa protocols to describe the catchment context of wetlands is still incomplete (Jewitt and Kotze, 1998). There is also a lack of systematic and practical methods of wetland conservation and monitoring in many countries worldwide (Gerritsen, 1997). These functions do vary among wetlands, however, necessitating a detailed hydrological study of each wetland, as physical properties change and effects are felt far downstream. The immediate community soon feels the effects of alterations to a wetland, and the economy of a region or nation can be affected if alterations are too great (Maltby, 1998). This is elaborated on in Section 4.6.

4. THE SOCIOLOGICAL IMPORTANCE OF WETLANDS

The hydrology of a wetland can have a significant effect on the lives of the communities local to that wetland. If a study of the hydrology of a wetland shows that the wetland is performing its typical wetland functions of water storage, nutrient retention and water purification, the sociological implications of the wetland will be positive for the local community. Communities can utilise wetlands as a source of water, especially in the dry season as wetland have the potential to store water in their soils. Communities may also benefit from the existence of a wetland in their immediate environment as wetlands attenuate floodwater that could otherwise damage their homes and fields, as well as cause loss of life. Wetlands also help to control the loss of sediment caused by local erosion, improve the quality of the water that passes through them by retaining toxins, and support agricultural practices, as wetlands are wet, fertile areas (Ramsar Convention Bureau, 2000). Wetlands may also hold value for local communities aside from their instrumental value, and may be of historic or cultural importance to a local community.

The effects of degradation of a wetland on the livelihoods of the local community are varied, depending on the characteristics of the community and of the wetland, and on the nature of the interactions between them. The manner in which a local community utilises a wetland has a significant effect on the degree to which the wetland becomes degraded. If the wetland is overused, such that too much water is extracted from the wetland, or the wetland is cultivated intensively, the wetland may be rendered incapable of performing functions such as groundwater recharge and sediment retention. In such a case the wetland will no longer be capable of sustaining itself and its own ecosystem, nor will it be able to sustain the local communities. Wetlands should thus be used such that they are able to continue to perform the functions that characterise them, for the long-term benefit of the wetland, the landscape in which the wetland exists, and the local communities that rely on the wetland.

Sustainable use of wetlands by the communities local to the wetlands is much more likely to be successful if the community are aware of the impacts that wetland use and management practices have on the wetlands. Natural and social scientists have encouraged community-based natural resource management in rural wetland areas for years (Ainslie, 1999), and the advantages of local and external participation in sustainable wetland utilisation and rehabilitation are becoming more widely recognised, as local participation in wetland use and management has been shown to substantially contribute to better management and use thereof (Ramsar Convention Bureau, 2000).

In order for community based natural resource management to succeed in rural areas, rights of ownership, access to and exclusion from cultivated areas need to be clearly defined (Shackleton, 2000). Rights of ownership, access to and exclusion from wetland sites, however, are seldom clearly defined, thus rights pertaining to wetland resources are also unclear at times. This is the case in South Africa, making community based natural resource management initiatives in wetland areas difficult to manage (Kotze, 2002). Although clearly advantageous, such initiatives are also fraught with problems, some of which are policy-related, thus beyond the scope of most community based research projects. Some of these problems, however, are specific to the community and resource under discussion, thus a better understanding of the interactions between these can aid the development of such an initiative. Understanding these links involves exploring the multiple livelihood strategies adopted by rural communities that involve the utilisation of the resource.

4.1 Wetland Value

As highlighted above, wetlands are valuable to local communities, not only as water and produce suppliers, but also as sites that hold cultural and historical value (Kotze, 2002). Wetlands are frequently used as fertile areas in which to position cultivation plots by members of local communities, but are also harnessed for the vegetation that grows naturally within them, such as reeds and sedges. In such cases the functions that wetlands perform, such as water and nutrient retention, give the wetland value for the local community, as the reeds and sedges that thrive in these fertile environments are used in practices that promote traditional, cultural craft making.

The functions that wetlands perform, although sometimes difficult to measure, tend to be more easily quantifiable than the value that wetlands hold for the people living near them. Although in some instances these functions enable the quantification of the value of local wetlands for these communities, in many cases the value is less productive and more abstract, making it more difficult to calculate. Some of the wetlands upon which the great Roman and Greek civilisations were founded continue to support rural civilisations today, giving them great social and historical value, a component that is also very difficult to quantify (Maltby, 1997). Although in previous cases wetlands have been classed as inaccessible wastelands, the sociological roles thereof are becoming more widely recognised. Many people are, however, still ignorant of the true value of wetlands, thus effective management thereof requires greater wetland awareness. The Ramsar convention, the foremost international agreement regarding the management and use of wetlands, highlights the importance of prevention of wetland loss and the promotion of the wise use thereof (Dugan, 1990).

4.1.1 Crafting

Research that explores the impacts of use of reeds and sedges growing in a wetland by the community members local to that wetland largely encourages the practice of crafting (Oellerman and Darroch, 1994; Munks, 1996; Kotze, 2002). Crafting that utilises wetland resources is a potential wetland use option for community members that has a number of advantages for the local community and for the wetland. Reeds and sedges are quick-growing plants that thrive under wetland conditions, making this vegetation less vulnerable to overuse than less prolific vegetation that is not the natural vegetation of the area. Promotion of crafting activities that utilise local natural resources in a manner sustainable to both the resource and the livelihoods of the community can encourage positive interactions between local communities and external project members. Because harvesting reeds from a wetland is a practice that is unlikely to encourage degradation of the wetland, and is likely to be a sustainable practice, this activity fulfils many of the major objectives of the majority of wetland conservation initiatives in rural areas. The objectives of supplying the local community with an immediate livelihood strategy, of implementing an activity that encourages conservation of the wetland from its onset, and the objective of finding at least one activity that is sustainable and of benefit to both the local community and the wetland in the long term are met. This does assume, however, that sufficient use can be made of the harvested product, either domestically or personally, to provide a viable livelihood strategy for the community.

Crafting also offers cultural benefits, including the maintenance of traditional skills and practices of local communities. Specific wetlands are frequently of value to communities local to that wetland, as they provide reed or sedge species that are used for traditional crafts specific to that community. This is seen in areas in which a community has a long history of residence in the area. Crafting is a traditional skill of many rural communities, and commonly holds historic, cultural and current financial value. Although the sale of the end products of these crafts can provide a worthwhile livelihood strategy to crafters, business constraints exist in most rural areas. These include under-valuing the socio-economic contribution of crafts and craftspeople, poor diversity of products, poor access to communication, transport and infrastructure, deadline problems and sometimes even difficulties in obtaining raw material. Although little research has been performed on the craft sector in South Africa, the promotion of self-reliance is considered very important to make the industry independent and less vulnerable to collapse (Kotze, 2002).

An example of the advantages and difficulties involved with crafting within an impoverished rural community is the Sand River catchment community that lives near the Craigieburn wetland. Many of the female members of this community make crafts, predominantly mats (see Figure 4.1), woven from *Leshago* (*Schoenoplectus corymbosus*) (see Figure 4.2). An informal discussion centered on crafts woven from reeds was held with some members of this community, and one of the results of this discussion is that *Leshago* is the plant most widely used for weaving sleeping mats in this area. Harvesting of this reed (see Figure 4.3) occurs predominantly from April to June, which is when the plants are ready for cutting. It takes approximately 6 hours to complete a mat, which is woven using a '*bongolo*', a wooden frame over which chords weighted with stones or batteries are individually crossed. The twine used for weaving is a plastic off-cut, and each mat typically lasts for about 2 to 3 years with regular use. The poorest households appear to be the most actively involved in harvesting and weaving, for both domestic and commercial use. Some individuals also sell the harvested raw materials.

Figure 4.1 A mat woven from *Leshago* by a Craigieburn wetland user

Awareness of the value of reeds to conservation of the Craigieburn wetland was not entirely lacking among the local community members. Those who were farming in the Craigieburn wetland in April indicated that slash and burn harvesting is ordinarily practiced over this period, as reeds from this part of the catchment are not as widely used for household and commercial purposes as those downstream are. They further mentioned that they did not partake in these practices, as the reeds bind the soil, minimising erosion and slowing the movement of water through the wetland.

Figure 4.2 *Leshago* flanking the main erosion donga in the Craigieburn wetland

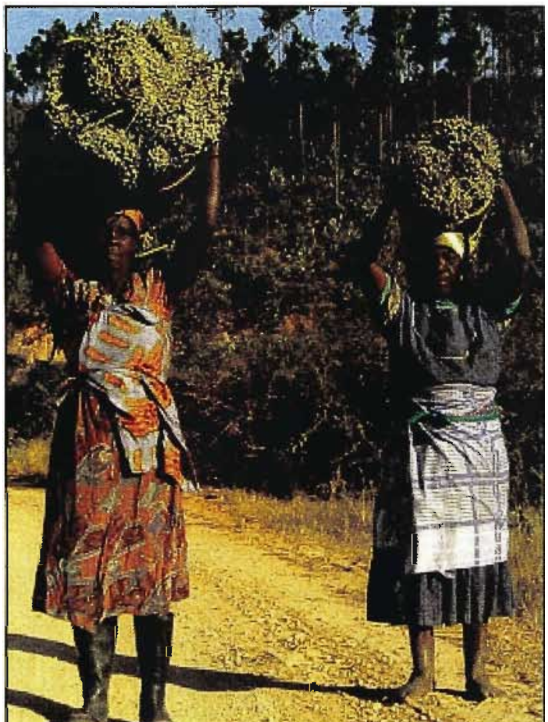


Figure 4.3 Bundles of harvested *Leshago*

4.1.2 Cultivation

Cultivated sections of wetlands in rural areas of South Africa commonly include community gardens and isolated individual plots. Motivation for local participation in community gardens tends to result from the ability of the members to share resources. Such participation enables community members to fence off cattle more cheaply, to engage in cooperative management and provides the knowledge that this may be a better manner in which to provide ones family with food and water. This can also lead to access to funds and the means to fight poverty. The more local people that benefit from the wetland resources, the greater will be their combined incentive to look after the wetlands (Kotze, 2002). The occurrence and maintenance of wetlands and the degree to which they are valued by a society is considered to reflect long-term characteristics of catchments, landscapes and regions (Jewitt and Kotze, 1998).

Great use is made of the wetlands of the Sand River catchment for cultivation practices (see Figure 4.4). Members of local communities of the Sand River catchment described the uses of certain of these resources, including those used for both cultivation and crafting practices (see Table 4.1). It is difficult to say exactly how many households utilise the wetland, as the household meetings with members of the WRL team were voluntary, but those present described them as 'well attended'. About sixty households were represented at these meetings, at which it became clear that all households in the area utilise the wetland. For this reason about 70% of the wetland is cultivated. Cattle belonging to the surrounding communities periodically use the Craigieburn wetland, and local cattle utilise other wetlands, making it difficult to quantify the cattle usage of the wetland. The wetland was used far less prior to 1994, as use was forbidden under the apartheid government. Since 1994 madumbes were grown in the wettest wetland plots, and maize on the higher plots. The wetland has subsequently dried, causing farmers to drain the wetter plots in attempts to grow maize on these. The plots have subsequently become too dry for maize cultivation. Wetland pressures are consequently increasing, as plots are becoming progressively drier and more people are attempting to cultivate within the wetland.

Table 4.1 Items of importance extracted from wetlands in the Sand River catchment by the local community

Items of greatest importance	
Name	**Comment**
Marope (Madumbes: *Colocasia esculenta*)	These have a specific requirement for wet conditions
Mabele (maize)	This is ground to make maize meal, a staple food source here
Morogo (a vegetable)	These accompany maize in the daily meal
Dinawa (a bean type)	These accompany maize in the daily meal
Items of intermediate importance	
Name	**Comment**
Moba (sugar cane)	This is eaten as a sweet
Leshago (*Schoenoplectus corymbosus*)	This is an important plant for crafts
Segaba (*Cyperus latifolius*)	This is an important plant for crafts
Items of least importance	
Name	**Comment**
Motombola (a bean type)	This is not an important part of the diet
Mangoes	This is not an important part of the diet
Lehlekanoka (reed)	This is no longer used for construction purposes

Figure 4.4 Project team and local community members in a Craigieburn wetland plot

4.2 Rights of Wetland Use and Access

The value that wetlands hold for rural communities is of little significance if the wetlands are, for one reason or another, inaccessible to the community members, yet uncontrolled use of and access to wetlands frequently encourages exploitation thereof. This poses a problem to wetland conservation projects involving local communities based in rural areas of South Africa, of which the Sand River catchment wetlands research is no exception. If conservation initiatives are implemented in an area, the local communities will be affected by this action, the long-term affects of which are not always clear. If no conservation action is taken, it is likely that both the wetland and the community will feel the negative effects of continued degradation of the wetland, but again the long-term effects cannot be predicted unquestionably. Policies specifying strictly regulated use of wetlands in rural areas of South Africa do not exist, largely as a result of the difficulties a body would be likely to incur attempting to implement such a policy, and because rural communities have been the subject of much interference at the hands of the government of South Africa in the past (Kotze, 2002).

Under the apartheid government, 'black' South Africa comprised 13% of the National territory, and included mainly rural areas. This has left South Africa with a legacy of former-homelands, such as the Gazenkulu and Lebowa former-homelands that the Sand River catchment falls into. A major question facing the 1994 government was how to address development issues in these former homelands. Reinforcement of apartheid spatial patterns in these areas has been highlighted as a risk when undertaking development tasks without full consideration of all the factors involved for those living in these areas (Marais, 2001). This highlights the potential social problems involved with attempts to devise and implement a conservation strategy in the Sand River catchment and elsewhere in rural areas of South Africa. On the other hand, because no conservation strategy is followed in the Sand River catchment and elsewhere, as no policy exists to guide such a strategy, insecure rights of access held in these areas lead to exploitative use of resources. Wetlands are extremely vulnerable to exploitative anthropogenic practices (Shah and van Koppen, 2001).

Within many communities in rural areas of South Africa, a series of tacit agreements as well as written laws permit or forbid use, entry, management, exclusion and alienation of an area of land. A government whose officials explicitly grant rights to resource users may enforce rights of access. Such rights are known as *de jure* rights, and are given lawful recognition. If a definitive national policy specifying rights of use and access of wetlands in rural areas were to be promulgated, these rights would be referred to as *de jure* rights. Rights are known as *de facto* rights if they are not recognised by any government authorities. Within a common-pool resource situation a series of both *de jure* and *de facto* rights may exist. These may overlap, complement, or, as is often the case, conflict each another (Cousins, 1997).

Evidence of a lack of state-regulated control over use of wetlands in rural areas of South Africa can be seen in the Sand River catchment communities that make use of the Craigieburn wetland. A member of the local community mentioned that permission to cultivate the wetland is generally not sought from the Tribal Authority. Rather, use is made of any potentially arable wetland area once it has been established that no other member of the community intends using it. Subsistence plots are also not restricted to any specific areas of the catchment, thus these plots can be found throughout the Craigieburn wetland, leading right up to the edge of the main channel running through the wetland in some areas (see Figure 4.5). Some degree of formal regulation of plot management was revealed, as community members further mentioned that the Chief had indicated that it is necessary to fence off plots. Within the area around the Craigieburn wetland there is not a lot of competition for wetland plots, people do not tamper with fields, and if a field is not used for some time, community members generally approach the previous user before proceeding with cultivation. Permission to harvest *Leshago* on a neighbouring plot must be obtained from the person cultivating that plot, but where it occurs outside of cultivation plots, it is available to all community members. This points toward the existence of a system of *de facto* rights that loosely govern at least some of the wetland use activities of the local community.

Indications of previous governmental influence over local community members' rights of access to and use of the wetlands can be identified from comments made by local community members. Community members stated that before the apartheid era more of the wetlands were cultivated, as there has been subsequent removal of community members from the upper portions of the catchment. Community members further mentioned that more land was previously available, that fields were larger than they are presently, and that the plots in the wetland are much better for cultivation than those outside of the wetland, as they are wetter.

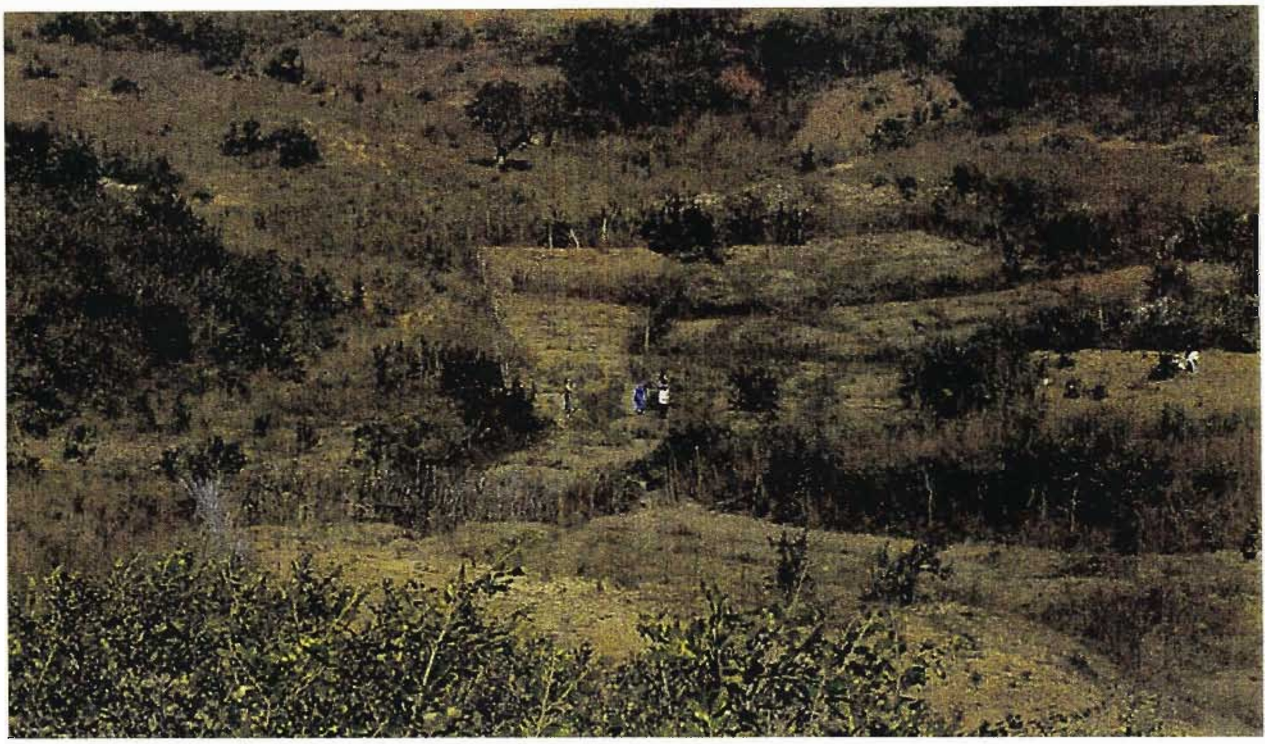


Figure 4.5 Agricultural plots running through the Craigieburn wetland

Even though rights of access and use tend to provide strong incentives for owners to sustainably manage resources, assigning such rights does not guarantee an avoidance of resource degradation (Carter and May, 1999). In this vein, those members of the Sand River catchment communities who hold rights of access to wetland plots are likely to interact in a more sustainable manner with the wetland and its resources than those who do not, yet the underlying geomorphological characteristics of the Sand River catchment wetlands may be such that assigning rights of access to wetland areas to certain community members will not be sufficient to ensure that further degradation is prevented. The evidently sandy soils and degradation one notices when first encountering the wetlands suggest that management practices outside of the financial means of the local community members may be necessary. Assigning rights to a resource, and monitoring an area in a manner so as to ensure that those who obtain rights receive the full benefits thereof, are very difficult processes. The outcomes are not necessarily always beneficial for the resource or the community members, as allocation of rights has the potential to be performed in an insensitive manner, such that not all the necessary considerations are accounted for in the process. Under such conditions rural communities elsewhere in South Africa have been known to show aversion to projects implemented by outsiders to the community, and thus do not actively take part in the project (Schlager and Ostrom, 1992).

4.3 Natural Resource Management

Because the acquisition of land rights in rural areas can potentially provide incentives for local community members to sustainably utilise natural resources, the acquisition of these rights can act as a pre-requisite for sustainable natural resource management. Community participation is widely encouraged in resource management initiatives in rural areas, and becomes especially necessary when the environmental resource is particularly vulnerable to anthropogenic impacts, as wetlands commonly are (Kotze, 2002). Some of the major advantages of community based natural resource management include enabling rural community members to take full advantage of the livelihood strategies available to them as a result of the existence of the resource being managed, raised awareness of the effects that cultivation and management practices have on the environment, and encouraging self-reliance and sustainable, equitable use of the environment (Ainslie, 1999). Unpredictable environmental changes, among other phenomena, have created worldwide natural resource degradation awareness in the last decade, thus improved methodologies and community compliance with environmental regulations have been emphasised and achieved in many cases (Bartnick, 1999).

The widespread degradation of natural resources in rural areas of South Africa has also motivated attempts to encourage local communities to assist with resource rehabilitation, some of which have produced positive results (Bergkamp, 1998). The initiation of the Reconstruction and Development Programme in South Africa highlighted that underdeveloped rural regions require more locally-aided initiatives to alleviate socio-economic and environmental problems. The programme initiators further highlighted that these issues need to be addressed jointly, as poverty leads to a dependence on natural resources, and that this has caused severe social and environmental degradation in some rural areas (du Plessis, 2002). Research has shown that the size of a farmer's plot frequently influences conservation decisions positively, as conservation structures take proportionally more space on smaller plots, leaving too little cropping space to financially justify the conservation structures on very small plots (Bekele and Drake, 2003). Community based initiatives could counteract this trend by taking advantage of joint resources within communal cropping areas in the Sand River catchment wetlands. The advantages listed above have motivated the investigation of application of community based management strategies to the Craigieburn wetland research.

Despite the perceived advantages, attempts to implement community based natural resource management strategies in rural areas have encountered hindrances for a variety of reasons. Socio-economic differences among members of rural communities, as well as different engagements with the resources available to these communities result in weak combined incentives to contribute to community based natural resource management (Ainslie, 1999). This is a problem one would potentially face when attempting to implement such an initiative in areas of the Sand River catchment, where the more affluent members of the community utilise the Craigieburn wetland to a lesser degree than their less affluent neighbours, lessening their incentives to sustainably utilise and manage the wetlands. Natural resource management strategies adopted by local community members in rural areas of South Africa are commonly not definitive, therefore very flexible resource use occurs. Resource users frequently do not support the introduction of formal natural resource management regimes that discourage flexible resource use, as this is perceived to potentially lessen the availability of these resources to the users. This may further hamper progress toward community based natural resource management among communities that utilise the Craigieburn wetland, especially as freedom of use of the wetland during the drier seasons prevents starvation among the poorest members of this community.

Projects addressing issues of wetland use that intend involving the community in the management thereof should ideally integrate local knowledge with external scientific knowledge pertaining to the wetlands under discussion, to encourage wetland utilisation that is sustainable to the community and to the resource (Bergkamp, 1998). In the case of the wetland research being conducted in the Sand River catchment, this ideal is being attempted by integrating the information gathered from interviews and meetings held with the local community with results of geomorphological and hydrological analyses performed on the wetlands utilised by these community members. Further factors affect, and in many cases hamper rural community based natural resource management, many of which are outside of the control of the community members and of those attempting to implement resource management measures (Lubisi and Matakanye, 2001). These include the local economic role of migrant remittances; the local community members' access to pensions, arable land and livestock; the length of residence of the local community in the area and the extent to which the local community members have access to political and bureaucratic power and patronage, among other external factors (Ainslie, 1999).

Although outside of their control, potential resource managers or researchers require an understanding of these factors, and of further factors that affect the daily lives of the local community members. This includes an understanding of the livelihood strategies the local community members adopt, and the consequent interactions that these communities have with the wetlands in their area. Discussions were held with members of the community that utilise the Craigieburn wetland in order to gain an understanding of the economic circumstances, access to government grants and the social hierarchy present within this community. Questions pertaining to the livelihood strategies that the Craigieburn wetland enables were also posed, in an attempt to understand the effects that the community and the resource have on one another, and thereby assess the potential difficulties and solutions that may be associated with community based wetland management in this area.

Despite the large amount of literature pertaining to community based natural resource management in South Africa, one is particularly hard-pressed to find an example of such management that has been implemented in any capacity within the country, successful or not. Documentation of South African examples of implementation of a management plan for rural common property resources used by multiple users for a multitude of reasons, if in existence, is also very difficult to acquire. Literature pertaining to conflict resolution within community-based natural resource management initiatives, of which much is available, frequently highlights the misconceptions held by project implementers and consequent misunderstandings encountered and mistakes made (Ashton, 2003). Here again, one will struggle to find examples of incidences in which these misconceptions were identified, and conflicts successfully resolved.

4.4 Livelihood Strategies

Members of rural communities commonly adopt multiple livelihood strategies, as income diversification can provide a buffer against economic risks as it lessens dependence on commonly unreliable resource bases. Although beneficial in this respect, adoption of multiple livelihood strategies can negatively impact on overall participation in community based natural resource management activities, as members are not equally dependant on the resource. Where a resource is limited, competition increases demographic pressure and resolving these pressures may require outside intervention, undermining the community, and again lessening incentives to use the resource in a sustainable manner (Ainslie, 1999). Adoption of multiple livelihood strategies is commonplace in the Sand River catchment, where a member of the community may take part in reed and craft selling, subsistence cropping and domestic work, depending on the time of year.

Discussions held with Craigieburn wetland users provided insight into the problems associated with adoption of livelihood strategies within this community. As is the case in many rural areas of South Africa, political, sociological, financial and environmental constraints to community members' livelihood strategies exist for the Craigieburn wetland users, although natural resources such as wetlands provide the material to support many of these (Carter and May, 1999). Political constraints include the inaccessibility of grants aimed at poverty reduction that members of rural communities are lawfully entitled to take advantage of. These include acquisition of pensions and child grants, for which no successfully operational structures are in place. Accessing many of the government grants requires a birth certificate. A member of the Sand River catchment community commented that many members do not have birth certificates, and legal structures in place enabling one to acquire such a certificate require transport that is outside of their financial means. This also highlights one of the many financial constraints to livelihood strategies felt in this community.

The degree of financial security that the livelihood strategies adopted by the Craigieburn wetland users offer can be explained in terms of entitlement theory. This refers to the vulnerability of these strategies to collapse as a result of the vulnerability of the entitlement relationships that residents of areas of rural South Africa currently make use of in order to acquire means to a living (Major, 1994). The entitlement relationships a person is able to take advantage of depend on the social, legal, political and economic characteristics of ones society, and ones position within it. Entitlement theory deals with the relationships one can establish to translate ones assets into assets necessary for life, including food and water, thus vulnerability of a livelihood strategy in terms of access to these essentials can be assessed by analysing the entitlement relationships that exist within a community. Extreme poverty occurs when entitlement relationships fail (Gore, 1993).

Entitlement theory highlights two types of entitlement relationships; access to endowments such as grants, land, water and capital; and to social assets, such as citizenship and kinship. Some distinct entitlement relationships based on ones access to endowments exist for rural community members. A trade-based relationship is one of these, utilised by the Craigieburn wetland users in the form of the livelihood strategy of selling of craft and produce (Major, 1994).

Transfer based relationships are another form of entitlement relationship, and involve the voluntary hand-over of money from one to another. This form of relationship is accessed via ones position of kinship or citizenship within a family and a country, respectively, and is a vulnerable relationship in rural South Africa, as one becomes fully reliant on another for his/her livelihood. Many of the Craigieburn wetland users are dependant on the few members of this community who are able to access grants as a result of their position as a child or a senior South African citizen. Dependence on state grants makes one additionally vulnerable in a developing country, where access to these grants is frequently unstable (Gore, 1993). The transfer relationship involving kinship is vulnerable to break down, and the vulnerability of the own labour exchange relationship of employment, in terms of the adults' vulnerability to losing their jobs, adds to the vulnerability of the transfer relationships that result in children receiving food (Major, 1994). Transfer based relationships often fail because laws change and many isolated rural communities are not aware of the change (Gore, 1993). This is a threat to the communities that utilise the Craigieburn wetland, as they are positioned in a remote area and do not have the financial resources to travel to larger towns and cities frequently in order to keep abreast with changing laws. Ideally, a research intensive policy geared specifically toward wetland use in rural areas should be promulgated, sensitively implemented, and the terms of this policy made accessible to members of rural communities that utilise the wetland for many of their livelihood strategies. These ideals are laden with complexities, however, as the following sub-chapter expands upon.

4.5 Policy

The change in South African government that prevailed with the 1994 elections has changed the political, social, environmental and economic conditions of the country, as directed through a series of new Acts. Priorities as specified in the new constitution are moving toward basic human and ecosystem needs, efficient solutions to water shortages and equitable allocation of water supplies (Gleick, 2000), thus should impact upon the lives of impoverished rural community members. The change in government had an impact on the water resources available to the local community of the Sand River catchment, who refer to times 'before the release of Mandela' and 'after the release of Mandela', as well as 'before '94, and 'after '94', and highlight that previously water resources and land were more strictly controlled by outsiders to the area.

No clear policy exists, however, pertaining to cultivation of wetlands by the rural poor in South Africa. Uncontrolled wetland cultivation is a matter that has not been adequately addressed at provincial, nor national level, yet is a practice that is widely taking place in South Africa. Some reasons for this may be that such action could be interpreted as interfering with local authorities, from whom permission to cultivate wetlands is ordinarily sought, and because there is reluctance to obstruct the current actions of the rural poor, who have endured so much political obstruction in the past (Kotze, 2002). In the Craigieburn wetland it is obvious that the farmers do not adhere to a regulated system of cultivation. The fact that there is no single Act specifying acceptable wetland use that could be applied to the Craigieburn wetland will make implementation of conservation or development strategies difficult. Activities and events such as soil erosion, new development, land use changes, floods and droughts may impact upon wetlands (Hope and Hewett, 2001), but these are governed by different legislation. Much South African legislation does potentially impact upon, and could be used to guide wetland conservation. If implemented sufficiently, a number of other Acts could largely determine the rights of use and access to land in the area in which the Craigieburn wetland users are based, and of access to water supplies and governmental grants. Some of theses Acts, however, have been criticised for exhibiting a lack of understanding of the communities at whom they are aimed, highlighted within these Acts by inappropriate emphasis on resource allocation. Others of these have been reviewed as appropriate pieces of legislation, the implementation of which has been hindered by a lack of understanding of the communities for whom they were intended (Shackleton, 2000). These are elaborated upon below.

A policy that could potentially improve the quality of life of rural community members such as those who utilise the Craigieburn wetland, is The National Water Act (NWA, 1998). This Act is widely regarded as 'fine piece of legislation', but the implementation thereof has proven to be difficult (Schulze, 2000). Because this Act places emphasis on efficiency of water use, water sources such as wetlands are specified as valuable resources. Furthermore, priority of water allocation is given to basic rights for humans and the environment. Despite this, the inability to implement this Act in rural areas prevents water rights from being realised. There is a growing awareness worldwide that wetlands functioning in a state in which they perform typical wetland functions of water and nutrient retention are potentially a reliable water resource for members of communities local to the wetland, as the water stored by the wetlands in the wetter months is released in the drier months (Maltby, 1997). This is highlighted within the Act.

In rural areas the implementation of environmental policies that address the rights of rural community members to natural resources and to government grants has largely failed as a result of a lack of understanding of the conditions under which rural communities live. This negatively impacts upon the Craigieburn wetland users, as these policies could benefit the community members, were they more appropriately researched and more effectively implemented. Although information pertaining to the implementation of environmental policies that promote sustainable development and wise use of resources is widely available, a lack of understanding of the starvation-prevention mechanisms in place in rural areas can severely hinder the opportunity for policy development in these areas (Shackleton, 2000). These policies also fail to address certain aspects of deprivation in South Africa, where technological, institutional and financial resources are widely available to some sectors of society and hardly reach the rural poor (van Koppen, 2000).

Further misconceptions deem South African environmental policies inadequate in rural areas. A rural area is commonly conceived to be an area of lesser infrastructure than an urban area, of abundant greenery, as less built up, with a lower population density that an urban area, and an area in which agriculture is of great importance (Shackleton, 2000). It is with this stereotype in mind that many of the policies aimed at improving the lives of rural community members are approached. As a result of the unique history of South Africa, a different rural reality exists, incorporating the former 'homeland' communal areas such as those of the Sand River catchment. In these rural areas, in extreme cases, population densities reach over 300 people per square kilometre in some areas (Shackleton, 2000), there is often no infrastructure, as opposed to less infrastructure and environmental impoverishment ensures that greenness is not a characteristic of the area. The Sand River catchment population was estimated at 336638 people in 1998, and is estimated to be about 447469 in 2010; this will equate to a population density of 234 people per square kilometre. In 2001, 44% of this population were younger than 15, and estimates of unemployment ranged between 40% and 80%, leading to an increasing reliance on the wetlands in the catchment (Pollard *et al.*, 2002). Human population growth, when it occurs at an unsustainable rate, places significant pressure on communities, and on the resources upon which they rely for their livelihoods (Harding, 2003).

Rights and constraints pertaining to wetlands in rural areas such as the Craigieburn wetland only exist in laws intended to define permissible use of communal lands. Wetlands are not specified, but where they fall into communal lands they fall under the laws pertaining to communal lands. The Department of Environment and Development (DEAT) have made available documents and pamphlets indicating plans for a community based natural resource management strategy and a National Action Plan with a branch that places emphasis on wetlands. The fact that it does specify wetlands, however, means that this section of the plan falls under the jurisdiction of Working for Wetlands, who do not highlight community based natural resource management among their priorities. A guideline document for development activities that may affect wetlands in urban areas of KwaZulu-Natal (Kotze, 2002) has been drafted in light of the lack of a National Wetland Policy. A new Land Act, still in a preparatory phase, may provide clearer guidelines to permissible use of and access to wetlands in rural areas. The Act intends transferring state-owned land to local communities via the tribal authorities present in these areas, and has proven to be a much contested and highly controversial document thus far (Ahmed, 2004). It has not yet been implemented in any area, so its potential for wetland conservation and conflict resolution can only be predicted at this stage.

Policies that have been implemented in rural areas of South Africa previously have largely negatively affected the lives of the local communities. An attempt to implement a project such as the Craigieburn wetland project may be met with aversion as a result of the legacy left by South Africa's past government. A policy that was implemented in the Sand River catchment previously that had a decidedly negative impact on the region is the 'Betterment Policy'. State-enforced regulatory conservation attempts, especially in the agricultural sphere, may conjure up images of this policy of the apartheid era. Masquerading as a conservation policy that was beneficial for all, the Betterment Policy regulated plot sizes, herd sizes, cropping and livestock allowances, and demarcated land into various functional areas. This policy specified areas for grazing, for cropping, and a residential area, which contravened the layout already present. Furthermore, the areas allocated to the various entities were not large enough to fulfil their specific purpose, and new rules and regulations were imposed. Based on such a past, it is not surprising that state-mediated conservation schemes are frequently sceptically received (Turner and Isben, 2000).

Although awareness that the lack of a wetland-specific environmental policy is detrimental to wetland conservation projects (Dugan, 1990) has existed for over a decade, no such policy appears to be likely to be promulgated in the near future. This knowledge, coupled with a worldwide trend toward use of Non-Governmental Organisations (NGOs) and community-based initiatives in order to solve problems that would previously have been directed toward governmental agencies (Bailey, 1998; McConnel, 1998; Diem, 1998), suggests that NGO-based approaches to wetland use in these areas may be worth adopting. This is supported by the view that governmental inefficiency at all stages of promulgation, implementation and monitoring of such a policy is likely to be detrimental to the wetlands and local communities in question. While such initiatives have experienced problems in the past, theories that make up the study of environmental economics, and consequently of wetland economics, provide insight into reasons why aspects of wetland conservation projects have failed in the past (Schlager and Ostrom, 1992; Hanson, 1997; Braunt, 2003), as well as potential solutions to wetland projects in which the environmental and sociological aspects thereof need to be accounted for.

4.6 Wetland Economics

Once the effects that the interactions communities have with local wetlands are understood, making decisions pertaining to the most beneficial use and management of the wetlands for all stakeholders involves assigning value to the wetland resources and the wetlands themselves. Wetlands are of varying importance to their stakeholders, and the value that they hold, although difficult to quantify in an economic sense, is most easily recognised in an economic sense. Furthermore, if this value is quantified, wetlands are more likely to be regarded as having value (Bateman, 2003). Not only should incentives for rural communities to sustainably manage wetland resources be found, but other stakeholders whose decisions affect wetland management should also be incensed to do so. Natural resource management initiatives are progressively incorporating economic principles and attempting to assign correct prices to environmental resources in order that they are not exploited. In this manner, project initiators, managers and implementers intend enabling rural community members to take full advantage of the livelihood strategies available to them, and to encourage sustainable, equitable use of the environment (Ainslie, 1999).

4.6.1 Macroeconomics of natural resources

Quantifying the value of natural resources such as wetlands involves an evaluation of the macroeconomics of the resource. The macroeconomic branch of environmental economics considers the effect that the global economy and Gross Domestic Product of a country have on the natural environment (Diao and Roe, 2001). This aids ones understanding of the effect that the economy of South Africa has on natural resources such as the Craigieburn wetland. Economic instability is a cause of environmental degradation, and resources are exploited under such conditions, as they are more thoroughly utilised as a livelihood strategy when others, such as the state poverty reduction measures, become unreliable. Economic stability is thus a prerequisite for sustainable development. In a symbiotic manner, the economy of many countries depends on their natural resource base, thus sustainable utilisation becomes necessary for economic stability (Sapsford and Morgan, 1994).

Current economic practices often have negative effects on the environment, and environmental deterioration leads to economic decline. To prevent this cycle from perpetuating, trends in environmental degradation need to be reversed. In the context of wetlands specifically, the political debate over third world economics usually turns into a choice between short-term direct food production and conserving the long-term economic, ecological and environmental functions of wetlands (Maltby, 1998). The economic value assigned to a wetland should incorporate its worth as a crucial livelihood resource to people such as the members of the Sand River catchment communities, as well as its worth as a historic and cultural heritage site and its worth to more affluent stakeholders, such as those intending to maintain the functioning and integrity of the landscape in which the wetland is positioned and of the communities local to these wetlands (Kotze, 2002).

Primary commodities, commonly defined as food, raw materials, fuels and base metals, are extremely important to world trade, especially in developing countries, making natural resources such as wetlands all the more valuable. Renewable and non-renewable natural resources are being exploited unsustainably, largely because of the global economic policies that determine their use. The quantities of primary commodities that are traded tends to grow less rapidly than those of other goods, thus the value of primary trade is more heavily influenced by price changes than the value of trade in other goods is (Sapsford and Morgan, 1994). Conflicting views on how to ensure a sustainable future economy continue to exist among environmentalists, some of who believe that preservation of resources for its users should be the key idea in conservation. This view supports the intention of the 'Wetlands and Rural Livelihoods' project to investigate how best to conserve the wetlands of the Sand River catchment without negatively impacting upon the lives of the local communities. Others believe that development is of greater importance, and that the balance of consumer supply and demand will correctly dictate the degree to which this development should take place (Dioa and Roe, 2001).

4.6.2 Microeconomics of natural resources

"All the outcomes of any proposed resource use – including outcomes affecting equity or sustainability – can be expressed to 'benefits' and 'costs'"
(Fuggle and Rabie, 1994).

In order to assign accurate value to natural resources, the microeconomics of natural resources need to be understood. The microeconomic branch of environmental economics deals with interactions between decisions people make in a market setting. This explores the monetary costs and benefits of environmental well being, and its effect on people. The sustainability of these systems is explored in order to correctly price environmental resources, again to prevent their exploitation. Environmental microeconomics explores the balance between the resources the environment supplies, and the demands man places on the environment for these resources (Ridge, 2002). Furthermore, it aims to achieve optimal production at an optimal rate of degradation - the degradation that is ideal for human production (McDonough and Braungart, 1998). Environmental degradation reflects inefficiency of resource use. Prices reflect scarcity and value of a resource to society, thus under-pricing natural resources gives out incorrect market signals. When costs are natural resources, maximising profits means using these resources efficiently, leading to more sustainable utilisation thereof (Ridge, 2002). Thus correct pricing benefits both the market and the environment. In the context of wetlands, assigning correct prices to commodities one may derive from a wetland will indicate how best to harvest wetland resources in a sustainable manner (Bartnick, 1999). As wetlands are subjectively valued resources, environmental economists are attempting to assign more objective value to wetlands, but are having difficulty establishing a universal manner in which to do so, especially as many wetlands fall into common property areas (Kotze, 2002).

> "How can we measure the value of resources for which no reliable pricing mechanisms exist because they are common property?" (Fuggle and Rabie, 1994).

This question has sparked numerous debates, and has impacted upon governmental policy and environmental awareness in South Africa and all over the world. The reason that reliable pricing mechanisms are so necessary in cases of common property, and are so difficult to obtain, lies in the theory known as 'the tragedy of the commons'. A 'commons' is any resource used as though it belongs to all, and is destroyed by uncontrolled use (Hanson, 1997), such as the Craigieburn wetland. The tragedy of the commons refers to a theory put forward in a thesis by Hardin (1968), the principle of which is best explained by the use of an example.

This example follows that the cattle of a group of hypothetical herdsmen grazed on common land. This land could not support any more cattle, thus although the addition of a further cow would benefit the farmer who owns the cow, the addition would negatively impact upon all the farmers. This occurs as further grazing causes each cow on the plot to receive less than the optimum amount of food it needs. The benefits to the owner of the extra cow on the plot are greater than the disadvantages to the owner, as the disadvantages are shared among all the farmers who use the communal land, and the owner of the cow experiences all the benefits thereof. Because all the other farmers start to experience a loss, they tend to also add further cattle to the plot, thus the negative impacts of the excess cattle are borne by all the farmers, and both the farming community and the individuals experience a loss (Fuggle and Rabie, 1994). In much the same way, the disadvantages of exploitative use of the Craigieburn wetland for all the users will outweigh the initial and temporary benefits thereof for those who do overuse the resource.

Potential solutions to environmental problems evidently cannot depend on the good of human nature, thus the correct pricing of natural resources is essential in order that these resources are not exploited. A potential manner in which to resolve such an issue could be to determine the value that the resource, such as a wetland, holds for the members of the immediate community in the state in which it is currently functioning, and the state at which it could function (Ridge, 2002). The principle of the 'tragedy of the commons' is of great relevance in the whole of the Sand River catchment, where the land is held under communal tenure. This serves to emphasise the need for the majority of the community to work together to improve and maintain the health of the wetlands.

4.6.3 Assigning economic value to wetlands

Understanding the macroeconomics and microeconomics of natural resources, although very useful to wetland research, is a far cry from all that is needed to understand the economic implications of the existence of a wetland in a populated rural area. Understanding the current and potential economic implications of the existence of the Craigieburn wetland, as well as other wetland research that focuses on the economics thereof, is thus of importance to this thesis.

Although the value of a wetland is difficult to quantify in an economic sense, some can be valued with a reasonable degree of accuracy. Agriculture-related enterprises, like pasture or hunting lease arrangements, can result in employment and economic profits for the people living in certain areas, and can be performed in a sustainable manner (Bartnick, 1999). The higher the agricultural potential of a wetland is, the smaller the benefits of the wetland in its natural state are, and the lower the incentive to preserve it is. Under such conditions there is commonly potential for conflict as a result of competition for scarce resources (Kotze *et al.*, 1994). Productivity, value and employment issues involved with wetland management and development are very sensitive issues in rural areas, and in some communities out-migration is viewed as detrimental to the local economy, thus employment opportunities within the local area are of great importance (Leitch and Ludwig, 1995). Presently about 50% of the men in the Sand River catchment communities are migrant workers. Rehabilitation of wetlands in order to encourage eco-tourism could provide employment in the Sand

River catchment, but awareness of land and water management is not likely to be observed if members of local communities are struggling to maintain basic livelihoods (Pollard *et al.*, 2002).

Previously drainage for agricultural purposes has been seen as a positive use of wetland areas, as only the direct economic benefits thereof were accounted for. As a result, entire ecosystems in developing countries have been at risk. Floodplain wetlands of the Waza-Logone region in northern Cameroon have suffered environmental degradation and economic decline, largely as a result of a rice irrigation scheme and a drought. The Waza-Logone Project is a floodplain restoration project created to address these problems and to create opportunities for the improvement of livelihoods of the local communities. The project aided community-based integrated land and water management by promoting traditional knowledge and resource-user groups, yet involved bioscience and hydrological input (Braunt, 2003). When wetlands are lost, the price of this loss has to be measured against the benefits of the converted wetland. There can be social benefits of exploitation, which are measured against foregone benefits of the wetland such as water purification and storm protection. Society and policy makers need a better understanding of the value of wetlands. The 'free goods' of water purification and flood attenuation tend to be ignored in economic calculations that determine what the best uses of wetlands are. These non-market values can have significant economic value, such as inexpensive purification of water (Dugan, 1990).

Eco-tourism is fast becoming a manner in which to encourage development in impoverished rural areas of South Africa. Embarking upon projects involved in eco-tourism require detailed initial analyses of the environmental effects that such activities will have on the area, as well as analyses of the economic benefits that tourism will bring to the area. An economic evaluation of these entities is a manner in which to determine whether the benefits that tourism will bring to an area outweigh the detriment that such an introduction will bring. Wetland areas commonly attract eco-tourism. The economic evaluation approaches that are currently used (Hartwick, 1977) remain largely unchanged from those in use over 50 years ago, as they have proved to be worthwhile methods of analysis. One such approach is the travel-cost method. It is an easy, inexpensive method of analysis that estimates the value of the recreational benefits generated by the environment. The basic principle is that although one cannot assign a price to recreational experiences, the costs incurred by those travelling to the site can be used as substitute prices (Burrows, 1979). These include the cost of travelling to the catchment, food for the duration of the visit, and benefits foregone by their visit (Knetsch and Davis, 1977). Benefits are defined in relation to the manner in which a project improves human welfare. For this reason alone, such an evaluation is necessary (Cleveland, 2001). This method of economic analysis is pertinent for use in the Sand River catchment when one considers that The Kruger National Park is very near to the catchment, and the catchment does have eco-tourism potential (Pollard, 2002).

4.7 Sociological Constraints

A number of constraints to daily living exist for those living in impoverished rural areas of South Africa, such as the Craigieburn wetland users. These constraints frequently make communities more reliant on natural resources, often contributing to the degradation of the resources, which adds to the daily hardships of those reliant on the resource (Ainslie, 1999). A study based in rural areas of KwaZulu-Natal highlights the reliance of a community on the natural resources in their area. The study deduced that farmers experience greatest financial difficulty in July to October. This can be directly attributed to a lack of home-produced food, which is exhausted at these times, combined with low levels of income from casual work, and high levels of spending, in order to buy seeds and fertilizers (May, 2000). Factors other than management factors can counteract the positive effects of conservation measures in some areas. For example, factors that are beyond the control the farmers such as slope, rainfall and soil physical characteristics are important erosion characteristics (Bekele and Drake, 2003).

External intervention in cultivation and management practices has previously added further constraints to the daily lives members of rural communities (May, 2000), as is the case for the Craigieburn wetland users. A white farmer, who the communities of the Sand River catchment called *Madoloso*, assigned people to destroy the crops that were planted in the Sand River catchment wetlands in the February of 1965 and of

1966. The local community members said that it was not clearly understood why these areas should not be cultivated, except that they had been told that the community were 'wasting water' by planting within the wetlands. They further stated that after 'the release of Mandela' they were free to cultivate the wetlands.

A current constraint to improvement of daily conditions in the Sand River catchment that has been identified is that the municipal area into which the catchment falls, the Bushbuckridge region (see Figure 4.6), has been proclaimed to be a 'difficult' area to work in by members of Working for Wetlands. Newsworthy stories of violence have characterised the area in the past, including a recent story of a road accident leading to the death of a man local to the Bushbuckridge area. The feeling among those in the area is that the man was driven off the road. On the tenth of February this year (2004), The Witness newspaper printed an article pertaining to a case in which a man was fed to lions on a farm near Hoedspruit, a town in this area. The article stated that the police had arrested a Limpopo game farmer and three accomplices after they fed a worker to lions (African Eye News Service, 2004). An article published in October 2002 states that the murderer of a British tourist was found and arrested near his home in Bushbuckridge, where the murder weapon was found (SAPA, 2002). An understanding that researchers who have worked among the Sand River catchment community members have gained is that the local residents tend not to want to stand out or 'rise above' other members of their community in any way, as it is potentially dangerous to do so. Such an approach to ones daily activities is unlikely to be conducive to livelihood strategy initiatives that require motivation and innovation, such as those of community based natural resource management projects.

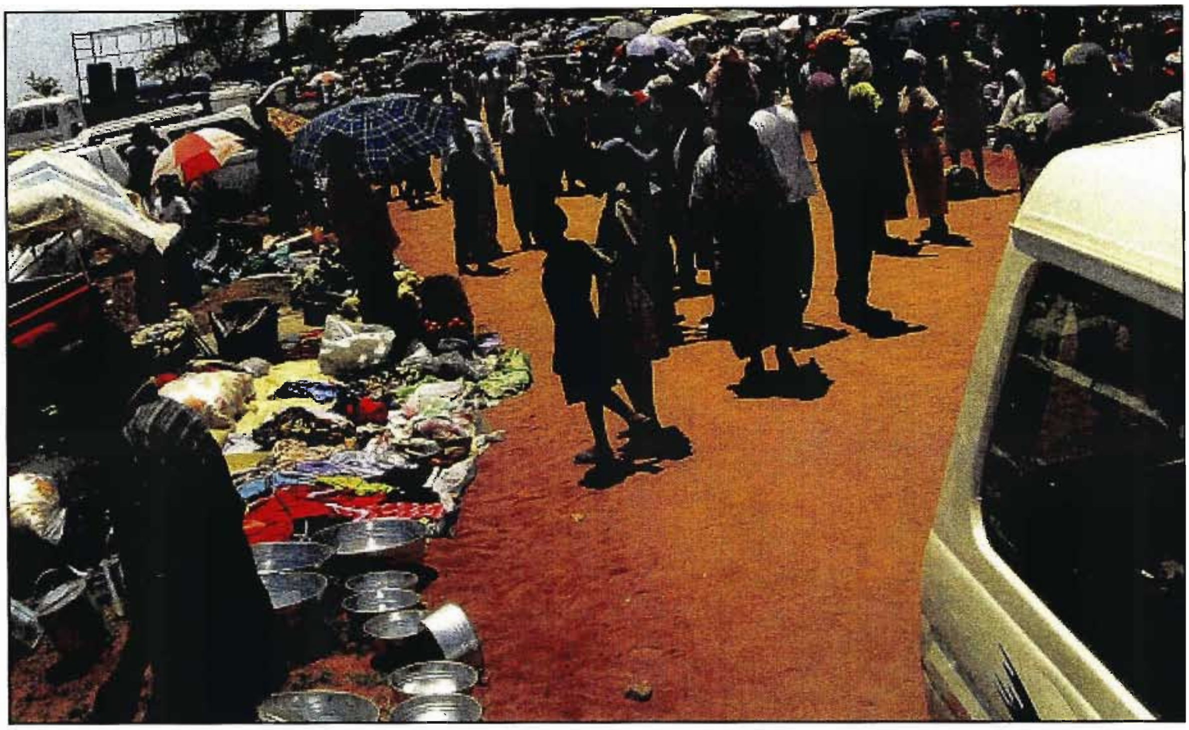


Figure 4.6 Members of the Bushbuckridge community

A further potential constraint to implementation of regulated resource use strategies has been identified by a researcher whose work is based in the Sand River catchment. Female members of some of the local communities who make use of the wetland reeds to weave mats, baskets and other such goods for domestic and commercial reasons, are finding this activity increasingly difficult. These women are encountering increasingly many of the areas in which they have previously collected reeds being fenced off such that they cannot gain access to these areas. These women are thus forced to walk great distances to gather reeds. Other, far more affluent residents of the area have reported having been overwhelmed by the numbers of people wishing to harvest reeds that are growing within their properties. The weavers appear, in some cases, to be operating at a loss. A reason for perseverance of this activity despite this may be that the weavers need to partake in an activity that gives them at least some sense that they are able to take control of their lives, and that the weavers gain a sense of pride from these activities.

Considering the constraints imposed on most facets of the daily lives of the Craigieburn wetland users, and on members of impoverished communities in rural areas of South Africa generally (Magadlela, 2001), it may seem unprincipled to encourage these communities to conserve wetlands instead of cultivating them (du Plessis, 2000). Hindsight, however, shows that some degree of conservation is commonly a more viable option for sustainability for the members of these impoverished communities (Boffin, 2001). Society's slow response to wetland issues previously has lead to wetland degradation on a large scale, and the response is expected to be slow in the future as well (Maltby *et al.*, 2000). Floodplain development previously has shown that wetlands are frequently destroyed where people see other uses of the available water as more productive. Productivity is a relative term, and the priorities and values of the various wetland stakeholders, including those who do not rely on the wetland for daily living, vary. In many countries the rate of wetland loss has reached the proportion of national crisis, and in developing countries wetland loss is having a significant influence on the local communities. To resolve this, the precise reasons for and effects of wetland loss need to be analysed, and new ways of addressing them identified (Dugan, 1990).

The sociological implications of wetland alterations, such as development, conservation and degradation cannot be viewed in isolation. Causative agents of such alterations may include hydrological and geomorphological characteristics of the wetland environment, or the political and economic climate of the region. These need to be studied and understood in conjunction with one another, in order to correctly determine the links between these aspects of wetlands, and the effects they may have on one another.

5. HYDROLOGICAL MODELLING

"One of the universal rules of happiness is: always be wary of any helpful item that weighs less than its operating manual" (Pratchett, 1997).

Cause and effect modeling of a complex agrohydrological system is neither a simple, nor a clear-cut task, and modelling cannot comprehensively answer all the hydrologically-related questions for which solutions are being sought (Schulze, 1995). Hydrological models can be used as tools to assess the potential effects of a change in the environment in which research is based. In such a manner, scenarios to compare the potential effects of these changes, and mitigation procedures, as well as conservation or rehabilitation practices can be investigated, thus hydrological models can be used to provide insight into potential problems and solutions. As these models can be applied at a range of scales, the effects of these changes at various scales can be investigated; incorporating the potential effects at a range of both spatial and temporal scales (Kite and Droogers, 2000). There exist hydrological models that, while not designed specifically for the purpose of modelling wetlands, can be used as tools to predict the causes of observed changes in a wetland, as well as the functions a wetland is potentially capable of performing (Bergkamp, 1998). As is commonly the case with scientific wetland research in general, the wetland component of these models is frequently fraught with difficulties (Schulze, 1995). The purpose of models, when used in such a manner, is to provide stakeholders with a means of assessing the potential impacts of change of a single component of the system on both that component of the system and on the system as a whole (Smithers and Schulze, 1993).

5.1 Wetland Modelling

A series of contradictions surrounding the hydrological processes involved in wetland functioning highlight the lack of understanding of these processes (Bergkamp, 1998). Simulation modelling of wetlands aids ones understanding in this respect, and may be used to predict the effects of both the existence of, and alterations to wetlands on the landscape (Schulze, 1995). Wetland modelling combines knowledge about wetland processes with measured data from specific wetlands, thus a successful wetland model needs to be able to determine the importance of, and manipulate the components of the hydrological cycle and the biophysical characteristics of the wetland (Schulze, 1995). Attempts were made to simulate conditions within the Craigieburn and 'control' wetlands using a number of modelling systems. Many of those models that did not prove applicable to this exercise did, however, depict movement of water through the wetlands, and provide insight into the effects of changing conditions on the hydrology of the wetlands. In such a manner a better understanding of both the processes taking place within the wetlands, and of the ways in which hydrological models represent these processes were gained.

Although the models require a variety of different inputs or forms of input variables, the core input variables were the same for all the models. These include rainfall, temperature, soils, vegetation and slope variables, and are elaborated on in Section 2.3.

5.1.1 Candidate modelling systems

Modelling systems that simulate hydrological functions in wetlands include the *ACRU* agrohydrological modelling system (Schulze, 1995), the Riparian Ecosystems Management Model (REMM) (Lowrance *et al.*, 1998), the RIPARWIN modelling system (Lankford and van Koppen, 2002), the HYDRUS-2D model (Poeter, 2003), the DRAINMOD model (Skaggs, 1990), the HILLS model (Hebbert and Smith, 1990), the Water Erosion Prediction Project (WEPP) (NSERL) model and the 'HOWWET?' model (Dimes *et al.*, 1993). Results pertaining to the hydrological functioning of the Craigieburn wetland were obtained from the two models that proved most applicable to this project. The simpler of these, the 'HOWWET?' model was set up to investigate the hydrological effects of geomorphological differences between the Craigieburn and 'control' wetlands. The more complex, *ACRU* model was set up in such a manner that a series of land use scenarios could be tested, to investigate the effects of these on the hydrology of the Craigieburn wetland, in its present geomorphological state. A brief description of each of these models follows.

5.1.1.1 The REMM model

REMM is a simulation model, initially designed for riparian forest buffer systems. It imitates a three-zone conceptual riparian system model, for which the user defines the vegetation of each zone. The model can use field data or field scale simulation model outputs from other models, as well as climate data or output from climate generators. REMM simulates hydrologic, carbon and nutrient cycling (see Figure 5.1), as well as plant growth processes on a daily time step (Lowrance *et al.*, 1998). The riparian system is considered to have three zones between the field and the water body. Each zone includes a litter layer and three soil layers, as well as up to six plant species. For each zone the daily surface hydrology, erosion, vertical and horizontal subsurface flows, carbon and nutrient dynamics and plant growth are modelled. The climatic input data include rainfall amount and duration, air temperatures, solar radiation and wind velocity. Daily outputs from the field draining into the riparian system; including surface runoff and associated eroded soil material, organic material, plant nutrients, subsurface drainage volumes and transported carbon and nutrients; are used as input data for the model. A further input is the 'change input', which indicates when a major change has occurred in the system, such as tillage or burning. The date and type of change forms a part of the input (Lowrance *et al.*, 1998).

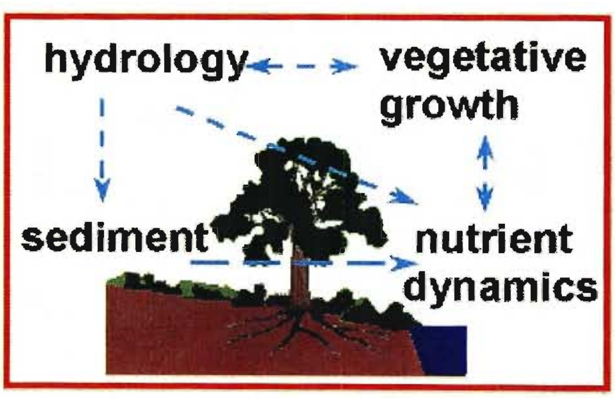


Figure 5.1 Relationships within the REMM model (Lowrance *et al.*, 1998)

In a diverse riparian area a change in one feature within the system may not correspond with a change in other features, thus average values for many of the REMM landscape input variables within each zone are commonly used. Vertical and lateral movement of water and dissolved nutrients are simulated through each soil zone. The litter layer covers, and is mixed with, soil from the top horizon. The soil data for this layer is thus that same as that of soil layer 1. REMM outputs include depth to the water table, which is assumed to be in the centre of each zone, as well as several water fluxes. Inputs to zones 1 and 2 include outputs from zones 2 and 3 respectively. Further model outputs include surface runoff from each zone, total evaporation losses, throughfall, deep percolation, sediment yield, and ammonium, nitrate, organic phosphorus, and inorganic phosphorus in surface runoff and seepage between the zones. Soil moisture of each soil horizon of each zone is also produced as output, as well as nitrogen and phosphorus concentrations in other forms (Lowrance *et al.*, 1998).

The REMM model operates at a scale similar to that of the Craigieburn wetland. Because it operates at such a small scale, it models intricate processes such as lateral soil water flows. Lateral water movement accounts for much of the water flow in wetlands, making this a beneficial criterion for a wetland model in order to accurately model water movement through a wetland. The REMM model is, however, very data-intensive, and has minimal user support. It concentrates on modelling the chemistry of wetlands to a greater degree than is required for this research. It thus requires a large amount of chemical data that is not available for this study. Furthermore, the REMM model is primarily a riparian area model, and would thus be more applicable to a riparian fringe wetland than to a headwater wetland, such as the Craigieburn wetland, and to a wetland that is not as dry as the Craigieburn wetland is. The REMM model was thus not considered any further.

5.1.1.2 The RIPARWIN project model

The RIPARWIN project is a river basin research project conducted in the Great Ruaha Sub-basin commonly known as Usangu Plains in the South Western Highlands of Tanzania. This is a very important basin for agriculture, the environment and for Hydro-Electric Power generation. RIPARWIN stands for Raising Irrigation Productivity and Releasing Water for Intersectoral Needs, and is a project undertaken to benefit members of impoverished communities of the Usanga Plains area, their local environment and other river basin stakeholders, as well as to discover new ways in which to improve irrigation efficiency. Some planned outputs thereof are greater local stakeholder understanding of the water demands of others under a variety of management practices, and enhanced understanding of means to transfer water between sectors. The project also aims to improve water professionals' understanding of river basin characteristics, and produce a river basin management decision aid (Lankford and van Koppen, 2002).

The main area of interest within the project is the possibility of intersectoral water allocation in river basins through improved irrigation efficiency. Three key river basin programmes were devised as subsections of the project, the third of which is 'The Sustainable Management of the Usangu Wetland and its Catchment'. The programme started in 1998 and ended in 2002, and investigated the causes of hydrological changes in the wetland and ways in which to improve rural livelihoods. In order to accomplish this, a hydrological model and a monitoring programme were developed that tested the results of a variety of scenarios. The outcomes suggested multiple causes of the wetland flow regimes. One such scenario monitored dry season flows with no major irrigation users tapping into these flows, the assessment of which questioned the original assumptions that the shrinking of the wetland and the lessening of low flow volumes was a result of overgrazing and excessive livestock water consumption (Lankford and van Koppen, 2002).

The RIPARWIN project and the consequent development of a water use model, are based on the same premises of sustainability, provision of water for the poor, intersectoral research and capacity building as those of the Sand River catchment project. Despite this, the RIPARWIN model differs too much in its emphasis, a lot of which is placed on irrigation, from that necessary to model the Craigieburn wetland and microcatchment and the 'control' wetland. The model is also still in its early stages, as is its user documentation, thus persevering with this model would have proved difficult, and was not undertaken.

5.1.1.3 The DRAINMOD model

The DRAINMOD model was initially used as a research tool to investigate the performance of a range of drainage and sub-irrigation systems and their effects on water use, crop response, treatment of wastewater and pollutant movement from agricultural fields. The objectives of DRAINMOD are to simulate the performance of water table management systems and to simulate lateral and deep seepage from cultivated fields (Skaggs, 1990). The model requires plant rooting depths, and ideally makes use of hourly precipitation data, but can use daily rainfall input data. It provides output values of infiltration, surface drainage in which the average depth of depression storage must be satisfied before runoff; subsurface drainage in which the rate of subsurface water movement into drain tubes or ditches is calculated, and soil water distribution values. The DRAINMOD model simulates the hydrology of poorly drained soils with a high water table on an hour-by-hour, day-by-day basis for long periods of climatological record, if data are available. Although the model was designed to predict the effects of drainage on water table depths, the soil water regime and crop yields, it has also been used to analyse the hydrology of certain types of wetlands. DRAINMOD has been successfully tested and applied in a variety of geographical and soil conditions (Skaggs, 1990).

DRAINMOD operates at a scale congruent with that of the Craigieburn microcatchment. It has previously proven to be a useful wetland-modelling tool, and is not data intensive, or difficult or time consuming to set up. Although DRAINMOD operates well under saturated conditions and on poorly drained soils, it does not operate as well under dry conditions or on well-drained soils (Bester, 2003). As areas of the Craigieburn wetland are very dry for large parts of the year, DRAINMOD was not considered the ideal small-scale model for this project.

5.1.1.4 The HYDRUS-2D model

HYDRUS-2D is a hillslope-scale hydrological model, thus it can accurately account for lateral flows. It includes a finite element model that simulates movement of water, heat, and multiple solutes in a variety of soils. The programme can be used to analyse water and solute movement in unsaturated, partially saturated, or fully saturated porous media. It also operates at the scale most applicable to the level of detail available for the small wetlands of the Sand River catchment. It provides a user-friendly interface (see Figure 5.2), with flow animation and easily understandable graphs (see Figure 5.3), thus does much for ones understanding of the processes that operate within a wetland. HYDRUS-2D is also a widely used model (Poeter, 2003). A slight disadvantage of the model is that, in order to classify the soil forms under discussion, a soil particle analysis has to be performed on the soils. Particle analysis data can be input directly into other models, such that the necessary calculations are performed based on the particle size analysis, not on the classification, which is a more coarse form of input data. Furthermore, HYDRUS-2D operates better when the user has access to specific, accurate data, including gauged streamflow data. As the stream that feeds the Craigieburn wetland has no weir data, HYDRUS-2D is not the best small-scale soil water process model for this project.

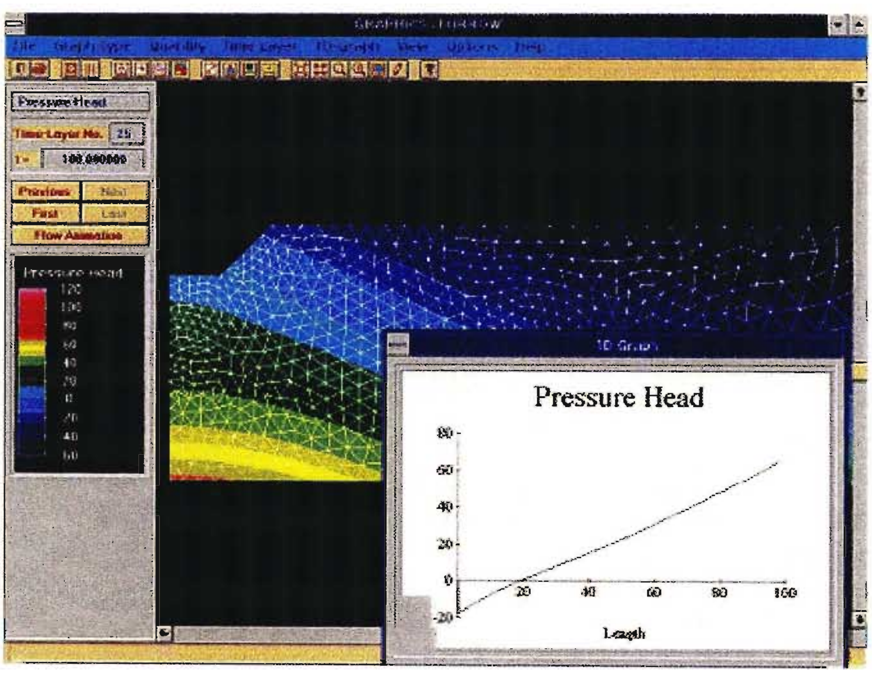


Figure 5.2 An example of a HYDRUS-2D interface (Poeter, 2003)

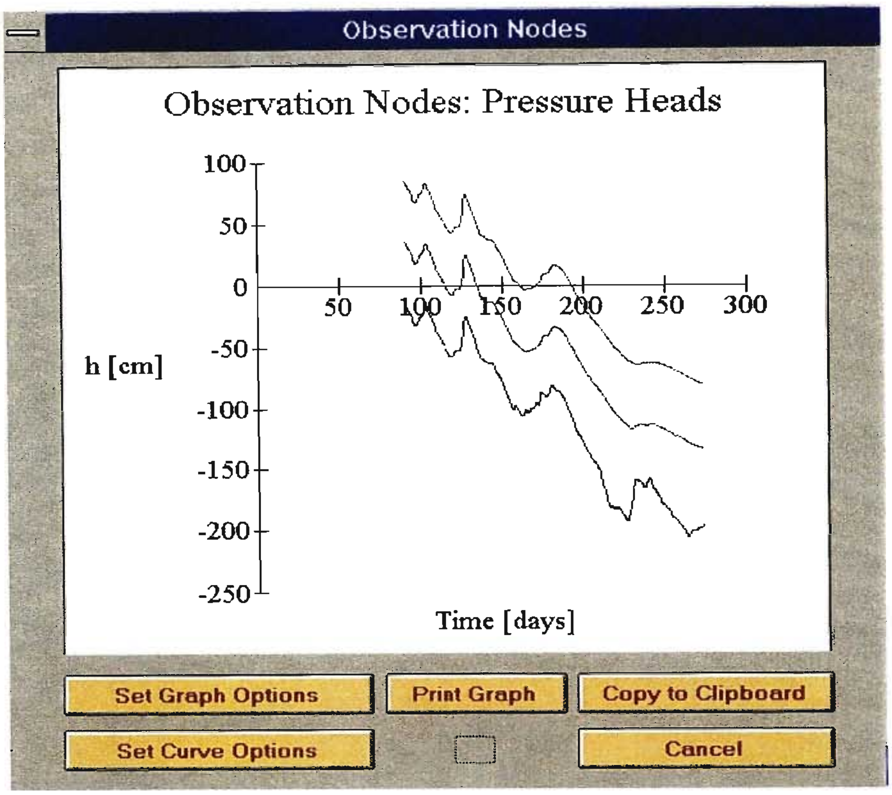


Figure 5.3 An example of a HYDRUS-2D graph (Poeter, 2003)

5.1.1.5 The HILLS model

'HILLS' is a soil water model that can simulate hillslopes comprised of a shallow surface soil, under which lies an extensive sub-soil of lower permeability than the upper layer. This sub-soil layer impedes the downward movement of water through the profile, causing a saturated zone within the surface soil (see Figure 5.4). The model aims to calculate the movement of the water within this saturated zone. The outputs allow the user to monitor the hillslope hydrologic conditions at specified time increments, and the model produces output values of component flow, water balances, and depths of perched water tables within the profile. The perched aquifer lower boundary condition is assumed to be a fixed, saturated depth within the soil, such as that which would be maintained by a stream. The hillslope sectional flow is mathematically one-dimensional, but flow may converge or diverge, and the section may be assumed to be part of a small upstream catchment. The hydraulic properties of the surface soil are specified sufficiently to approximate water movement, including saturated hydraulic conductivity, saturated and residual water contents, and capillary rise heights. The ability to customise this information is beneficial to the study of the Craigieburn wetland, where the hydraulic conductivities are high. Input parameters include those that describe the soil hydraulics, the hillslope geometry and the soil hydraulic characteristics (Hebbert and Smith, 1990). Unfortunately, the HILLS model was not compatible with all the software used in conjunction with this thesis, thus was difficult to use from a technical point of view.

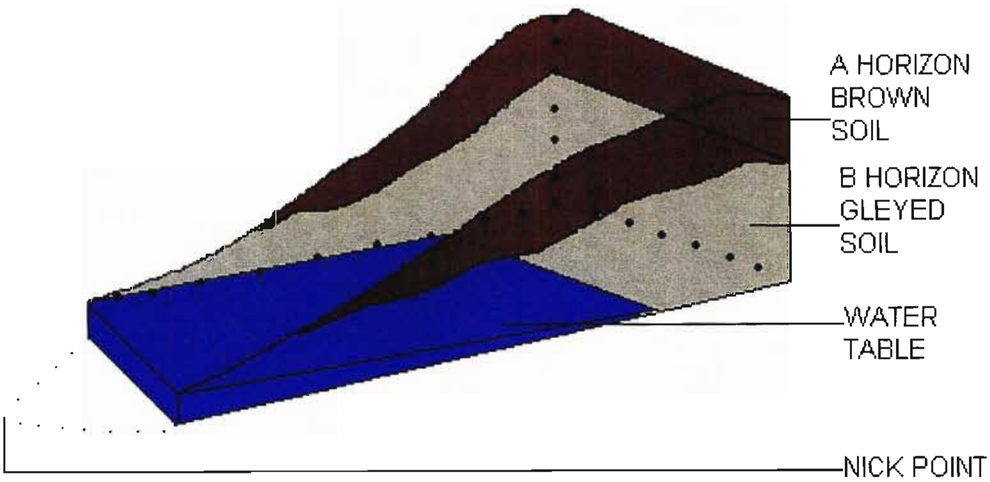


Figure 5.4 The Craigieburn wetland conceptualised within the HILLS model

5.1.1.6 The WEPP model

A small-scale soil water model that initially seemed to prove applicable and adequately accessible for the modelling exercises involved in this study was the WEPP model (National Soil Erosion Research Laboratory, 1995). The WEPP model was initially created as an erosion model, and the calculations it performs are thus based on hydrologic and soil erosion mechanics. Output variables from the model include spatial and temporal erosion and deposition values. WEPP operates in catchments consisting of hillslopes and channels ranging from simple, uniform slopes to very complex, non-uniform areas (see Figure 5.5). The model may be used at both hillslope and catchment scales, and is a distributed parameter, continuous simulation, erosion prediction model. The distributed input parameters include rainfall amounts and intensity, soil textural properties, plant growth parameters, slope shape, steepness and orientation, and soil erodibility parameters. As it is a continuous simulation model, it is able to simulate a number of years worth of hydrological output variables, for which each daily value may contain a different set of climatic input data. On each of these days a rainstorm may occur, which may cause a runoff event. If runoff is predicted to occur, the soil loss, sediment deposition, sediment delivery off-site, and the sediment enrichment for the event will be calculated and added to series of sum totals. At the end of the simulation period, average values for detachment, deposition, sediment delivery, and enrichment are determined by dividing by the time interval of choice. The entire set of parameters is important when predicting erosion.

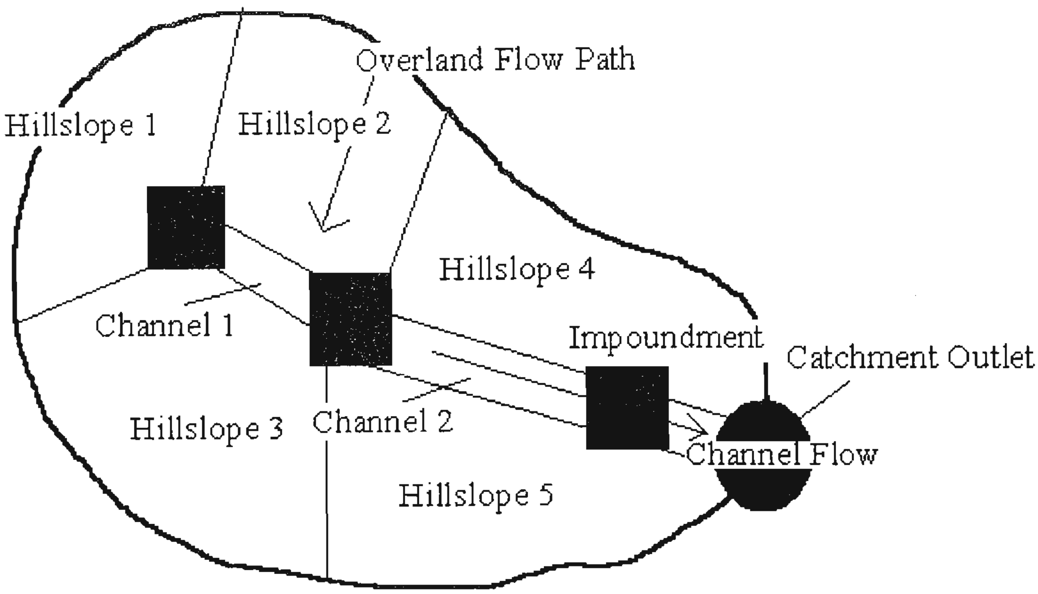


Figure 5.5 A catchment area conceptualised by WEPP

Within WEPP, a catchment is defined as one or more hillslopes draining into one or more channels (see Figure 5.6). Runoff characteristics, soil loss and deposition are first calculated on each hillslope with the hillslope component of WEPP for the entire simulation period. The most basic output one can derive from the WEPP model contains the runoff and erosion summary information, which may be produced on a storm-by-storm, monthly, annual, or average annual basis. Time-integrated estimates of runoff, erosion, sediment delivery, and sediment enrichment are contained in this output, as is the spatial distribution of erosion on the hillslope. The model predicts detachment or deposition at each of a minimum of 100 points on a hillslope, and the sum totals of these values are divided by the number of years of simulation to give average annual detachment or deposition at each point.

Figure 5.6 A WEPP conceptualisation of the Craigieburn microcatchment

Soil erosion studies performed by Tukahirwa in 1995 assessed the extent of accelerated erosion in south western Uganda at Kachwekano in the Kabale Highlands, and evaluated WEPP as a tool to predict soil erosion trends on hillslopes. WEPP proved to be sensitive to trends of erosion dynamics and predicted the soil loss within a range of observed data, but tended to overestimate runoff. This study was performed outside of semi-arid environments and for a period of barely 3 years, thus may not be very reliable in predicting long-term trends and patterns of runoff and soil loss (Tukahirwa, 1999).

WEPP has a very user-friendly interface, making it an appealing model to use, and easy to understand from the onset. It is not overly data intensive for the scope and scale of the Craigieburn microcatchment modelling exercise, but requires enough detail to accurately simulate the processes at play within the wetlands in question, such that an accurate understanding of these processes can be gleaned from the exercise. WEPP comprises three relatively simple input files to manipulate, but manipulating the fourth, the climate file, 'can be a true test of endurance' (Maritz, 2003). The CLIGEN sub-model is used to generate daily climate input data for WEPP, and CLIGEN itself requires specially formatted monthly statistical weather data as input, which are not readily available in many countries. Climate data, including rainfall amount and intensity, temperature, wind speed and direction, and radiation values are required in a specific format in any text editor as input into the CLIGEN model. This model then places the various components of the four newly created input data files together in a single file of a specific format that WEPP can read (see Appendix 7), and WEPP uses this file in its simulations (BPCDG, 1996). Daily rainfall values and temperature data for Craigieburn and the 'control' wetland were available for this exercise (see Section 2.3.3), and average rainfall intensities, wind and radiation data were obtained from the regional parameters available for South Africa found within the *ACRU* User Manual (Smithers and Schulze, 1995a).

The WEPP soil database requires input values pertaining to the percentage of sand and clay that make up each soil layer, the depth of each layer, the percentage of organic carbon and of rock in each layer and the Cation Exchange Capacity (CEC) of each layer. Much of this information was gathered from intensive on-site sampling of the soils of the Sand River catchment wetlands (see Section 2.3.4). From this information WEPP can calculate the hydraulic conductivity and erodibility of the soils in question. As WEPP was created as a soil erosion model, it is applicable to this study, (see Figure 5.7), as one of the areas of interest when comparing the Craigieburn and the 'control' wetlands is a comparison between the degrees to which each of the respective wetlands have eroded. The topographical data required are the wetland length, width and slope (see Figures 5.8 and 5.9). There were calculated using survey data involving transects plotted across the wetland area, and height and angle measurements taken (see Section 2.3.2). Extensive vegetation and land cover information was collected at the wetland sites and used as input into the management section of the model (see Section 2.3.4).

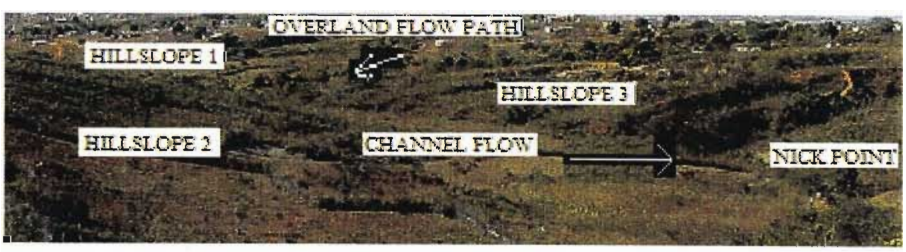


Figure 5.7 A WEPP conceptualisation of the Craigieburn wetland

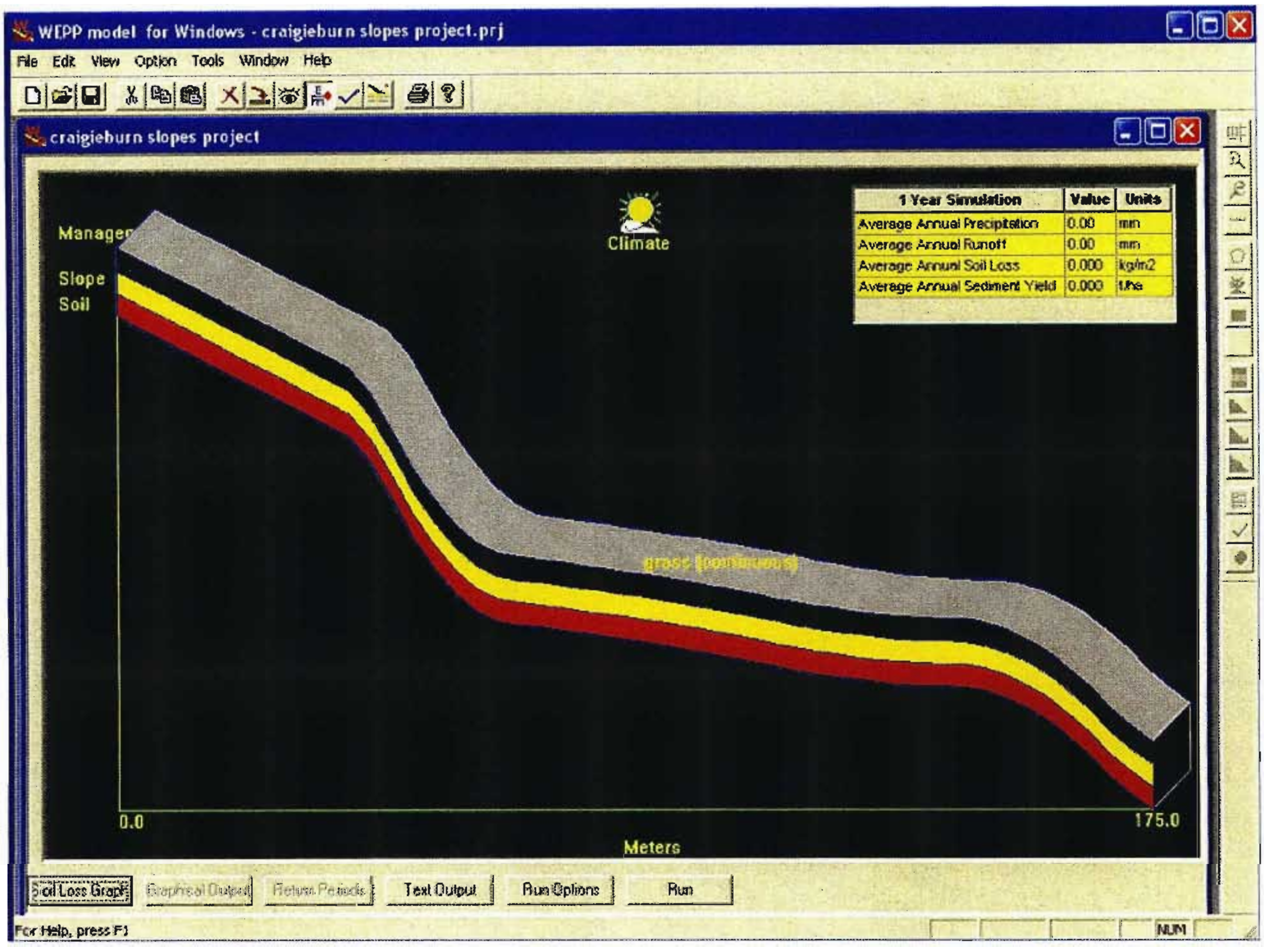


Figure 5.8 The Craigieburn wetland modelled by WEPP as a hillslope

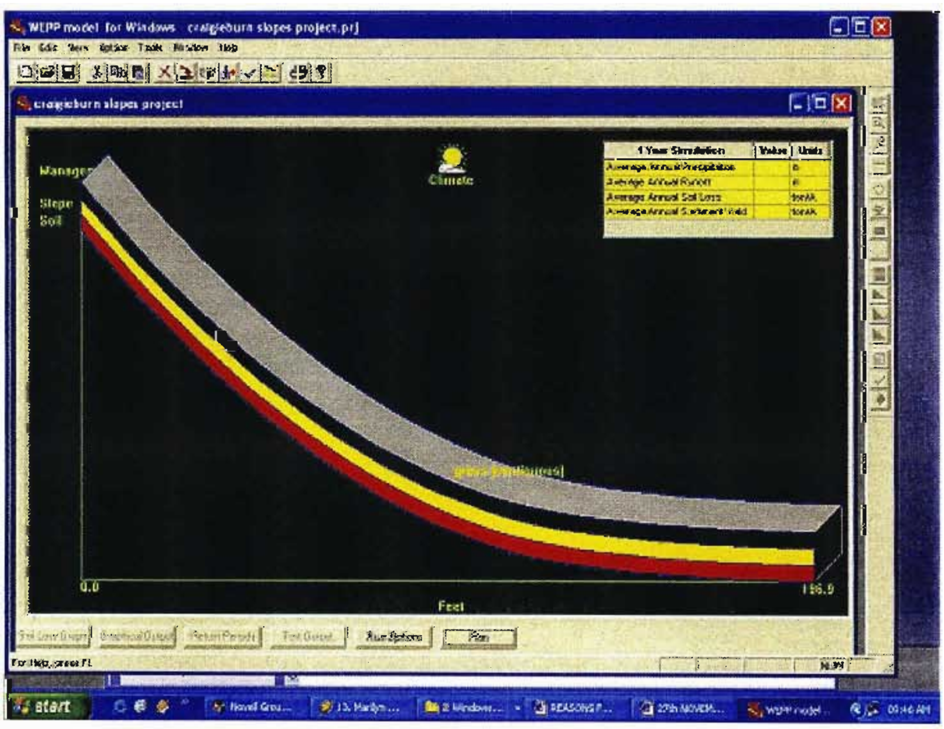


Figure 5.9 The 'control' wetland modelled by WEPP as a hillslope

WEPP is extremely sensitive to rainfall values and intensity data, and to soil and vegetation conditions at the onset of a storm. Providing that the model can be run in the 'dry season', a very important parameter is the initial saturation level of the soil, which is low in the wetlands of the Sand River catchment, especially the Craigieburn wetland. Within the Craigieburn microcatchment the soil type and the condition of the grassed area of the wetland determine the dominant runoff mechanisms. WEPP considers mainly Hortonian flow, or flow which occurs when the rainfall rate exceeds the infiltration rate. It does not explicitly consider variable partial area responses. These responses describe the movement of water that has infiltrated into the soil, flowed laterally within the soil profile, and re-emerged as overland flow at a position downslope. Lateral flow could be a more dominant process within the profile of the Craigieburn soils if the clay content of these soils were higher, but as it is not, it is suggested that Hortonian flow does not make up the dominant runoff generation mechanism operating within these soils (van Zyl, 2003).

A large amount of modelling of the Sand River catchment wetlands was performed using the WEPP model, but as it is an American-based model, user-support was not easy to acquire, and others who have used the model in South Africa have battled to use it in the past (van Zyl, 2003). WEPP has performed well in the areas for which it was designed, as it contains weather station data for these areas. Although a complex set of procedures have been designed for the creation of further, area-appropriate rainfall files that WEPP can read, this task proved unsuccessful for the purpose of this research, and user-support was limited. Thus, although WEPP did offer much potential in terms of aiding understanding of soil water processed and the intricacies of hydrological modelling and data-file creation, it did not prove successful for the proposed outcomes of this thesis.

5.1.1.7 Candidate model use conclusions

Of the models investigated, few proved able to meet the hydrological modelling aims and objectives of this study. Extensive input requirements and limited user support, among other factors, deemed many of these models inappropriate for use within this study. The advantages, disadvantages and tasks to which these models are best suited are tabulated below (see Table 5.1). Although they did not produce results that were of use within this study, working with these models did provide insight into the movement of water within hillslopes and wetlands, as well as insight into the manners in which soil-water models interpret and simulate these processes.

Table 5.1 A brief summary and comparison of the models reviewed

NAME	MODEL SPECIALITY	ADVANTAGES	DISADVANTAGES	USES
REMM	RIPARIAN AREAS	WETLAND SCALE	DATA INTENSIVE	A TYPICALLY WET WETLAND PROJECT FOR WHICH MUCH CHEMICAL DATA IS AVAILABLE
		MODELS LATERAL FLOWS	CHEMISTRY ORIENTED	
		GOOD IN WET CONDITIONS	LIMITED IN DRY CONDITIONS	
RIPARWIN	WETLANDS	SIMILAR AIMS TO THIS THESIS	EMPHASIS ON IRRIGATION	AN IRRIGATION PROJECT AIMED AT LOW-COST, SMALL SCALE FARMERS
		WETLAND SCALE	EARLY IN DEVELOPMENT PHASE	
			DIFFICULT TO ACQUIRE	
DRAINMOD	SOILS AND WATER TABLES	WETLAND SCALE	LIMITED ON WELL-DRAINED SOILS	A SIMPLE, TYPICALLY WET, WETLAND PROJECT
		NOT DATA INTENSIVE	LIMITED IN DRY CONDITIONS	
		USER FRIENDLY		
HYDRUS-2D	HILLSLOPES	WETLAND SCALE	SOIL FORM, NOT TEXTURE INPUT	A HILLSLOPE SCALE SOIL WATER STUDY OR AS A TEACHING AID
		USER FRIENDLY	BETTER WITH GAUGED DATA	
		GOOD EDUCATIONAL TOOL		
HILLS	HILLSLOPES	WETLAND SCALE	INCOMPATIBLE WITH SOFTWARE	A WETLAND SCALE PROJECT WITH SPECIFIC SOFTWARE
		EMPHASIS ON SOIL WATER		
WEPP	EROSION	CATCHMENT OR HILLSLOPE SCALE	NOT DEVELOPED FOR SOUTH AFRICA	A WETLAND SCALE PROJECT WITH EMPHASIS ON EROSION
		EMPHASIS ON EROSION	LIMITED USER SUPPORT	

5.1.2 Application of Selected Modelling Systems

Of the models that operate at a scale appropriate to the modelling of the individual wetlands that were investigated, the 'HOWWET?' model (Dimes *et al.*, 1993) was chosen to compare the likely effects of the different geomorphologic properties of the Craigieburn and 'control' wetlands on the hydrology of these wetlands. The 'HOWWET?' model operates at a scale that makes its output easily comparable with the geomorphological and sociological conclusions drawn from the research. This facilitated establishing links between the characteristics of the wetlands and the livelihoods of the local community members. Although it is not data-intensive enough to account for all the differences between the small wetlands under discussion, the point-based 'HOWWET?' model modelled the wetlands sufficiently accurately for the intended purpose of highlighting the simulated hydrological effects that certain geomorphological changes have on the wetlands, and drawing parallels between these results, the comments of the local community members, and literature pertaining to the hydrology of wetlands. A more time and data-intensive model was thus not necessary for this phase of the research.

In order to investigate the effects of land use changes on the hydrology of the microcatchment, and the effects that the Craigieburn microcatchment wetland and other small wetlands may have on the hydrology of the Sand River catchment, a more data-intensive model that operates at larger scales than that of the 'HOWWET?' model was necessary. The Agrohydrological Catchment Research Unit *(ACRU)* modelling system (Schulze, 1995) was chosen for this purpose. The *ACRU* model cannot model lateral water flows explicitly, but does contain a useful wetlands sub-model, sufficient to address the modelling aims and objectives of this study. As this sub-model operates at a scale too coarse for the intricate wetland modelling portion of this study, it cannot aid ones understanding of the intricate processes that operate within a wetland. For this reason the small-scale models were used in conjunction with the *ACRU* model. As outlined and depicted in Section 2.2.2, this study comprises three modelling objectives that operate at three different scales. The *ACRU* model is able to operate at all of these scales, thereby serving as a tool that meets the modelling requirements of this study, as elaborated upon in Section 5.1.4.

5.1.3 The 'HOWWET?' model

The model that was finally chosen to model the Craigieburn and 'control' wetlands was the 'HOWWET?' modelling programme (Dimes *et al.*, 1993). 'HOWWET?' is a computer programme initially designed to estimate the amount of rain stored as plant-available water in the soil of the area being modelled, the amount of nitrogen that has been mineralised in the soil and the amount of erosion caused by runoff water during a specified period. The model provides a water balance for either a point in a field or catchment, or for average soil conditions for the area of interest. 'HOWWET?' was conceived as a user-friendly educational tool as well as a decision support aid, thus the user interface comprises animated graphs. This aids ones understanding of the soil processes at play within the soil, and proved useful in this respect when modelling the wetlands of the Sand River catchment. 'HOWWET' proved to be neither a time nor data-intensive model. Although this is advantageous, the lack of input data limits the use of the output data, such that the values produced can be used comparatively with other 'HOWWET?' output, but are not necessarily volumetrically accurate.

Input variables include limited soil types, rainfall data, slope, organic carbon percentages, and default plant-available water capacities can be selected to customise soil responses. The effects of soils of a different texture in a climate and on a slope accurately representative of the Sand River catchment can be accurately determined, but soil types cannot be intricately customised. The soil plant-available water was customised such that typical values of soils such as those of the Sand River catchment wetlands were used. This was calculated using a soil physical properties calculator (Saxton, 1986), the results of which were verified with appropriate literature (Hillel, 1998).

5.1.3.1 Climatic variables

A set of rainfall data from the 'Wales' rain gauge (0594819W) was used for the small-scale modelling as for the larger-scale modelling exercise. As the proposed outcome of this exercise was to illustrate the potential hydrological effects of the difference in soil textures of the Craigieburn and 'control' wetlands, it was considered that it was only necessary to model the wetlands for a single year. The year chosen was the most recent year for which a full set of data is available, and this was 1999 (see Figure 5.10). As this data set spans a full year, it spans a wet and a dry season. Rainfall is entered in a simple spreadsheet calendar and output is produced as tables of total rainfall, runoff, evaporation and mineralised nitrogen; as well as a series of graphs depicting monthly rainfall, plant available water in the soil profile in relation to rainfall and runoff, soil loss and runoff, nitrate accumulation and soil moisture changes in the surface layer of the soil.

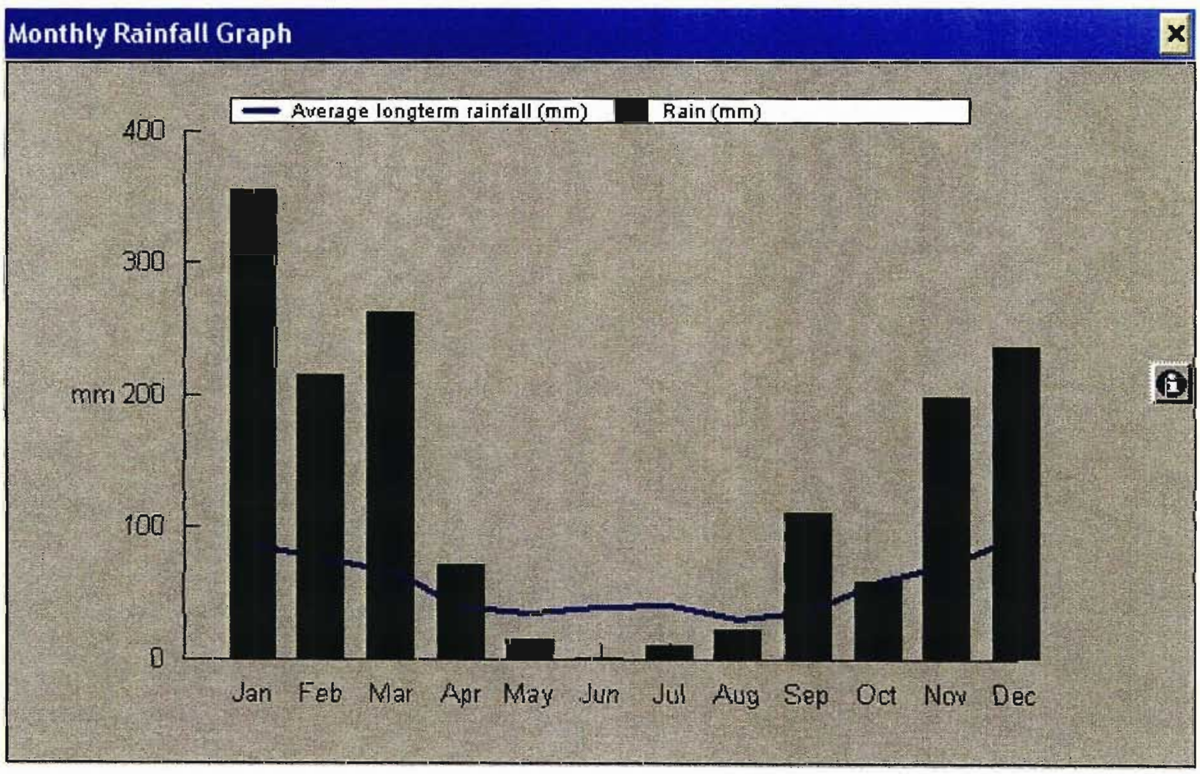


Figure 5.10 Monthly rainfall values in 1999 for the 'Wales' rain gauge as depicted by the 'HOWWET?'model

The 'HOWWET?' model was set up in order to compare the hydrological outputs from the Craigieburn wetland and 'control' wetland, under the same climatic conditions. 'HOWWET?' is a point-based model, thus it models outflow at a point, irrespective of the size of the areas being modelled. This did not deem 'HOWWET?'

inappropriate for the purpose of this modelling exercise, as the results were expected to give an accurate account of the effects of differences in soil texture on the soil water retention and release from the wetlands, but not to give volumetric values that are necessarily an accurate account of the amount of water that moves through the wetlands, such as a water balance for each land use and soil type. This is because 'HOWWET?' was created as a model that is easy to use, and not data nor time intensive, thus cannot be expected to necessarily provide volumetrically accurate results. Furthermore, the Craigieburn and 'control' wetlands are similar enough in size for this difference to be negligible when modelling at this low level of intricacy.

5.1.3.2 Geomorphological and soil variables

Representative organic carbon values for each of the wetlands were entered into the model by altering the model value representing the number of years for which the wetland has been under cultivation. This was a necessary input, as there exists a direct relationship between organic carbon levels and vegetative coverage within a wetland soil. A measure of organic carbon in a soil is a convenient laboratory measurement one can make in order to establish the amount of organic matter present in the soil. Typical organic carbon values for the soils of these wetlands were established (Packer *et al.*, 1998), and the input value specifying numbers of years for which the area has been under cultivation were altered accordingly, such that the model used these laboratory assessed organic carbon values as input values (see Table 5.2).

Table 5.2 Mean organic carbon values for various soil textures (Packer *et al.*, 1998)

MEAN ORGANIC CARBON (%)				
CLAY	FRIABLE	LIGHT TEXTURE	**MEDIUM TEXTURE**	**SAND**
1.05	1.19	0.95	1.04	**0.74**

Although 'HOWWET?' operates at a point scale, the slope of the area in question is a necessary input variable. The average slope of the Craigieburn wetland is 2.1%, as established by the geomorphological study (See Section 2.3.2). The average slope of the 'control' wetland was estimated at 1%. The approximate vegetative coverages of the wetlands in early January, estimated from site visits, were 60% for the Craigieburn wetland, and 90% for the 'control' wetland. This is because this is the wettest time of year for these wetlands, thus they are at their most densely vegetated. Analysis of the soil samples taken of the wetlands in question showed that the 'control' wetland soils are medium textured, and that the Craigieburn wetland soils are sandy. In order to model the sandy Craigieburn wetland soils such that they comprised of 0.74% organic carbon, and the medium textured 'control' wetland soils of 1.04% organic carbon, the former was specified as having been cultivated for '0' years, and the latter for 5 years. The 'control' wetland has hardly been cultivated, perhaps for fear of the area being haunted, and the Craigieburn wetland has been progressively cultivated since 1994, roughly 60% of which is currently cultivated. The underlying table (see Table 5.3) shows the input variations, aside from soil texture input values, used to model these small wetlands:

Table 5.3 Differences in input variables used within the 'HOWWET?' model for the Craigieburn and 'control' wetlands

WETLAND	PAW	SLOPE	OC	COVERAGE
CRAIGIEBURN	9%	2.1%	0.74%	60%
'CONTROL'	7%	1%	1.04%	90%

KEY: PAW: Plant Available Water

OC: Organic Carbon

Coverage: Vegetative Coverage

As the model does not account for wetlands areas, results of the scenarios were used comparatively, but the volumetric results were not considered necessarily accurate. In the above manner the effects that some geomorphological and soil textural differences have on wetland hydrology could be established, thus a clearer idea of the effects that such differences could have on water availability for a local community could also be gained. In order to further investigate the links between wetland characteristics and rural livelihoods, and to make the study more specific to the Sand River catchment wetlands, more advanced hydrological modelling exercises were performed.

5.1.4 The *ACRU* model

In order to establish the effects that changes in the composition and management of the small wetlands of the Sand River catchment may have on the hydrology of the wetlands and thus on the food and water security of the local wetland users, a more detailed, data-intensive and site specific model that accounts for re-routed water flows and land use areas, as opposed to only modelling a water balance at a point, was necessary. For this modelling exercise the *ACRU* modelling system (Schulze, 1995) was used. The Craigieburn microcatchment proved to be an appropriate site for this *ACRU* scenario-based modelling exercise, as sufficient soil, rainfall, vegetation and community wetland use data was available for this wetland-dominated microcatchment.

ACRU is a multilevel, multiple soil layer, physically based, conceptual, agrohydrological modelling system that operates at time steps of a day or less (Smithers and Schulze, 1993) (see Figure 5.11). Of the hydrological output variables *ACRU* can produce, those particularly pertinent to the modelling exercises undertaken for this thesis, in varying degrees, are total evaporation, interception by plants, catchment streamflow, stormflow and baseflow. For these exercises total evaporation is considered to include evaporation of intercepted water as well as evaporation from the A soil horizon and plant transpiration. Stormflow includes the runoff produced, after initial abstractions such as interception, from the surface of the soil and a depth of topsoil specific to the soil chosen for the simulation. Baseflow includes the water that has percolated downward through the soil profile, and is available to recharge the groundwater. Streamflow is made up of the stormflow and the baseflow.

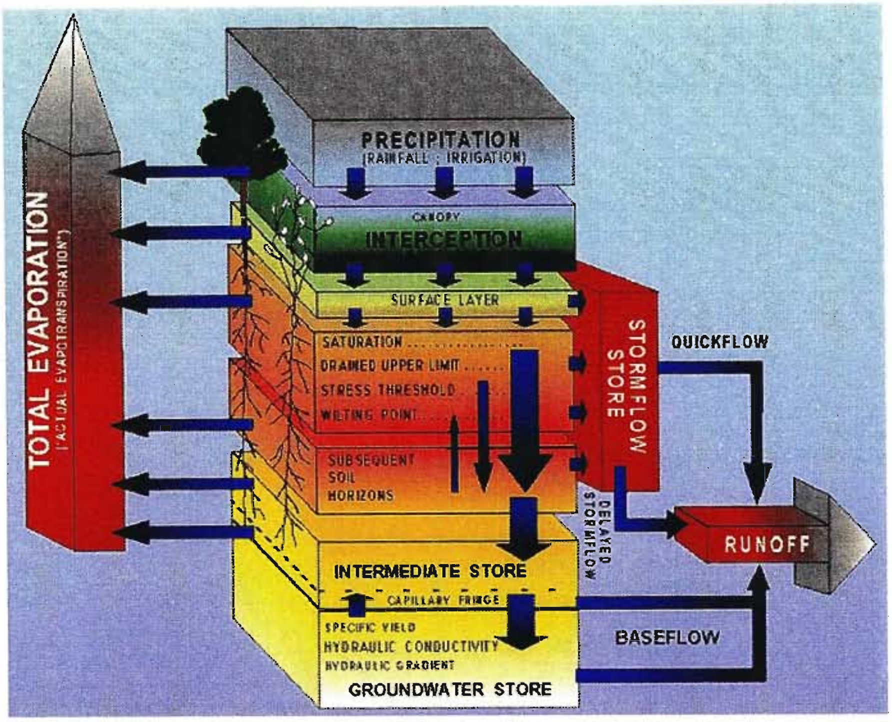


Figure 5.11 The *ACRU* agrohydrological modelling system: structure (Schulze *et al.*, 1995d)

5.1.4.1 The *ACRU* wetlands sub-routine

ACRU includes a wetlands sub-model (Smithers and Schulze, 1995b), used to model the Craigieburn wetland microcatchment. The wetland sub-model is conceptualised as a water budget (see Figure 5.12). Water losses to and gains from the conceptualised wetlands are made up of inflows and evaporation from open surfaces, transpiration from wetland vegetation, rainfall into the wetland area, losses to or gains from underlying aquifers and outflows from these features. The morphology of the wetlands is also accounted for, as are the effects of increases in ponded surface areas. *ACRU* routes the surface flows from all contributing areas into the main channel through the wetland, and routes baseflows from these contributing areas to the main channel as sub-surface flows. If the soil profile becomes saturated to the soil surface, excess water is added to the stormflow contribution (Pike and Schulze, 2000).

The wetland is modelled as a separate subcatchment with fixed outer boundaries, and free standing water in the wetland is modelled as a reservoir situated at the outlet of the catchment, modelled separately to the rest of the catchment (see Figure 5.13). The simulated streamflow from the non-permanently saturated zone of the wetland becomes inflow to the reservoir, and overflow from the reservoir forms streamflow from the catchment. A 'spillway' constricts overflow from the reservoir. The main channel through the wetland is modelled as having a defined maximum flow rate capacity and inflows from upstream catchments that exceed this capacity spill, giving rise to the non-permanently saturated soils (Smithers and Schulze, 1995a).

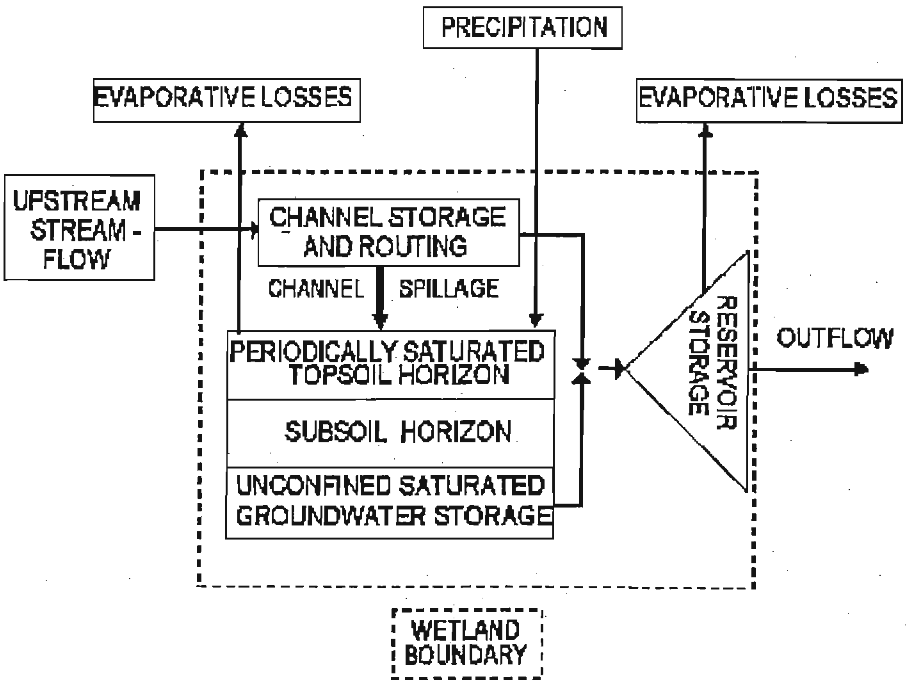


Figure 5.12 The *ACRU* wetland water budget (Schulze *et al.*, 1995d)

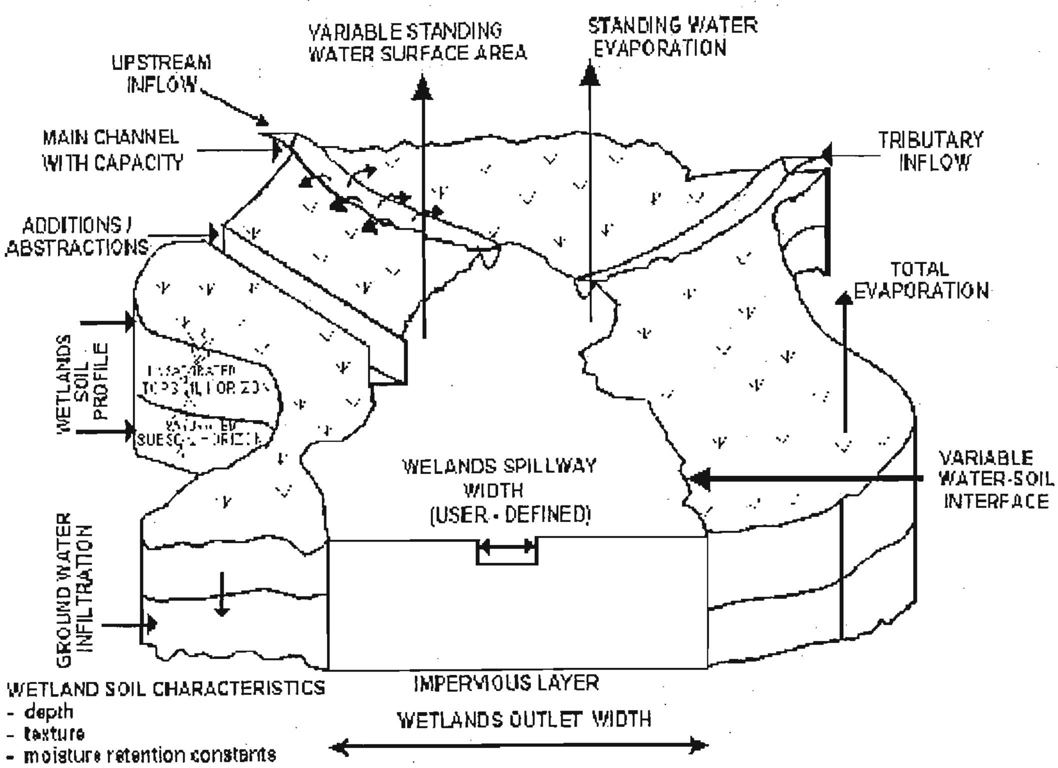


Figure 5.13 A wetland conceptualised within the *ACRU* model (Schulze *et al.*, 1995d)

5.1.4.2 Previous *ACRU* exercises relevant to this study

Motivating the decision to use *ACRU* for the modelling component of this thesis were previously successful wetland-based modelling exercises undertaken using *ACRU*, and comprehensive user support documentation that accompanies the model (Schulze, 1995; Smithers and Schulze, 1995a). A conclusion drawn from wetland modelling projects undertaken in the Ntabamhlope catchment using the *ACRU* modelling system was that the *ACRU* wetland sub-model can be used as a wetland management tool (Smithers and Schulze, 1993). The first of these exercises simulated scenarios in which firstly no wetland, then a wetland of a specified extent, and finally a wetland of twice this extent were modelled. The results were used to establish trends in total water yield, seasonal sustainability and temporal distribution of the streamflow and the effects of the wetland on flood attenuation. *ACRU* was used successfully on another occasion in a study in the Ntabamhlope wetland to determine the amount of water released from the vadose zone as a result of total evaporation, and results were calculated for two vegetation types (Donkin *et al.*, 1995). *ACRU* has also been successfully used more recently as an Integrated Water Resource Management (IWRM) tool (Schulze, 2002).

5.1.4.3 *ACRU* in the context of the Craigieburn wetland

ACRU operates in a number of 'operational modes' (see Figure 5.14), each of which is pertinent to a type of study performed at a specific scale, thereby meeting the needs of this study as a tool used for the point-based modelling exercise, the microcatchment-scale hydrological modelling exercise and the catchment-scale modelling exercise, as depicted in Section 2.2.2. *ACRU* proved to be the most complex model successfully used to simulate the Craigieburn microcatchment, and proved adequately data-intensive to use as the tool to address the modelling objectives of this study.

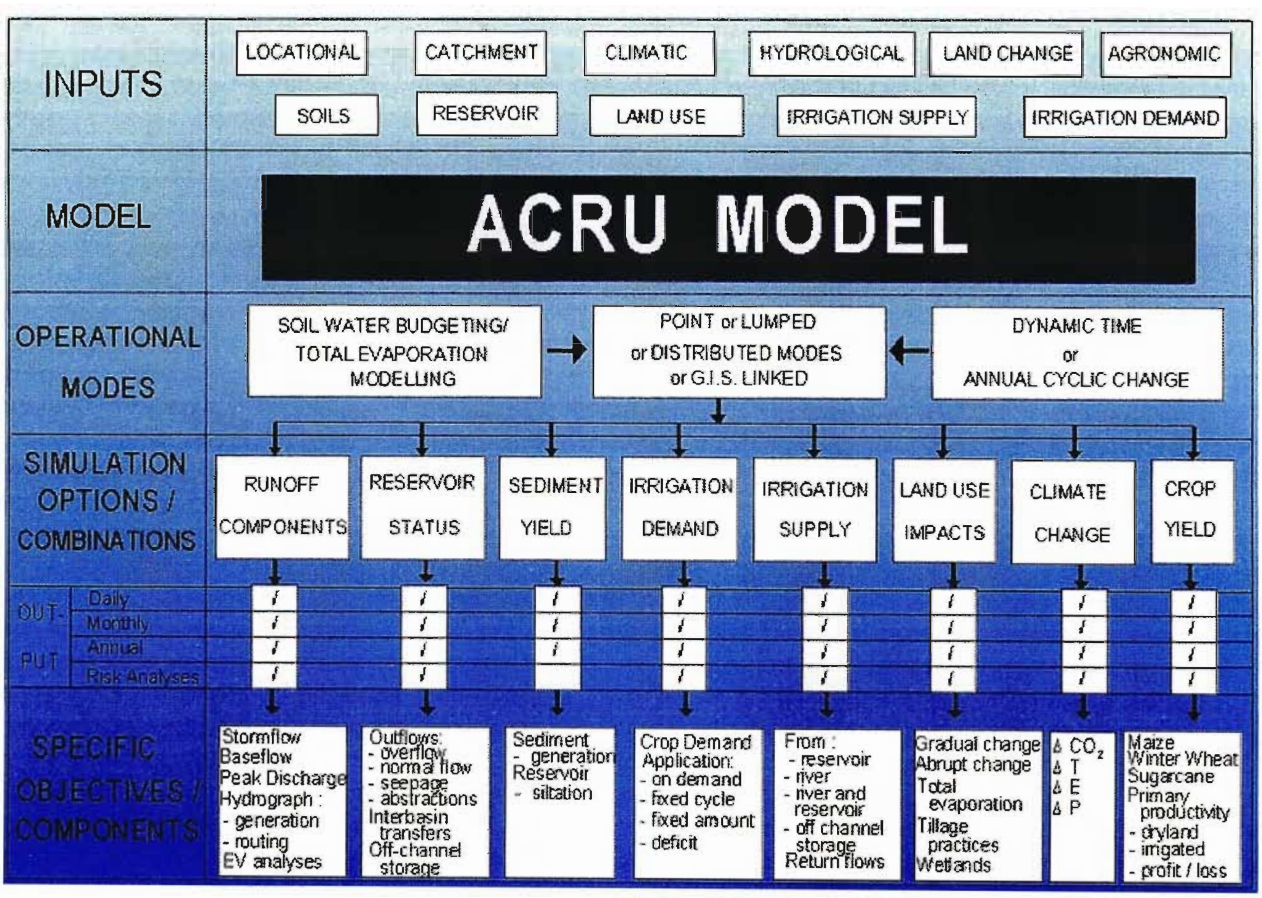


Figure 5.14 The *ACRU* agrohydrological modelling system: concepts (Schulze *et al.*, 1995d).

The point-scale modelling exercise performed in order to establish the effects of the land uses present in the Craigieburn microcatchment on the hydrology of the microcatchment, was set up such that many of the input variables were kept constant for all the land uses. In this manner hydrological outputs could be directly attributed to land use changes and their associated soils (Schulze *et al.*, 1995c). In order to simulate the effect that each of the major land uses identified in the Craigieburn microcatchment have on the hydrology of this microcatchment, *ACRU* was set up using the rainfall records (Schulze *et al.*, 1995a) from the 'Wales' rain gauge (0594819W) for the years 1950 to 2000, with the wetland option turned off (Smithers and Schulze, 1995b). This instructs *ACRU* to account for the hydrological effects felt only within the land use area specified (Schulze *et al.*, 1995b), thus does not account for inputs from upstream land use areas. Six land use and soils scenarios were simulated (see Table 5.4), as elaborated upon in Sections 5.1.4.10 and 5.1.4.9, respectively.

Table 5.4 Hypothetical land use and soil scenarios simulated in *ACRU*

NUMBER	LAND USE	SOIL
1	VELD IN GOOD CONDITION	LOAMY SAND
2	RESIDENTIAL AREA	LOAMY SAND
3	SUBSISTENCE MAIZE CULTIVATION	LOAMY SAND
4	REEDS	SANDY CLAY LOAM
5	VELD IN POOR CONDITION	SANDY CLAY LOAM
6	SUBSISTENCE MIXED CULTIVATION	SANDY CLAY LOAM

Each of the six land use areas identified was assigned an area of $1km^2$. The land uses described as 'veld in good condition', an informal, rural 'residential area', and 'subsistence maize cultivation', were simulated on a moderately deep, sandy, well drained soil, classified as a Loamy Sand; and those described as 'reeds', 'veld in poor condition' and 'subsistence mixed cultivation', were simulated on a deep, typically gleyed but still quite sandy wetland soil, classified as a Sandy Clay Loam.

In this initial, point-scale *ACRU* modelling exercise, the outputs of average monthly rainfall, interception, total evaporation, stormflow and baseflow were identified in order to perform an average monthly water balance for each of the major land uses identified within the microcatchment, as outlined in Section 5.1.4.10. This exercise was performed in order to verify that that all the components of the water balance, as modelled within the *ACRU* model, were accounted for. This water balance is described in the underlying equation:

$$I+E+S+B = R$$

Where I = Interception

E = (total) Evaporation

S = Stormflow

B = Baseflow, and

R = Rainfall

Such a water balance provided insight into the effects of changes in land use on the partitioning of water within the microcatchment, and thus into the effects thereof on water availability and security for the local community wetland users.

A second, microcatchment-scale *ACRU* modelling exercise was subsequently performed in which *ACRU* was configured to simulate catchment land uses representative of the years 1954, 1965, 1974, 1984 and 1997. A further microcatchment-scale scenario was simulated to provide an indication of the effect that 'remedial action' may have on streamflow volumes, were this action to involve converting this microcatchment back to its natural vegetation such as 'veld' and reeds. This scenario was termed the 'baseline' scenario, and involved hypothetical land uses comprising roughly 50% 'reeds' in the lower, wetter reaches, and 50% 'veld in good condition' on the upland soils, modelled for the years 1950 – 2000. Approximately half of the Craigieburn microcatchment is comprised of soils upon which reeds can grow, as the extent of reed growth in the microcatchment showed during a WRL project visit to the microcatchment in January, 2003. This hypothetical modelling exercise enabled a comparison between hydrological output values under various climatic conditions. A final microcatchment-scale scenario, termed the 'plots' scenario, was simulated in order to determine the effect that extensive cultivation of the area may be having, and may have in the future, on the volumes and timing of streamflows through this microcatchment. Hypothetical land uses comprising roughly 50% 'mixed subsistence plots' in the lower, wetter reaches, and 50% 'maize subsistence plots' on the upland soils were modelled for the years 1950 – 2000. The land use details of the abovementioned scenarios exist in Section 5.1.4.10.

Output variables analysed for these six scenarios included total streamflow, baseflow and stormflow, as well as soil evaporation and transpiration. The most representative of the output variables listed, and thus the one from which conclusions have been drawn, is total streamflow, as this variable accumulates baseflow and stormflow values from upstream land uses. In this manner the results obtained could best account for the combined effect of the various land use areas of the microcatchment on streamflow at the outlet of the microcatchment. As these scenarios route water movement as accurately as can be established, and make use of actual land use areas, they enable one to better analyse the effects of interactions between the Craigieburn wetland and the wetland users, and potential effects of changes in use, access and general management of these wetlands can be more accurately accounted for. Because the magnitudes of the results of the modelling exercise for which year-specific rainfall data was used were heavily driven by the rainfall input values, the mean annual results for the five years modelled were comparatively graphed as percentages of the total rainfall for that year, as seen in Section 6.2.2.1. In this manner the potential effects of changes in land use over the years on the hydrology of the microcatchment can still be seen.

The streamflow values typical of wet, dry and average months, for each combination of land use areas, were investigated in order to gain an indication of the regularity of streamflow under these conditions, and thus of the potential effects of such land use combinations on water security for the local community. The average daily, monthly and annual values for typical wet, dry and average months were investigated in order to determine the degree to which streamflow volumes may change within these periods. This was also performed in order to provide an indication of the reliability of the wetland as a water source under a variety of land use conditions, again in order to illustrate the degree to which the wetland provides water security to its users. The typically wet, dry and average months refer to January, June and September, respectively. These results are displayed in Section 6.2.2.2.

The following sub-sections make reference to the *ACRU* menu input variables used to run the *ACRU* model simulations in the context of this study. The example menu given in the appendices (see Appendix 8) was used to run the point-scale, land use, water balance simulations. The menus used to run the microcatchment-scale simulations for which land use areas and time-specific climatic data were used have not been included as they are identical to the appendix menu, aside from the changes that have been specified within the appropriate sections of this thesis. An example of an *ACRU* output file used for this thesis can also be found in the appendices (see Appendix 9). As these files do not present data in a manner in which they are easy to read, the pertinent *ACRU* outputs contained within further output files have been tabulated and presented within the body of this thesis.

5.1.4.4 *ACRU* configuration

ACRU can operate as a lumped small catchments model, as it does for the Craigieburn microcatchment modelling exercise based on complex, realistic past land use areas, or in distributed mode for large catchment modelling, as it does for the exercise in which the whole of the Sand River catchment has been modelled. Within *ACRU* land uses can be identified as individual subcatchments. In this way water and other media can flow from cell to cell, and each subcatchment is able to generate individual outputs. This was a necessary model requirement, as the hypothetical, point-based modelling exercise required that the cells generated individual outputs, and the microcatchment scale exercise that used land use areas required water to flow from cell to cell.

The land use configuration for the simulations involving realistic land use areas ensures that water, sediment and any other materials from each of five of the land uses lead into the wetland area characterised by reeds (see Figure 5.15). This configuration is an accurate representation of the microcatchment, as all the water in the microcatchment passes through riparian fringe wetlands on its way to the main channel.

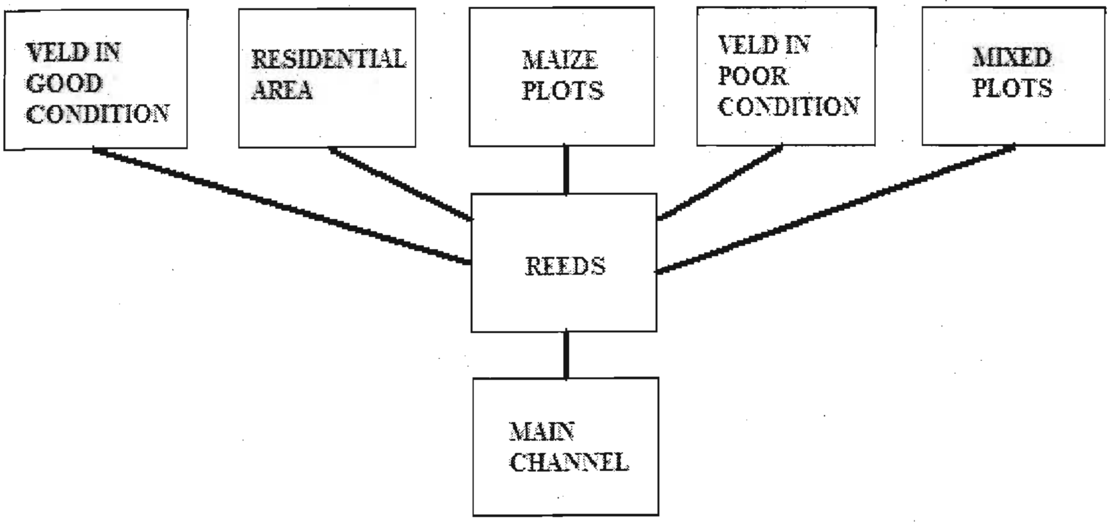


Figure 5.15 The *ACRU* configuration for realistic Craigieburn microcatchment land use simulations

5.1.4.5 Hydrograph routing

Although *ACRU* does include hydrograph routing options, these were not invoked for any of the comparative wetland simulations. The daily, simulated flow volume from upstream catchments is thus assumed to be uniformly distributed throughout the day, and daily flow volumes in excess of the capacity of the main channel through the wetland are distributed evenly over the land portion of the wetland. Any volume in excess of the full supply capacity of this channel at the end of the day is assumed to be overflow. The hydrograph routing option is applicable to modelling of large areas in which volumes of water far greater than those of the Craigieburn microcatchment are stored.

5.1.4.6 Climate input files

The rainfall file made up of the gauged data from 1950 to 2000 at the 'Wales' rain gauge site (0594819W) was used throughout the simulations. This is because this is a full, reliable set of typical rainfall data of the area. A composite data input file, comprising rainfall amounts, daily maximum temperatures and daily minimum temperatures for the area was set up for all the Craigieburn microcatchment wetland simulations, and no adjustment factor was required for the 'Wales' rainfall data as the gauge is close enough and at a similar altitude to the Craigieburn microcatchment. Data making up this input file is discussed in more detail in Section 2.3.3. Some simulations were not driven by all 50 years worth of data contained in this file, as elaborated upon in Section 6.2.2.1. Within some of the simulations for land use areas obtained from aerial photographs, only the year of climatic data was used so as to match the land use areas being simulated. The climatic data for the year 1997 was thus used in conjunction with the land use areas identified in this year and so on. In this manner hydrological output values produced by *ACRU* for these time periods are as representative of actual environmental conditions as possible, and are thus potentially of greater use when comparing these with comments made by local community members pertaining to these periods, as described in Section 6.3. Streamflow data are not available for the Craigieburn microcatchment, so the simulated streamflow cannot be verified.

5.1.4.7 Locational information

Locational information derived from 1: 50 000 maps of the Sand River catchment was input into the model. A general heading for the particular simulation; the area of the subcatchment (km^2), whether accurate or hypothetical, the average altitude (m) above mean sea level of the subcatchment; the latitude and longitude values of the centre of the subcatchment (degrees and minutes), and information pertaining to which hemisphere and which side of the Greenwich Meridian the catchment lies were obtained. Starting and ending dates of the rainfall and temperature records used, as well as values of temperatures were entered, the means of which were calculated within the model.

5.1.4.8 Potential evaporation

As mean monthly potential evaporation values were not available for the Craigieburn microcatchment, these values were calculated within the *ACRU* model. A number of options to simulate reference potential evaporation are available within *ACRU*. The equation used was chosen from a list of such equations used within the *ACRU* model. Some of the equations rely on variables for which there is limited or no data for the Craigieburn microcatchment, but the Linacre equation of 1991 (Linacre 1991) relies largely on daily maximum and minimum temperature values, of which a large amount of reliable data are available for this area, using the 'Gridded Daily Temperatures for Southern Africa' database (Schulze and Maharaj, 2003). This equation is;

$$E_{apan} = [453\, R_c(T_a + 0.006z)/(84 - \phi_d) - (72\, R_c) + 3.6\, u_{2ms}(T_a - T_d)]/[28.57(1 + 1.56\gamma/\Delta)]$$

where R_c is the radiation correction term given by:

$$R_c \quad = \quad 0.00945\varphi_d + 1.219$$

where;

u2ms	=	windspeed at 2 m (m.s-1)
Ta	=	mean air temperature (°C)
z	=	altitude (m)
φd	=	latitude (°)
Td	=	dew point temperature (°C), and
γ/Δ	=	inverse of the energy budget weighting factor

The γ/Δ term is dimensionless, and makes allowance for the relative significance of net radiation in total evaporation. The terms used for which actual data does not exist are largely calculated within the model, or default values can be obtained from the A*CRU* User Manual (Smithers and Schulze, 1995a). Mean daily windspeed (in $m.s^{-1}$) is required by the Linacre equation. If monthly windrun (km/day) data are available, this is converted to mean daily windspeed internally in the *ACRU* model. If mean monthly windrun values are not available, then the default value (1.6 $m.s^{-1}$) can be used, as is the case in the Craigieburn microcatchment simulations. Dew point temperature is calculated within *ACRU* based on minimum and maximum temperature data, and the energy budget weighting factor is contained within the model.

5.1.4.9 Soils information

Information pertaining to the soil horizon depths (m), soil water content (m/m) at permanent wilting point, at the soil's drained upper limit and at saturation, for both horizons, as well as the ease of movement of water from one horizon to the next in the Craigieburn microcatchment soils, are available from field surveys, as elaborated on in Section 2.3.4. Soil depths within *ACRU* (Schulze *et al.*, 1995c) can be specified as a number between 1 and 6. These numbers relate to different typical soil depths (see Table 5.5). The depths of the Craigieburn microcatchment soils (see Table 5.7), are referred to as 'deep' on the upslopes of the microcatchment, and are thus assigned a value of '2', and as 'very deep' in the lower reaches, and are thus assigned a value of '1'. The depths were established from measurements taken within the Craigieburn microcatchment for this study (see Section 2.3.4).

Table 5.5 *ACRU* soil depth classes in meters (Schulze *et al.*, 1995c)

Number	A horizon	B horizon	Depth
1	0.3	0.8	Very Deep
2	0.25	0.5	Deep
3	0.2	0.2	Moderately Shallow
4	0.15	0.15	Shallow
5	0.1	0.1	Very Shallow
6	0.02	0.02	Impervious (e.g. rock)

ACRU also requires a value representative of the fraction of saturated soil water distributed daily from the topsoil into the subsoil, and from the subsoil into the groundwater store. These values (see Table 5.7) can be obtained from the *ACRU* User Manual (Smithers and Schulze, 1995a), and are based on soil texture. These values are within a high range in the Craigieburn microcatchment simulations, as the soils are sandy. Soil texture values that correspond to a soil texture class were entered as *ACRU* input data (see Table 5.6). The soils of the Craigieburn microcatchment fell comfortably within a variety of sandy classes. The upland soils were classified, according to a soil texture triangle classification system (Saxton, 1986), as Loamy Sands, and the lower-lying soils as Sandy Clay Loams.

Table 5.6 Soil texture classes for which *ACRU* parameters are specified (Schulze *et al.*, 1995c)

1	Clay
2	Loam
3	Sand
4	Loamy Sand
5	Sandy Loam
6	Silty Loam
7	Sandy Clay Loam
8	Clay Loam
9	Silty Clay Loam
10	Sandy Clay
11	Silty Clay

A further input requirement is the specification of clay mineralogy. The clay mineralogy that characterises the soils of the Craigieburn microcatchment is 1:1, non-expanding Kaolinite. As rainfall intensity plays a large role in soil erosion and sediment yield, the typical rainfall intensity distribution of the Craigieburn microcatchment was specified according to available information for the region into which this microcatchment falls, as determined within the *ACRU* User Manual (Smithers and Schulze, 1995a). The initial values of soil water retention constants for each horizon were further required input values, estimated by members of the WRL project team from field surveys and from literature (Hillel, 1998). These were estimated as 8% for the A horizon and 20% for the B horizon of the soils with a Loamy Sand texture, and 13% for the A horizon, and 70% for the B horizon of the Sandy Clay Loams. The fraction of plant available water at which plant stress sets in was also estimated from field visits, and estimated as 0.4 for the 'veld in good condition', 0 for the 'residential area', 0.5 for the 'subsistence maize cultivation' plots, 0.7 for the 'reeds', 0.4 for the 'veld in poor condition' and 0.5 for the typical 'subsistence mixed cultivation' plots. Values for water content of the soils at their respective wilting points, drained upper limits, porosities and water movement to the next horizon was obtained from the *ACRU* User Manual, based on their textural classes. The final soil input values of these parameters, for soils for all the land uses were as follows (see Table 5.7):

Table 5.7 Soil property information for the land uses within the Craigieburn microcatchment

LAND USE	TEXTURE	DEPTH 'A' (m)	DEPTH 'B' (m)	WP (m/m)	DUL (m/m)	PO (m/m)	ABRESP (m/m)
VELD – GOOD	Loamy Sand	0.3	0.4	0.068	0.143	0.432	0.7
RESIDENTIAL	Loamy Sand	0.3	0.4	0.068	0.143	0.432	0.7
MAIZE	Loamy Sand	0.3	0.5	0.068	0.143	0.432	0.7
REEDS	Sandy Clay Loam	0.3	0.9	0.159	0.254	0.402	0.5
VELD – POOR	Sandy Clay Loam	0.3	0.7	0.159	0.254	0.402	0.5
MIXED	Sandy Clay Loam	0.3	0.7	0.159	0.254	0.402	0.5

KEY:

DEPTH 'A' (m) = Depth of 'A' horizon

DEPTH 'B' (m) = Depth of 'B' horizon

WP (m/m) = Wilting Point

DUL (m/m) = Drained Upper Limit

PO (m/m) = Porosity

ABRESP (m/m) = Water movement to the next horizon

5.1.4.10 Land cover information

Land cover information for each of the 6 land uses (see Table 5.8) was selected from the numerous options specified within the *ACRU* model decision support tools, which provide input parameters for a large number of options (Schulze *et al.*, 1995b). These parameters are elaborated upon in Section 6.2.1.2.

Table 5.8 Hypothetical land use scenarios simulated in *ACRU*

NUMBER	LAND USE
1	VELD IN GOOD CONDITION
2	RESIDENTIAL AREA
3	SUBSISTENCE MAIZE CULTIVATION
4	REEDS
5	VELD IN POOR CONDITION
6	SUBSISTENCE MIXED CULTIVATION

Land use 1 reflects 'veld in good condition', as this is the condition of some of the grass present in the microcatchment, and the condition in which 'veld' would be specified under rehabilitated conditions. Land use 2 refers to the residential area near the Craigieburn wetland microcatchment, and has been specified as an informal, rural area, with characteristic runoff conditions. The third land use is maize subsistence plots, as maize is a staple food source grown in the Sand River catchment, grown mostly in non-wetland plots. Maize has significantly different water use characteristics, and grows on significantly different soils to warrant naming it a separate land use from other subsistence crops. The maize option chosen specifies maize grown as a subsistence crop. The 'reeds' land use requires various variables relating to the vegetative characteristics of reeds in its calculations. Water and vegetative parameters for sedges and reeds used were those provided in the *ACRU* User Manual (Smithers and Schulze, 1995a). 'Veld in poor condition' describes much of the 'veld' in the microcatchment, and the final area represents a mixture of typical, scattered subsistence crops. In the Sand River catchment these include potatoes, groundnuts, madumbes, sweet potatoes, varieties of beans and tomatoes among other subsistence crops.

The parameters of properties of the land uses identified formed further *ACRU* input data. An explanation and summary of these parameters exist among the results of a general land use survey of the microcatchment, in Section 6.2.1.2. The land cover canopy interception loss values (mm.rainday^{-1}) are estimated from daily rainfall and Leaf Area Indices (LAI) of the various vegetation types. LAIs are estimated internally in *ACRU* using the respective vegetation crop coefficients, as are the fractions of the active root systems in the topsoil horizons of each vegetation type. The effective total rooting depth and coefficients of initial abstraction of each of the 6 respective land uses (see Table 6.4) were established from site visits to the microcatchment, and the *ACRU* Theory Manual (Schulze, 1995) and User Manual (Smithers and Schulze, 1995a). The default values available within *ACRU* for the fraction of plant available water at which plant stress sets in and the critical leaf water potential were chosen, as the aim of the modelling exercise is not to establish crop yields, thus the small differences that more precise values would make are not significant in the context of this modelling exercise. The mean temperature threshold for active growth to take place was set at 10 degrees, as this is a standard value for many vegetation types (Stock *et al.*, 2004), and because temperatures very seldom drop below 10 degrees in the Craigieburn microcatchment.

The land use areas for the microcatchment-scale *ACRU* modelling exercise performed in which *ACRU* was configured to simulate catchment land uses representative of the years 1954, 1965, 1974, 1984 and 1997 (see Table 5.9) were calculated from aerial photographs taken in the years specified (see Figures 5.16 - 5.20), and from measurements taken in the field.

Table 5.9 Previous land use areas in the Craigieburn microcatchment

	AREAS (m^2)						
Year	**VELD – GOOD**	**RESIDENTIAL**	**PLOTS – MAIZE**	**REEDS**	**VELD – POOR**	**PLOTS – MIXED**	**TOTAL**
1954	1114337	46800	5584.81	223277.8	10000	10000	1400000
1965	1064064	36000	8213.119	281722.5	10000	10000	1400000
1974	652162.6	484200	14607.8	213114.6	10000	25915.05	1400000
1984	803184.3	383400	16552.48	172514.8	10000	14348.34	1400000
1997	887663.6	352800	15535.27	120380.2	10000	13620.87	1400000

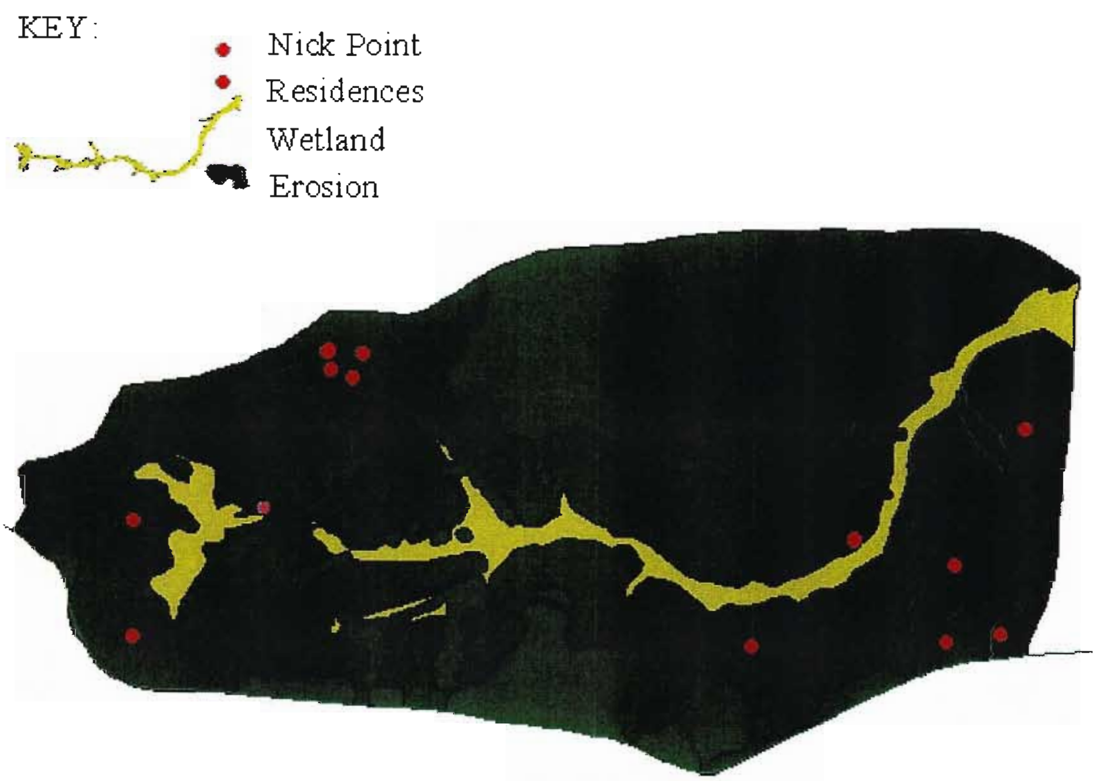


Figure 5.16 Land use areas in the Craigieburn microcatchment in 1954

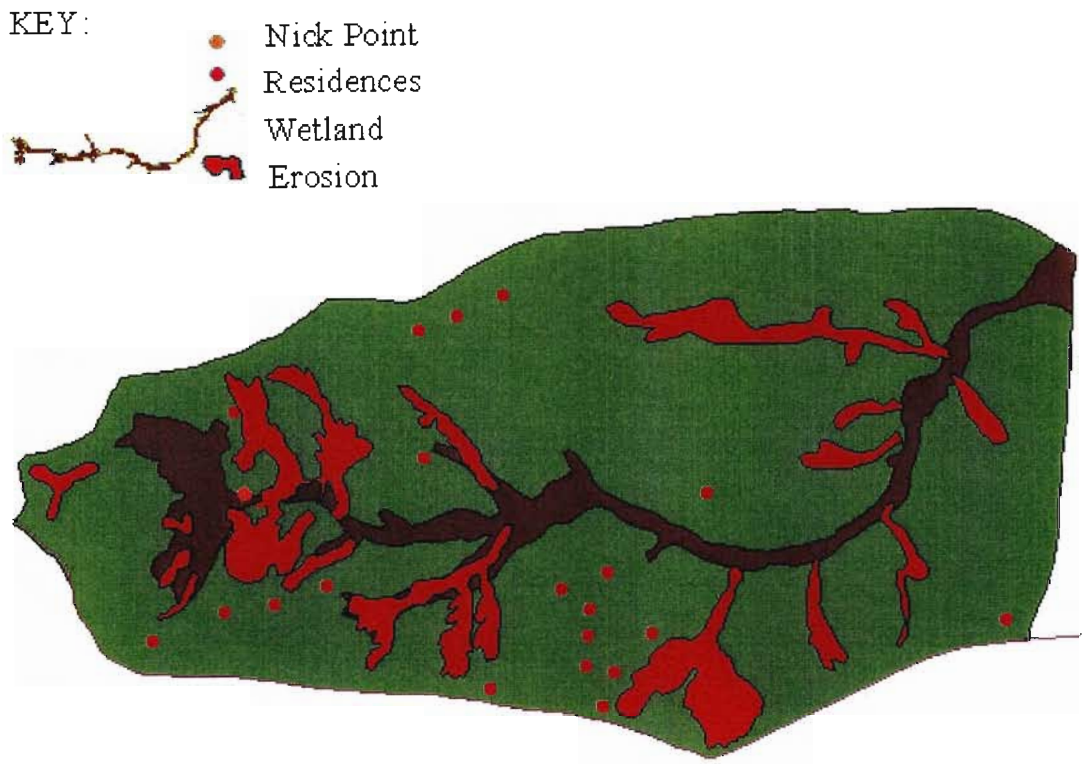


Figure 5.17 Land use areas in the Craigieburn microcatchment in 1965

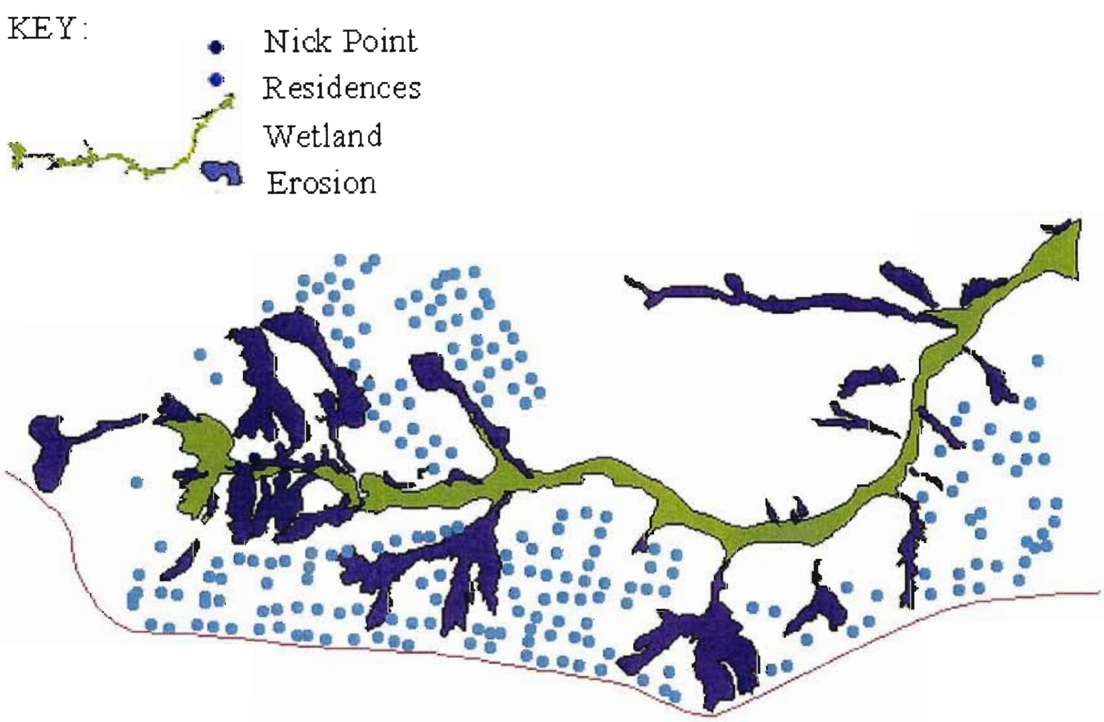


Figure 5.18 Land use areas in the Craigieburn microcatchment in 1974

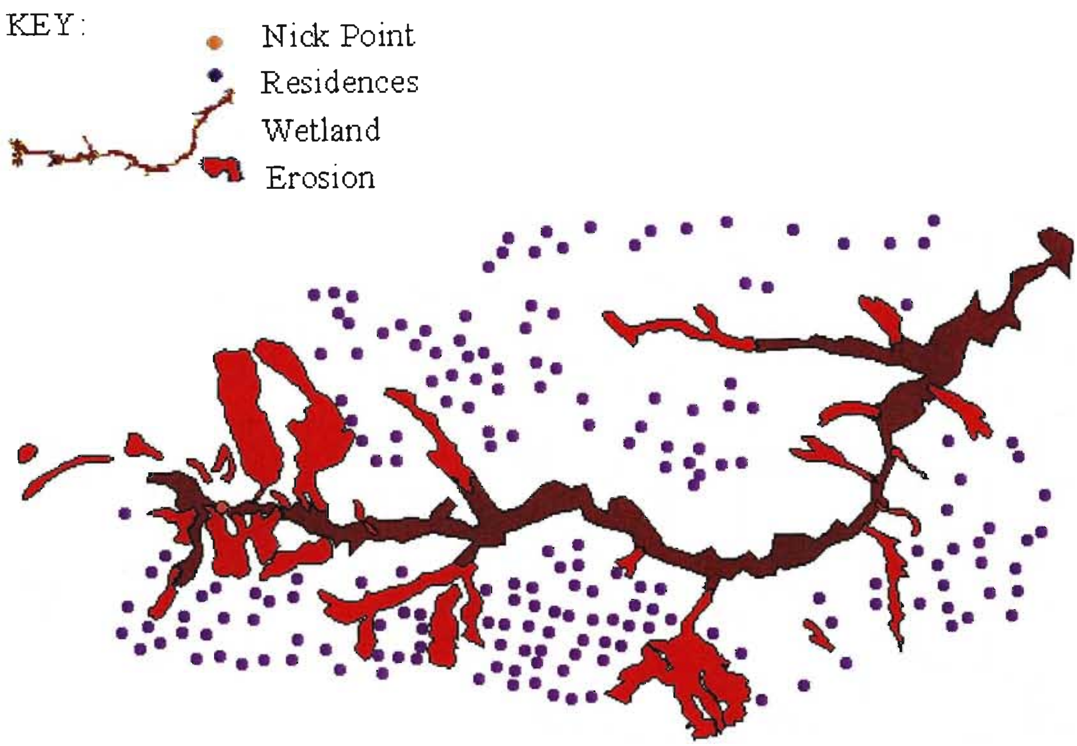


Figure 5.19 Land use areas in the Craigieburn microcatchment in 1984

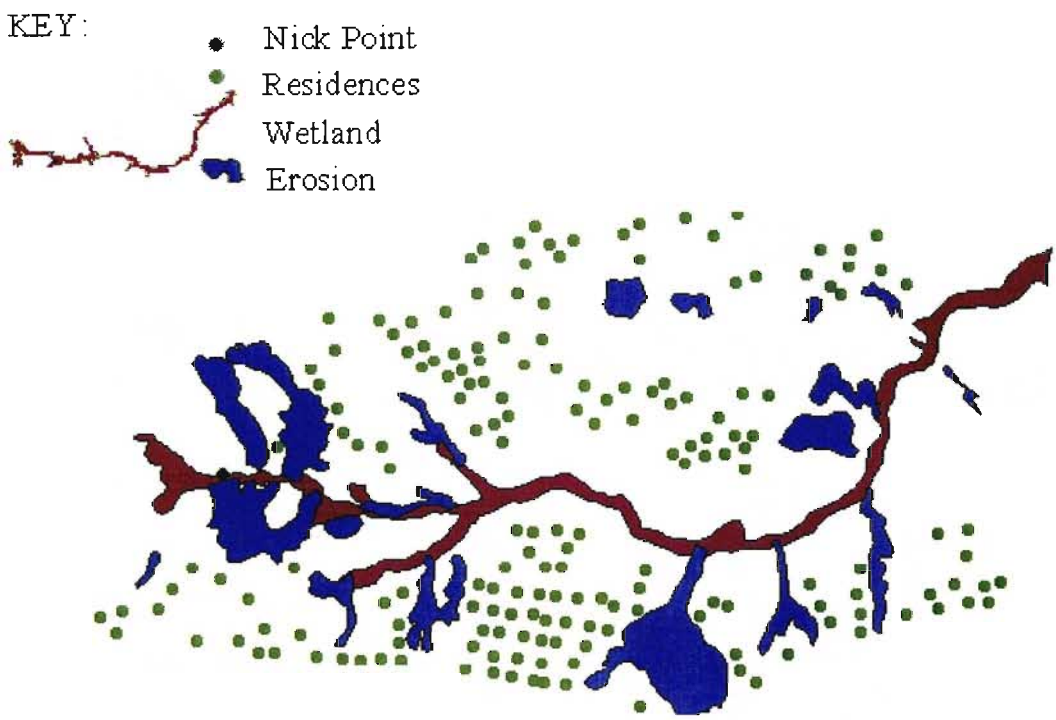


Figure 5.20 Land use areas in the Craigieburn microcatchment in 1997

The land use areas specified in the microcatchment-scale 'baseline' and 'plots' scenarios, explained in Section 5.1.4.3, were assigned values of 0.68km^2, such that the total microcatchment area, including four land uses of 0.01km^2 each, still totalled 1.4km^2 (see Table 5.10).

Table 5.10 Land use areas for the 'baseline' and 'plots' scenarios

	AREAS (m^2)						
SCENARIO	**VELD – GOOD**	**RESIDENTIAL**	**PLOTS – MAIZE**	**REEDS**	**VELD – POOR**	**PLOTS – MIXED**	**TOTAL**
BASELINE	680000	10000	10000	680000	10000	10000	1400000
PLOTS	10000	10000	680000	10000	10000	680000	1400000

5.1.4.11 Stormflow

During a large rain event only a fraction of the generated stormflow will appear on the day of the event at the catchment outlet. This fraction is made up of 'quickflow', and is low for large, flat areas, and high for steep, small areas, in highly urbanised areas, or in semi-arid areas where overland flow dominates. The variable that determines these values in *ACRU* is an 'adjunct impervious areas' parameter, the values of which were estimated for the Craigieburn microcatchment from site visits, given the typical range into which they fall, and typical values of certain land uses from the *ACRU* Theory Manual (Schulze, 1995). For example, the areas comprised of reeds were designated a low value, as little water falling in this area becomes quickflow, whereas residential, impervious areas were assigned higher values. This variable accounts for the hydrological effects of residential areas and permanently saturated areas around channel networks. Rain falling on this portion of the catchment is assumed to become part of streamflow immediately as a component of quickflow, and is not subject to other stormflow generating factors and catchment lags.

Water collected in impervious areas such as on rooftops or roads is not a factor worth considering for any of the land uses identified in the Craigieburn microcatchment except for the residential area. Parameters pertaining to stormflow calculations made up *ACRU* input requirements. The coefficient of initial abstraction is the initial amount of rainfall that does not contribute to stormflow because of initial infiltration, interception or temporary surface storage. It is generally defaulted to 0.20, but in urban or peri-urban areas it decreases to 0.05, thus 0.05 was the value used to represent the 'residential area'. In *ACRU* a fraction of the water from the groundwater store is released daily as baseflow, typical values of which range from 0.01 to 0.03. Again values for the Craigieburn microcatchment were estimated from site visits, and the areas comprised of reeds were assigned a value of 0.03, and the 'residential area' a value of 0.01.

The antecedent soil water status of a catchment significantly influences the stormflow generation process. The effective depth of the soil that contributes to stormflow generation can be left to default to the topsoil thickness, which is the option chosen for the Craigieburn microcatchment simulations. The option to exclude baseflow from the total streamflow in the statistical routines in *ACRU* was not invoked, as baseflow is an important component of these simulations, and this option is a routine used mainly when determining design stormflow (Smithers and Schulze, 1995a).

5.2 Catchment Modelling

The *ACRU* model was also used to simulate the Sand River catchment at a scale that incorporates the full extent of the catchment. A configuration that represents the Sand River catchment was previously configured by Pike and Schulze, (2000) for the *ACRU* model, and spans an area of 687km^2. This configuration does not include wetlands, thus was adopted within this study and altered to include areas that represent small wetland areas at the outlets of the Sand River subcatchments, as delineated within this configuration. When considering the model configuration at the scale of the Sand River catchment, hydrological and geomorphological information pertaining to the catchment collected previously was used (Pike and Schulze, 2000). Rainfall data for the period 1 January 1930 to 31 December 1997 was used. This data, used to drive the *ACRU* model for the configuration of the Sand River catchment, was assumed to be applicable, representative data of a good quality, as the reports produced based on previous use of this data within an *ACRU* configuration have undergone successful peer review.

An investigation pertaining to some of the hydrological aspects of managing the delivery of the ecological reserve to the Sabie river system was undertaken in 1997 (Pike and Schulze, 2000). Consequently it was necessary to refine and reconfigure the *ACRU* modelling system for the 25 Department of Water Affairs and Forestry (DWAF) Quaternary Catchments (QCs) making up the Sabie (16 QCs) and Sand (9

QCs) river systems. It was envisaged that the final configuration could be used as a hydrological modelling framework for use in future water resource conflict resolution in the Sabie catchment. Owing to the range of soils, land uses, reservoir locations and climatic variation, the QCs were subdivided into 17 subcatchments for the Sand River catchment (see Figure 5.21) with each subcatchment having its own unique climatic and other inputs. For modelling purposes, the final Sand River catchment configuration used within the *ACRU* model comprised 287 subcatchments, with streamflow from these subcatchments contributing to the streamflow values obtained from the final subcatchment (Pike and Schulze, 2000).

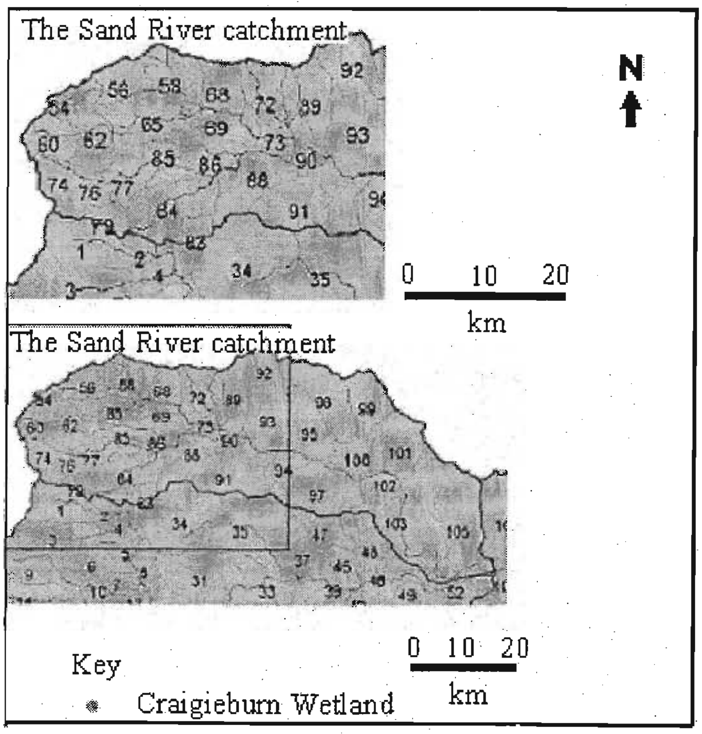


Figure 5.21 A configuration of the Sand River catchment for the *ACRU* model (after Pike and Schulze, 2000)

The final *ACRU* modelling exercise performed in the context of this study was based on this initial configuration. For this exercise the 'distributed mode' of simulation was used to model the Sand River catchment. At this scale individual subcatchments, ideally not exceeding 30 km^2, are identified, and water and other media can flow from cell to cell. The model was configured in order that four scenarios could be run, the first of which comprised no wetland areas, and was thus identical to the original configuration. Scenarios that incorporate wetland areas at the outlets to each of the subcatchments making up this Sand River catchment configuration; such that these areas made up 5%, 10% and 20% of the total area, respectively; were simulated, such that the results provided an indication of the overall effect that the wetlands may have on water yield from the catchment. Of the 287 subcatchments making up this configuration, those numbered 54-105 made up the Sand River catchment area in question for this study. These results thus potentially provide an indication of the effect of the existence of wetlands on the overall hydrology of the catchment, an understanding of the degree of water security that the communities local to these wetlands potentially gain from the presence of the wetlands, and how this security may be affected under various scenarios.

An option within *ACRU* was invoked such that the newly-created wetland areas functioned in a manner characteristic of wetland areas, as elaborated upon in Section 5.1.4.4. Areas the same size as those allocated to the newly-created wetland areas at the outlet to each subcatchment were removed from either bushland, forest or subsistence plot areas within the same subcatchment, such that the total area of the subcatchments did not change. Further simulations were modelled, in which the wetland area was increased to 5%, 10% and 20% of the total catchment area. The effect of the increased size of wetland areas on the streamflow volumes simulated in *ACRU* was investigated. The degree to which the Craigieburn wetland is representative of the wetlands of the catchment was established during an early site visit, in which the geomorphological characteristics of the wetlands were coarsely compared and found to be similar.

6. RESULTS

Assumptions made pertaining to the inherent properties of the Craigieburn microcatchment that motivated and formed the basis for this study were substantiated by further study in this area. The results of this study are presented below, beginning with a display and discussion of the results of the biophysical study performed in order to gain a thorough understanding of the Sand River catchment wetlands, and input data for the hydrological study of the Sand River catchment wetlands. This is followed by the results of the hydrological modelling exercises that made use of the results of the biophysical study, organised into separate sections for water balance studies, the study of microcatchment modelling, and the study of catchment modelling. The final sub-section addresses the potential sociological implications of these results. As the biophysical, hydrological and sociological aspects of this study are inextricably linked, and a major objective of this study is to discover these links, the aforementioned subsections incorporate all aspects of this study, although the focus changes.

6.1 Biophysical Results

The understanding of the geomorphology and the soil properties of the study area that the biophysical results provide enables one to better understand the movement of water through the soils of this area. Furthermore, the results of tests performed on the biophysical data collected in the Craigieburn microcatchment and surrounding area served both as input into the hydrological models used within this study, and as verification of results of the sociological and hydrological findings of this study. The biophysical results include a topographical survey of the Craigieburn microcatchment and downstream area and of the 'control' wetland, the textural analysis of the soil samples collected in these areas and quantities of the chemical composition of these samples by X-Ray Fluorescence (XRF) analysis.

6.1.1 Changes in topography

The topography of an area can dramatically affect the movement of water through the soil of that area. The erosive kinetic energy of the water moving through an area is directly related to velocity, discharge, sediment supply, soil loss and grain-size characteristics of the area (see Section 3.3), thus the geomorphologic analysis performed on the Craigieburn microcatchment and downstream area focuses on the topography of this area and on the relationship between the topography and the particle sizes of the soils of this area. The closeness of the relationship between soil loss and water movement is illustrated by the runoff and soil loss results of the 'HOWWET?' model, as shown in the underlying 'screen dump' produced by the model, which assumes a very direct relationship between these processes in order to calculate these output values (see Figures 6.1 and 6.2). Although 'HOWWET?' is a point-based model, it does account for the gradient of the slope under investigation.

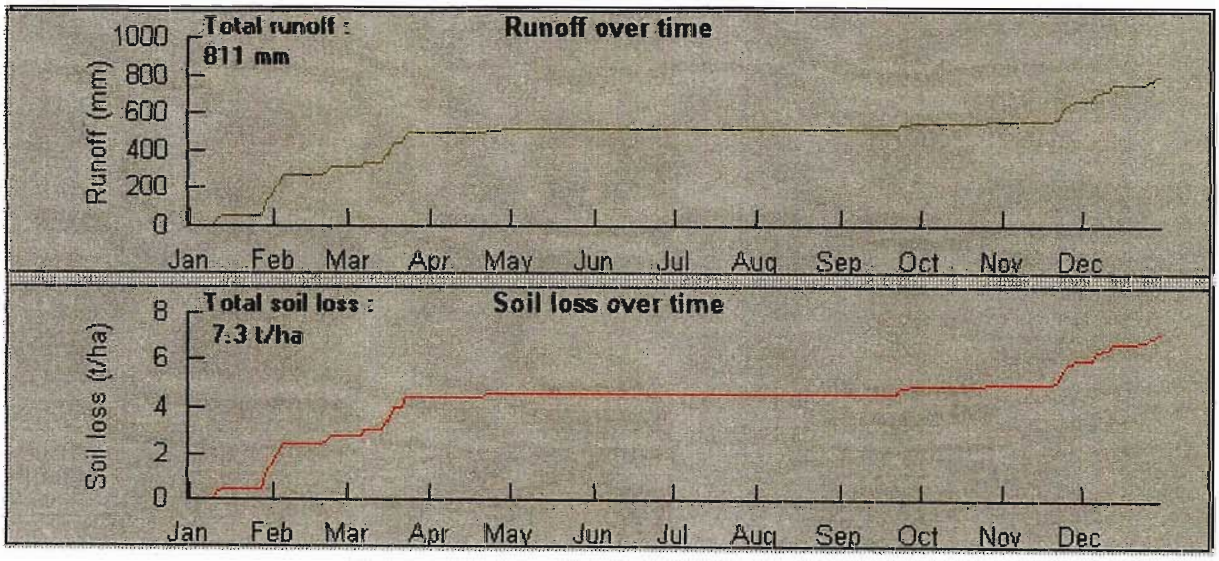


Figure 6.1 Runoff and soil loss over time for the Craigieburn wetland calculated by 'HOWWET?'

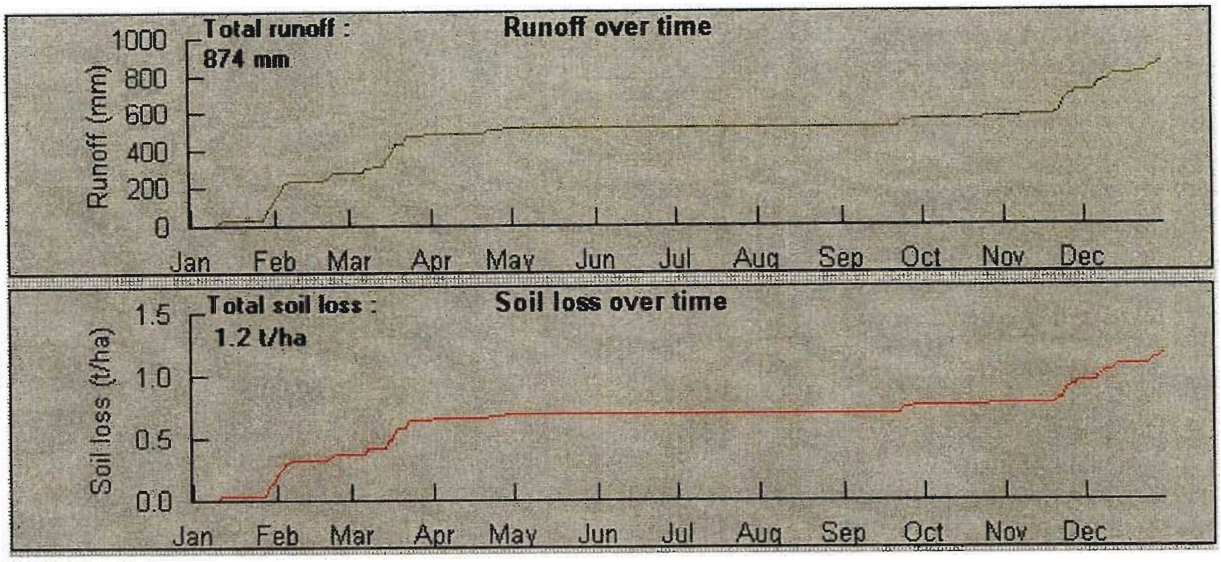


Figure 6.2 Runoff and soil loss over time for the 'control' wetland calculated by 'HOWWET?'

Parts of the topographical analysis of the area downstream of the Craigieburn microcatchment (Ellery, 2004), although not specifically under investigation within the scope of this hydrological study, has been briefly included below, in order to illustrate the relationships between topography, particle size and soil water movement in this area. The relationship between particle size and soil water movement is further illustrated in Section 6.2.1.1.

Gradients throughout the Craigieburn microcatchment and downstream area (see Figure 6.3) vary in accordance with the degree of gully erosion incurred (see Figure 6.4). The Craigieburn microcatchment has a mean longitudinal gradient of 0.21m/m in the area upstream of the encroaching gully erosion (B-D). This is the area under consideration for the modelling of the Craigieburn microcatchment using the *ACRU* model. Downstream of the microcatchment a nick point approximately 4m high can be seen (D-E), and downstream of this the gradient is 0.11m/m (E-F). The erosion donga downstream of the wetland has become increasingly densely vegetated, and in its lower reaches its gradient changes to 0.23m/m (G-I). The hydraulic conductivity of the area downstream of the Craigieburn wetland and microcatchment is high as a result of the coarse texture of the soils that make up the wetland, and the catchment in general, and the degree of erosion present in the area. The percentage of fine particles (silts and clays) in the soils of the microcatchment increases slightly downstream, but below the nick point the sediment is again extremely coarse. The soil textural composition that both influences and is influenced by the topography of the Craigieburn microcatchment and downstream area is elaborated upon in Section 6.1.2.

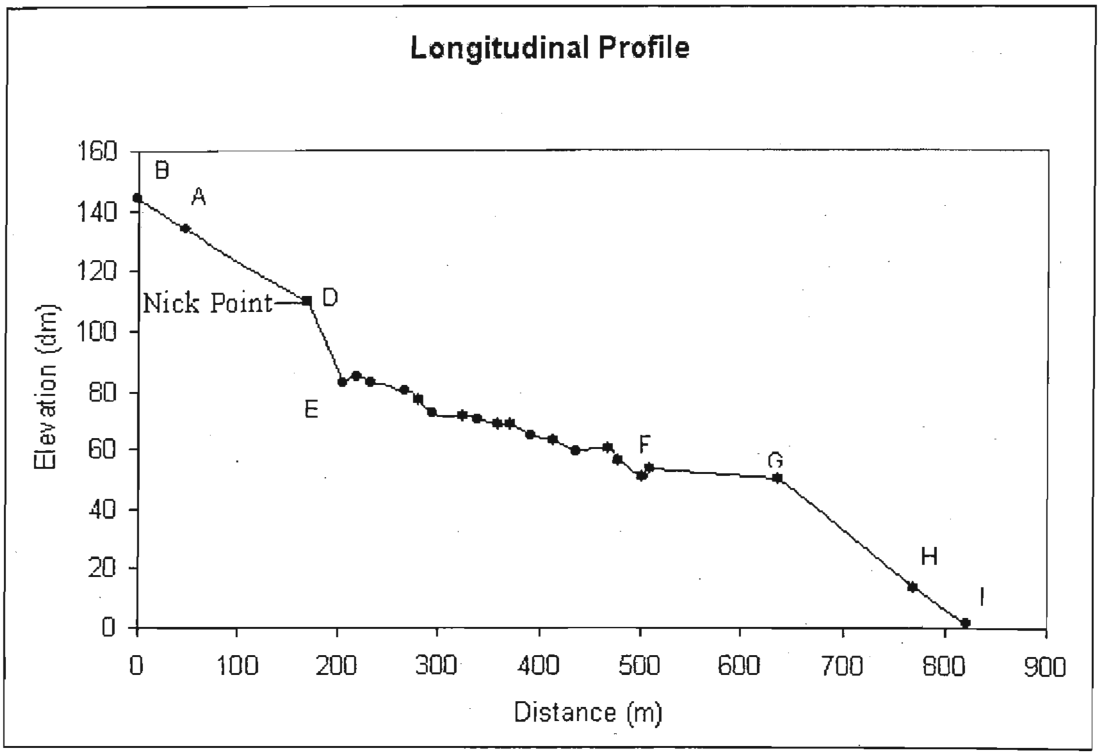


Figure 6.3 The longitudinal profile of the Craigieburn microcatchment and downstream area (Ellery, 2004)

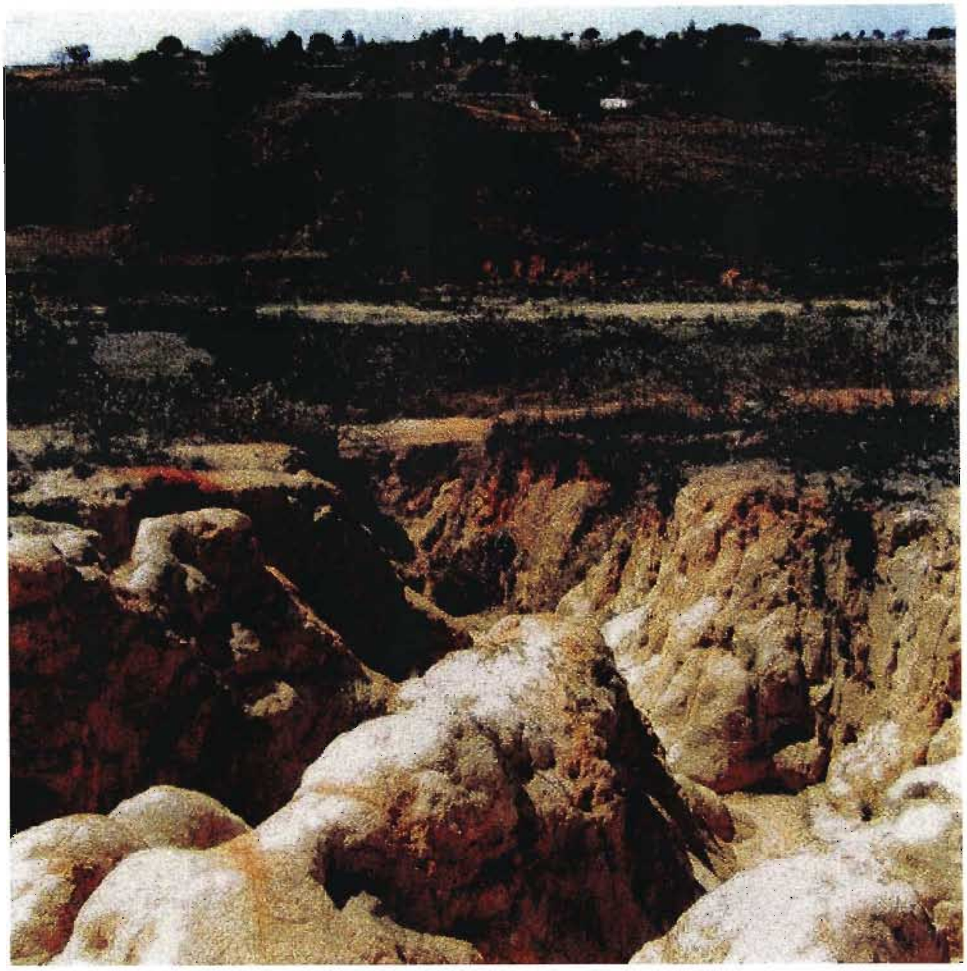


Figure 6.4 An erosion gully downstream of the Craigieburn wetland

The changing gradients indicate that the downstream area is considerably oversteepened, as a result of low discharges of water from the Craigieburn wetland. This means that the area is of a gradient steeper than would be expected as a result of weathering or deposition processes. The oversteepening of the wetland can, in part, be attributed to the vegetation found at the head of the wetland, which lowers water velocities and traps sediment at this point. Sediment accumulates in response to flow velocity, thus accumulation occurs behind vegetation clusters that attenuate the flow of water through the landscape. Sediment, especially fine particles, is lost from the rest of the wetland as a result of the high hydraulic conductivity of the wetland soils, the removal of natural vegetation throughout the microcatchment, and the erosion nick point at the base of the wetland, indicative of increased erosion moving upward through the wetland (Ellery, 2004).

In a self-sustaining manner, the sediment-trapping vegetation at the head of the Craigieburn wetland causes oversteepening of the wetland, and the oversteepening causes low current velocities, low hydraulic radii and dense, newly emergent vegetation in the wetland. This vegetation causes areas of high roughness, and the dense mass of fine roots of these species binds the sediment, limiting sediment entry into the channel. Maintenance of this vegetation is vital for protection of the wetland, and agricultural practices that damage this vegetation cover will further degrade the wetland, as erosion will result when initial slope readjustment takes place.

Results of the topographical survey of the 'control' wetland show that the average slope of this wetland (1%) is more gradual than that of the Craigieburn wetland (2.1%). Differences between the properties of these small wetlands are tabulated in Section 5.1.3.2. The narrow, riparian fringe 'control' wetland performs typical wetland functions of water and sediment retention and houses a variety of wetland vegetation. Soil survey texture data presented in Section 6.1.2 and 'HOWWET?' modelling results presented in Section 6.2.1.1, verify initial assumptions about the make-up and properties of this wetland, made when the geomorphology and hydrology researchers of the WRL project first encountered the wetland. It was assumed that it is a wetland that contains more water than the Craigieburn wetland does throughout the year, largely as a result of its smaller gradient and because it comprises less sand particles and more silt and clay-rich soil. It is more densely vegetated than the Craigieburn wetland, yet many of the same vegetation types were encountered in both wetlands (see Appendix 10). Its outlet meets the tributary upon which the Craigieburn wetland is found, and its position relative to the Craigieburn wetland can be seen in Figure 1.4. It comprises a distinct main channel than drains it, unlike the Craigieburn wetland in which increased numbers of subsistence plots and erosion have altered the course of and lessened the volume of water flowing through it.

Although subsistence plots are present in this area of the catchment (see Figure 6.5), far fewer plots are present in this wetland, despite its evidently favourable farming conditions, and gradual slope. A theory offered by a local community member to explain this phenomenon is that this area of the catchment is home to an evil spirit, thus members of the local community fear cultivating this area.

Figure 6.5 Plots alongside the 'control' wetland

6.1.2 Soil texture

As Section 6.1.1 highlights, the topography, soil textural composition and movement of water through the Craigieburn microcatchment are inter-determined. The results of the 'HOWWET?' modelling exercise illustrate the relationship between water movement and soil texture in the Craigieburn microcatchment and surrounding area, by means of a comparison between the hydrological responses of the Craigieburn wetland and the 'control' wetland. Early assumptions made based on field visits to the Craigieburn wetland and the 'control' wetland were that the textures of the soils making up the Craigieburn wetland differed from those of the 'control' wetland, leading to differences in hydrological properties between these wetlands. Subsequent laboratory tests performed on these soils confirmed their textural differences (see Table 6.1). These results formed part of the input data for the hydrological model 'HOWWET?', described in detail in Section 5.1.3.

Although only the results of the 'HOWWET?' model are highlighted in this part of the study, many candidate models were explored and added value to this study. As mentioned in Section 5.1.1.4, the HYDRUS-2D model uses soil forms, as opposed to soil particle size percentages, as input data. For this reason a soil texture triangle (Saxton, 1986) was used in order classify the soils of the respective wetlands (see Figure 6.6). Results showed that a significantly higher sand percentage is present in the soils of the Craigieburn wetland than in those of the 'control' wetland, and significantly more clay is present in those of the 'control' wetland. Using this classification system, the average texture of the Craigieburn 'A' horizon soils is a Sandy Loam, and the 'B' horizon a Loamy Sand. The 'control' wetland comprises of a Sandy Clay 'A' horizon and a Loamy 'B' horizon. When using this data to specify soil textures within the *ACRU* model, the 'A' and 'B' horizons are not classified separately, thus the Craigieburn upland soils are classified as Loamy Sands, and the lower-lying soils as Sandy Clay Loams.

The underlying table represents the average percentage values obtained from all the allocated soil sample plots in each of the wetlands. Examples of the data from which this table was constructed exist in Appendix 5, the transect labeling of which is consistent with that used in Section 2.3.2.

Table 6.1. Soil texture classification summary table

Upper 0 - 10 cm of the soil profile			
	Average % Sand	**Average % Silt**	**Average %Clay**
Craigieburn wetland	72.62	8.46	18.92
'Control' wetland	48.50	26.04	25.46
Lower 40 – 50 cm of the soil profile			
Craigieburn wetland	78.05	9.22	12.73
'Control' wetland	47.97	35.40	16.63

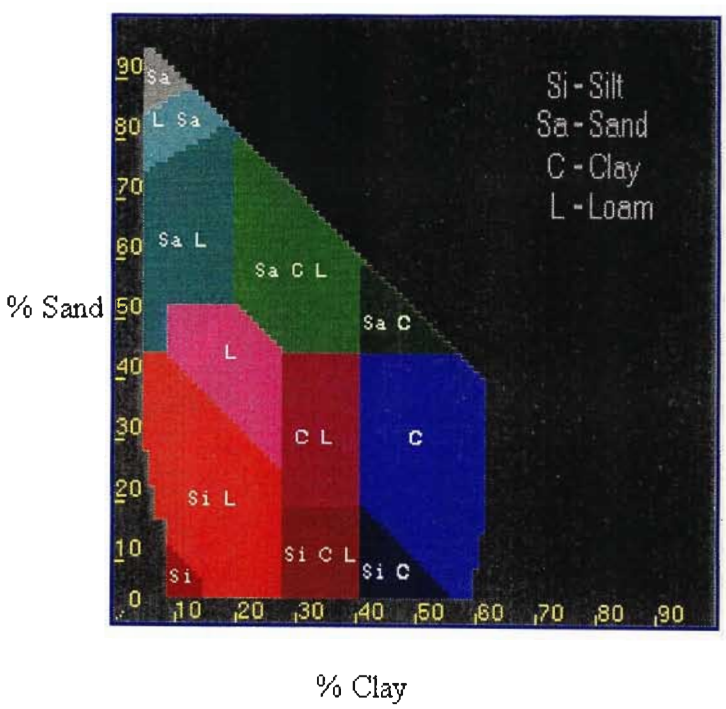


Figure 6.6 Soil texture classification triangle (Saxton, 1986)

Following the analysis of the soil results, the 'HOWWET?' model was employed to test the aforementioned assumption that these soil differences would result in different hydrological responses.

6.1.3 X-Ray Fluorescence results

Initially it was assumed by the WRL project team that the inherent properties of the granite derived soils of the Craigieburn wetland lead directly to the desiccation of the wetland. Such parent material typically produces sodic soils that show a marked increase in clay content down the profile. These soils are also prone to erosion. The XRF analysis (Ellery, 2004) performed on the soils of this wetland (see Appendix 6) proved these initial assumptions incorrect. Although detailed laboratory analysis of soils in the Craigieburn wetland revealed the presence of sodium in high concentrations, producing values that are generally greater than 1% and occasionally greater than 5%, these are not classified as sodic soils. Sodic soils refer to soils in which high concentrations of sodium have built up and have weakened the forces of attraction of the soil particles to one another, thereby reducing the cohesiveness of the soil, and making it more erodible. As a result of the lack of clay particles within the Craigieburn wetland soils, the sodium in the soils does not adhere to the soil particles easily, thus a build-up of sodium will not occur, and the sodium levels will not contribute to dispersion and erosion of the soils.

The XRF analysis results also show that there is not a marked increase in clay content down the profile (see Appendix 6) as was expected by the WRL researchers. These results are verified by those of Table 6.1. Clay content is measured by the presence of aluminium ions, as the clay minerals present in these granite derived soils are aluminium silicates. Soils that increase in clay content down the profile that are typical of the granitic terrain of the Sand River catchment are commonly known as duplex soils, identifiable by an evident line within the profile after which the clay content of the soil increases considerably. Duplex soils typical of the granitic terrain of the Sand River catchment are not present in the Craigieburn wetland, as the wetland is located at a high altitude where weathering rates are matched by rates of erosion, such that localised redistribution of material within the landscape is not a predominant process. The assumption that these soils are highly weatherable and markedly prone to erosion as a result of their parent material was thus proven incorrect, and the soils were classified as moderately erodible, as apposed to highly erodible (Ellery, 2004). The inherent properties that the Craigieburn wetland displays as a result of its parent material are a lack of fine particles and an abundance of sand particles in its textural composition. The inherent properties that this wetland displays as a result of its position in the landscape are an oversteepened gradient and reduction in vegetation, and these factors do make the wetland prone to erosion, and thus to desiccation (Ellery, 2004).

6.2 Results of the Hydrological Modelling

The results discussed in this section include water balance analyses performed using the selected models. The 'HOWWET?' model results depict the 'control' wetland and the Craigieburn wetland simulations, and focus on the manner in which the water balance within these small wetlands is affected by the different soil textural properties of these wetlands. The *ACRU* model results depict simulations of the water balance for different land uses in the Craigieburn microcatchment, of which the Craigieburn wetland makes up a large part. Further *ACRU* model results include simulations of the effects of land use changes in the Craigieburn microcatchment, as well as those of the hydrological effects of the existence of wetlands in the Sand River catchment.

6.2.1 Water balance studies

In order to identify the effects of changes in land use and soil conditions on the hydrology of the Craigieburn microcatchment, a series of water balance studies were performed at the 'plot scale' (see Figure 2.2). The 'HOWWET?' model was used to simulate the hydrological effects of the differences in soil texture measured in the Craigieburn and 'control' wetlands, and the *ACRU* model was used to perform a water balance for each of the major land uses identified within the microcatchment. Such a water balance provided insight into the effects of changes in land use on the partitioning of water within the microcatchment, and thus into the effects thereof on water availability and security for the local community wetland users.

6.2.1.1 'HOWWET?' results

Results of the 'HOWWET?' modelling exercise suggest some reasons for the desiccation apparent in the Craigieburn wetland, which is not present in the 'control' wetland. As explained in Section 5.1.3.1, the 'HOWWET?' model was driven by rainfall data collected at the 'Wales' rainfall station for the year 1999. Results of the 'HOWWET?' modelling exercise show lower values of surface moisture present in the Craigieburn wetland than the 'control' wetland throughout the year simulated (see Figures 6.7 and 6.8). These results can be attributed to the sandier textural input values of the Craigieburn wetland. The sandier soils of the Craigieburn wetland comprise of larger inter-particle pores than those of the less sandy 'control' wetland, leading to higher infiltration rates. In such a manner water is more quickly and readily drained away from the surface of the Craigieburn wetland soils. The 'control' wetland produces higher surface moisture values as soils of a less sandy texture exhibit greater water retention capabilities.

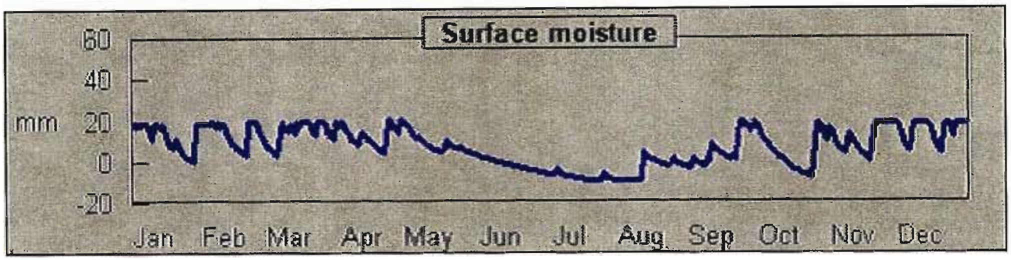


Figure 6.7 Monthly surface moisture conditions in the Craigieburn wetland calculated by the 'HOWWET?' model

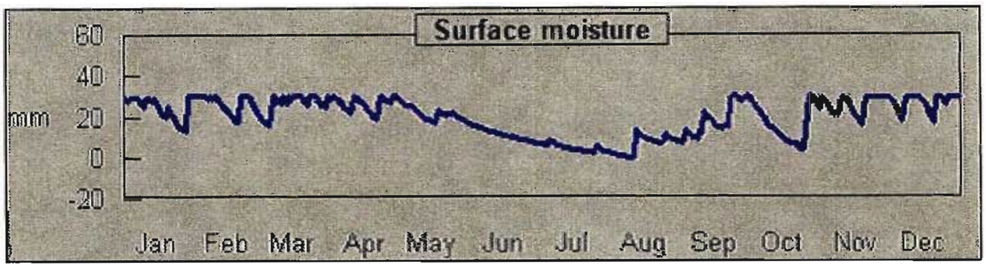


Figure 6.8 Monthly surface moisture conditions in the 'control' wetland calculated by the 'HOWWET?' model

The surface moisture evident when visiting the 'control' wetland during the typically dry months of June and July, absent from the Craigieburn wetland, can be attributed to a number of factors. These include the less sandy soil texture and consequently higher water retention capability of the 'control' wetland, as accounted for by 'HOWWET?', and because water drains away from it at a slower rate as a result of its lower gradient. Furthermore, at the exit to this wetland, in stark contrast to the erosion donga nick-point present at the outlet to the Craigieburn wetland, lies a 'clay plug'. This plug is a collection of finer soil particles, specifically the clay and silt particles present in the soil, as well as organic matter, positioned in the narrow outlet to the wetland, where the fine particles are deposited, trapped, and consequently build up, also causing a build up of water behind the plug.

The greater values of plant-available water in the Craigieburn wetland (see Figures 6.9 and 6.10) simulated by the 'HOWWET?' model can also be directly attributed to the sandier texture of the soil of this wetland (see Table 6.1). As clay-rich soils hold water at higher tensions than sandier soils, the energy barrier that is set up at the soil/water interface is commonly too great for the plant roots to break, thus although clay-rich soils hold more water than sandier soils, much of this water is unavailable to plants. These results appear to contradict the visual evidence of greater vegetation densities in the 'control' wetland, largely because 'HOWWET?' cannot perfectly customise soil texture input data. Despite being more clay-rich than the soil of the Craigieburn wetland, the soil of the 'control' wetland is a soil from which typical wetland vegetation can easily extract water.

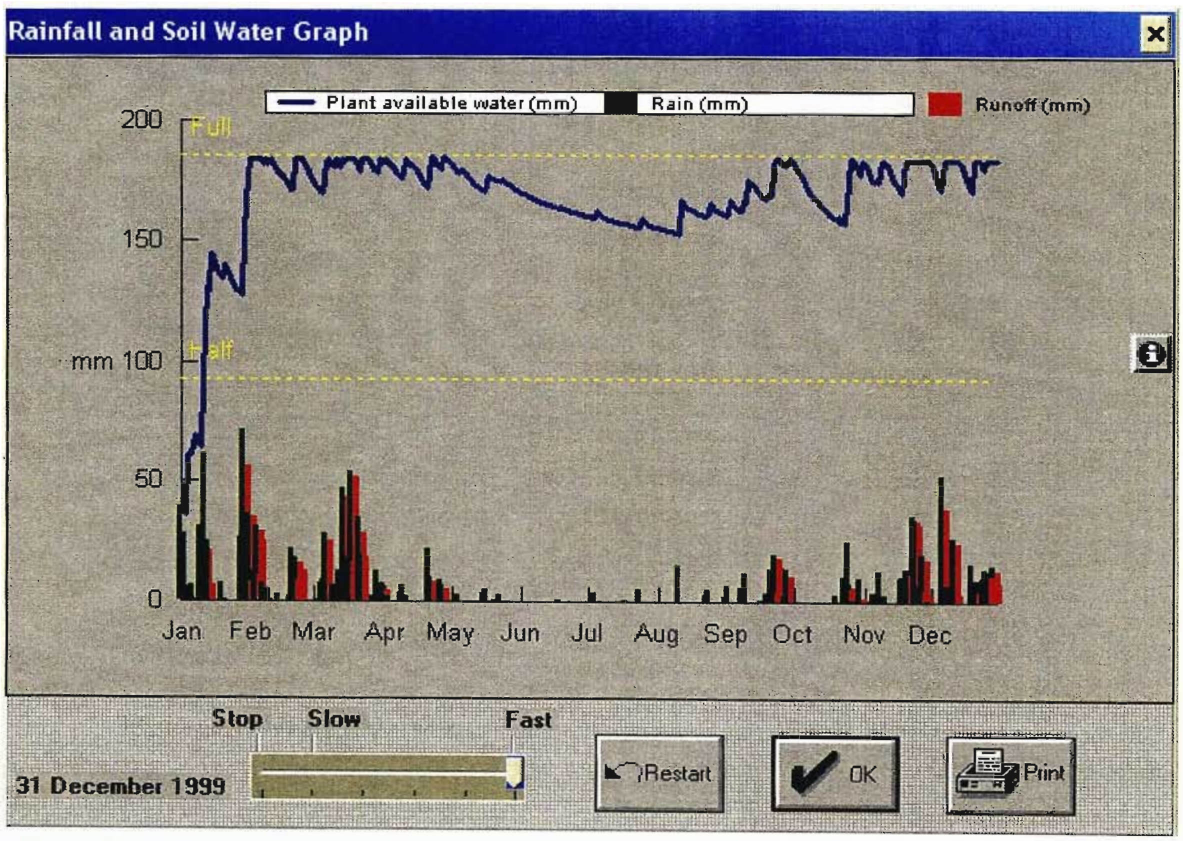


Figure 6.9 Plant available water in the soil of the Craigieburn wetland calculated by the 'HOWWET?' model

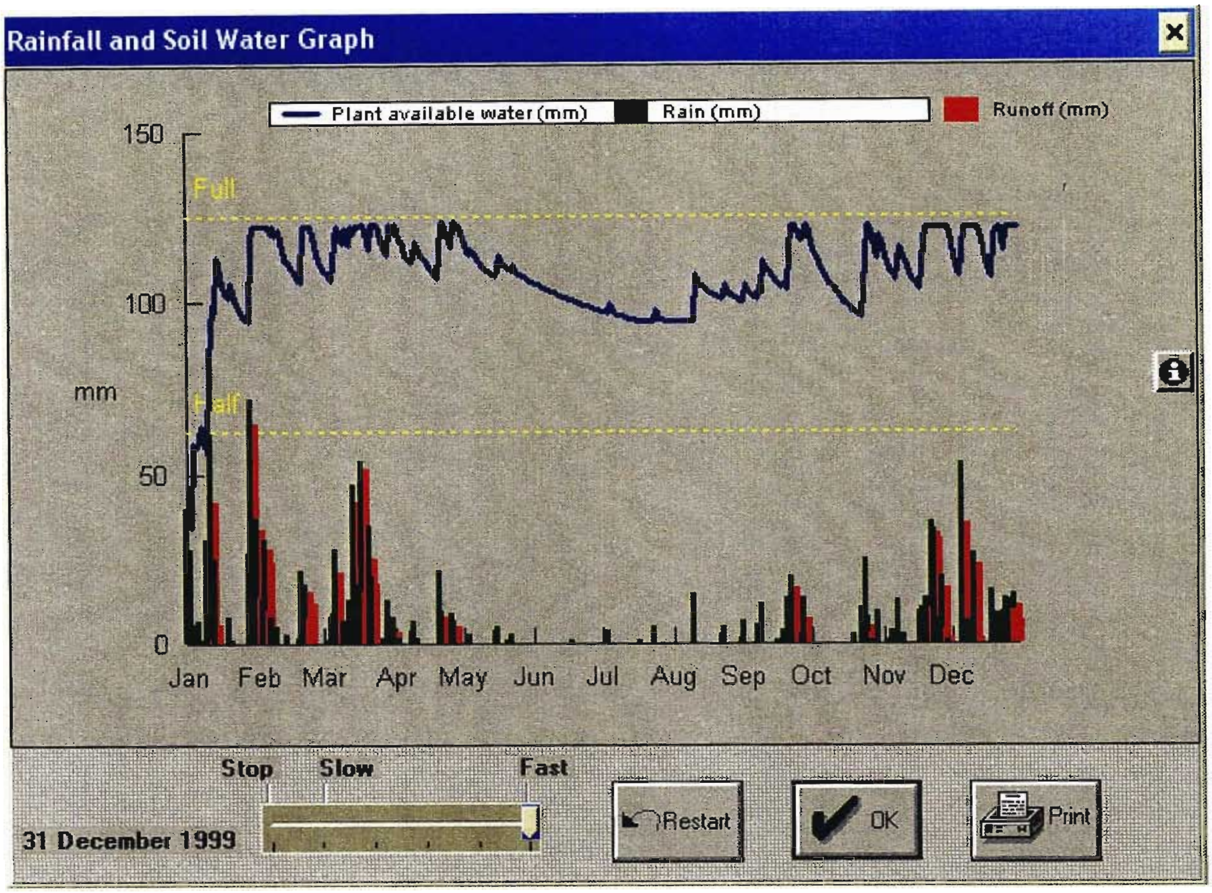


Figure 6.10 Plant available water in the soil of the 'control' wetland calculated by the 'HOWWET?' model

Further results of the 'HOWWET?' modelling exercise show that more total evaporation occurs from the Craigieburn wetland than from the 'control' wetland (see Table 6.2), despite the higher level of vegetative cover present in the 'control' wetland. This can also be attributed to the textural differences between these wetland soils. As more clay-rich soils comprise smaller inter-particle spaces, more energy is required to release water from these spaces than is required to release water from the larger inter-particle spaces created by sandier soils. As a result, water is more tightly retained in the soil of the 'control' wetland than the Craigieburn wetland soil, thus more evaporation occurs from the latter. This link between soil texture and water retention can be explained based on the principle of Darcy's Law (Darcy, 1857). This follows that the cohesive forces that exist between water molecules act in opposition to the forces of adhesion between the water molecules and the soil particles. As a result, soils of a fine texture experience comparatively more forces of adhesion than those of a coarse texture, and thus hold soil water more tightly. Water thus moves much more quickly through soils of a coarse texture, which is why the hydraulic conductivity of the coarse textured wetland soils of the Sand River catchment is so high generally.

Table 6.2 'HOWWET?' evaporation values for the Craigieburn and 'control' wetlands for 1999

WETLAND	EVAPORATION (mm)	% OF RAINFALL
CRAIGIEBURN	627	40
'CONTROL'	503	32

Runoff from the Craigieburn wetland is less than that from the 'control' wetland (see Figures 6.11 and 6.12) for much the same reason. The runoff specified in 'HOWWET?' is the water that runs off the surface of the soil without infiltrating, it is thus a portion of the water falling on the catchment that is of limited use to the local communities who benefit more from water that is stored in the soil, and is released slowly in order to provide a supply of water in the drier months of the year. As the 'control' wetland retains water in its small soil pores, water landing on the soil surface infiltrates this soil at a slower rate than that of the sandier soil of the Craigieburn wetland does. During high intensity rain events some rainfall will run off the soil of both wetlands before it has time to infiltrate, yet water will infiltrate into the sandier soil more rapidly, again as a result of the larger pore sizes. The steeper gradient and lesser vegetative cover of the Craigieburn wetland, when compared with those of the 'control' wetland, have the opposite effect to that of the sandy textured soils. Although these characteristics encourage runoff, the soil texture has a more dominant effect on runoff from these wetlands than the combined effects of the slope and vegetative characteristics have.

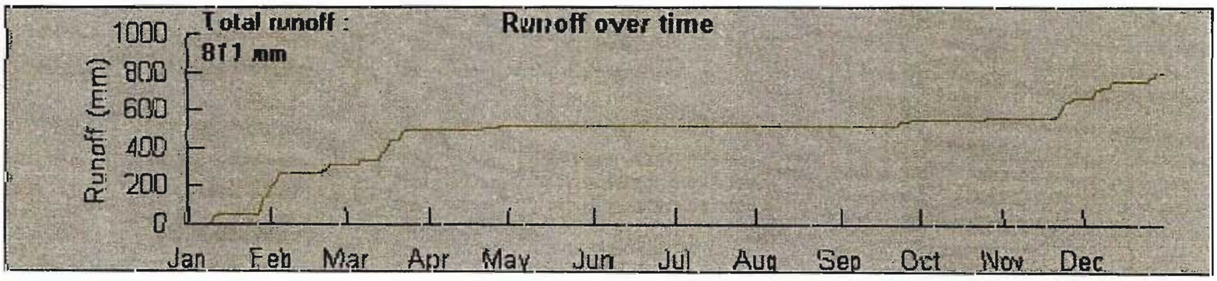


Figure 6.11 Runoff from the Craigieburn wetland calculated by the 'HOWWET?' model

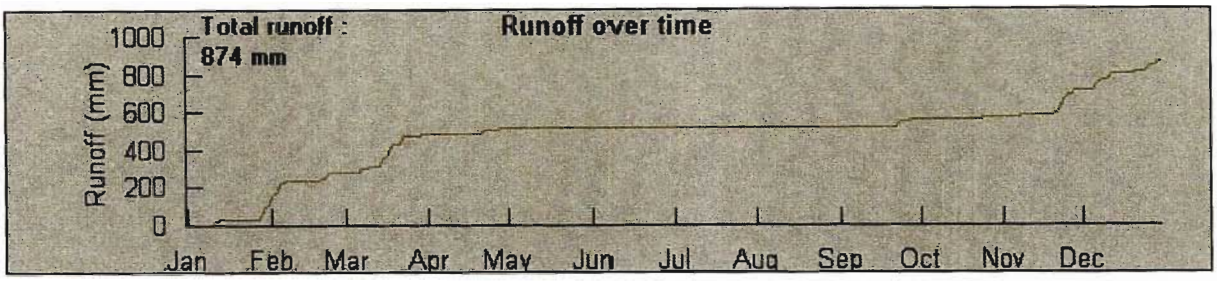


Figure 6.12 Runoff from the 'control' wetland calculated by the 'HOWWET?' model

The effect that the loss of soil water to evaporation has on the mean annual soil water content of the soils of the Sand River catchment is greater than the effect that the loss of water to runoff has, as illustrated by the fact that despite losing more water to runoff than the Craigieburn wetland does, the mean annual soil water of the 'control' wetland is greater than that of the Craigieburn wetland, as illustrated by the 'final' soil water content (see Table 6.3). The 'HOWWET?' model has shown in the past to accurately simulate the sensitivity of various soils to runoff and evaporation (Glanville *et al.*, 1996; Allen *et al.*, 1996). These results can thus be attributed to the fact that the hot, dry conditions experienced in the Sand River catchment lead to low antecedent soil moisture conditions and runoff volumes, thus changes in soil texture within the catchment wetlands have a greater effect on evaporation than on runoff from the soil.

Table 6.3 'HOWWET?' water loss results table

		Craigieburn wetland		**'Control' wetland**	
		mm	**% of rain**	**mm**	**% of rain**
Fallow Rainfall		1560		1560	
Less	**Evaporation**	627	40	503	32
	Runoff	811	52	874	56
Gain In Soil Water		122	8	183	12
Final Soil Water		122	97% saturated	183	99% saturated

The 'HOWWET?' results shown in the underlying 'screen dump' indicate that more than six times more soil will be lost from the Craigieburn wetland than from the 'control' wetland in the year simulated (see Figures 6.13 and 6.14). These results can be attributed to the greater vegetative cover, organic matter content and clay content simulated to be present in the 'control' wetland than in the Craigieburn wetland, as described in Section 5.1.3.2. The clay and organic matter content in soil infer cohesive properties to soils. As these are the chemically reactive particles in soil, chemical bonds that occur within soils occur between these and other particles, leading directly to the cohesive properties of soils. Sandier soils, such as those of the Craigieburn wetland, thus display little cohesiveness, and a small mechanical disturbance can thus lead to erosion of this soil. Such erosion leads to extensive soil loss from the wetland, making the presence of vegetation as an erosion control measure very important in the Craigieburn wetland and microcatchment. A greater vegetative cover will act as a physical barrier to soil loss, as the roots of the vegetation bind the soil, and add organic matter to the soil.

Many of the local community members who farm in the Craigieburn microcatchment reported significant loss of crops and soil previously, particularly during floods. Clear signs of sheet erosion were evident in the plots constructed in the hillslope areas of the Craigieburn microcatchment, where no signs of contour banks or vegetation conservation measures of any kind are present.

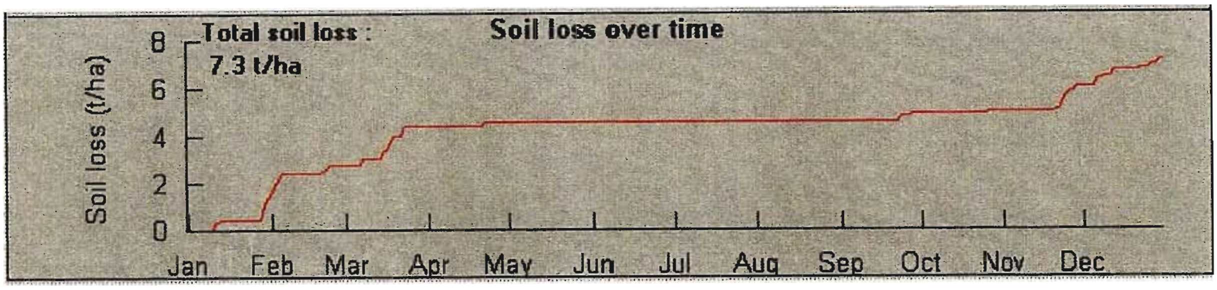


Figure 6.13 Soil loss over time for the Craigieburn wetland calculated by 'HOWWET?'

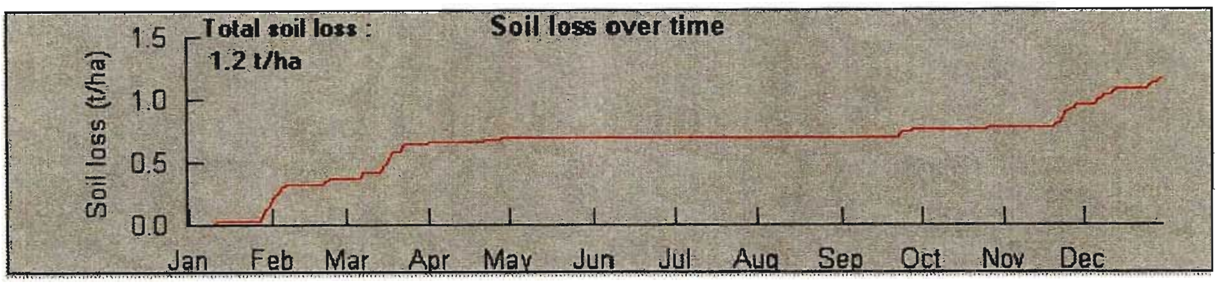


Figure 6.14 Soil loss over time for the 'control' wetland calculated by 'HOWWET?'

An area with a dense vegetative coverage is indicative of high fertility levels in the soils of that area. The 'HOWWET?' model is able to calculate nitrate levels in the soils under simulation, providing an indication of the differences in the fertility levels between the Craigieburn and 'control' wetlands. The 'HOWWET?' results presented in the underlying 'screen dump', representing the cumulative gain in nitrate throughout the year for the wetlands in question, show that the 'control' wetland experiences a greater gain in nitrate throughout the year than the Craigieburn wetland does (see Figures 6.15 and 6.16). These results can be attributed to the textural differences between the soils of these wetlands as the higher content of the chemically reactive clay particles enable the 'control' wetland soil to retain nitrates, whereas the chemically inert sand particles, more prevalent in the Craigieburn wetland soils, do not encourage retention of nitrates. These results suggest that the 'control' wetland would be more agriculturally productive to the local wetland users than the Craigieburn wetland is. Local Craigieburn wetland users complained to WRL researchers of a decrease in the fertility of the Craigieburn wetland.

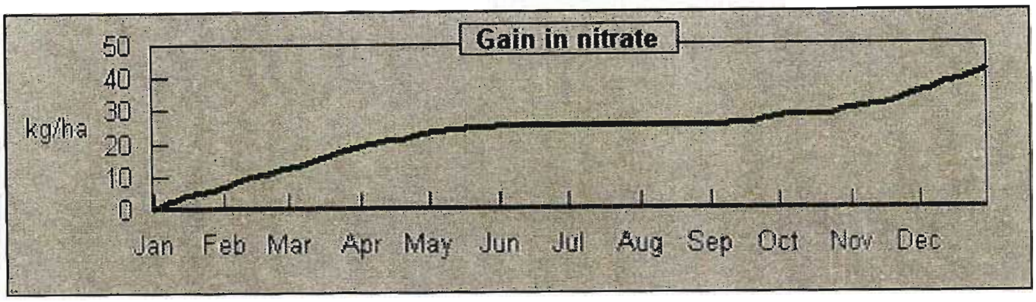


Figure 6.15 Monthly nitrate gains for the Craigieburn wetland calculated by 'HOWWET?'

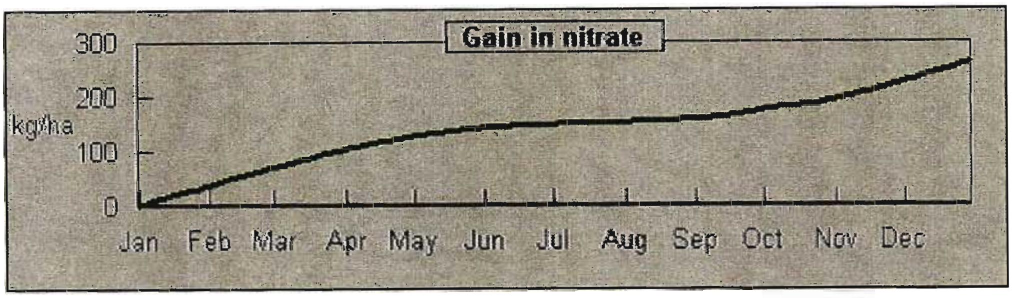


Figure 6.16 Monthly nitrate gains for the 'control' wetland calculated by 'HOWWET?'

6.2.1.2 *ACRU* results

The *ACRU* model was initially configured to simulate the water balance for six hypothetical land use areas of equal size. These land uses were selected to represent the most prominent land uses identified within the Craigieburn microcatchment. The simulations were performed in order to establish the effects of different land uses in the microcatchment and their corresponding soil types (see Section 5.1.4.10) on the hydrology of the microcatchment. The *ACRU* model was run for 50 years of daily rainfall data, as described in Section 5.1.4.6. The land uses found in the higher reaches of the microcatchment were simulated to exist on sandier soil than those found in the lower reaches, based on soil analyses performed on soil samples collected throughout the microcatchment, as described in Section 6.1.2.

Results of the soil survey reported in Section 6.1.2 show that in the higher reaches of the Craigieburn microcatchment (see Figure 1.5) the textural composition of the soils dictates that the higher lying soils are classified as Loamy Sands, and the low lying soils as Sandy Clay Loams, again using the data available in Appendix 5 and the classification procedure explained in Section 6.1.2.

Results of a general land use survey of the microcatchment performed by the WRL researchers were matched with the land uses identified within the *ACRU* modelling decision support tools that most accurately represent the six major land uses in the Craigieburn microcatchment. The characteristics of these land uses often vary depending on the season. Included in these land use characteristics are ranges of the crop coefficients and the leaf area indices of the land uses (see Table 6.4). The crop coefficient refers to the fraction of water used by a plant under conditions of maximum evaporation in relation to that evaporated by an A-pan in a given period, and the leaf area index is the ratio of the total area of all the leaves on a vegetation type to the area of ground covered by the vegetation type.

Table 6.4 A summary of the properties of the major land use areas identified in the Craigieburn microcatchment

LAND USE	SOIL TEXTURE	SOIL DEPTH (m) 'A'	'B'	CROP COEFFICIENT	LEAF AREA INDEX	PLANTING DATE	GROWING PERIOD	FRACTION OF ROOTS IN 'A'
/ELD – GOOD	Loamy Sand	0.3	0.4	0.4 - 0.65	N/A	N/A	All year	0.9 - 0.94
₹ESIDENTIAL	Loamy Sand	0.3	0.4	0.4 - 0.75	N/A	N/A	N/A	0.8 - 0.94
/IAIZE CROPS	Loamy Sand	0.3	0.5	0.2 - 1.1	0 - 5.25	01-Dec	120 days	0.74 - 1
REEDS	Sandy Clay Loam	0.3	0.9	0.4 - 0.8	3 - 6.25	N/A	All year	0.9 - 0.92
/ELD – POOR	Sandy Clay Loam	0.3	0.7	0.3 - 0.5	N/A	N/A	All year	0.92 - 0.96
/IIXED CROPS	Sandy Clay Loam	0.3	0.7	0.2 - 0.8	0 - 3.75	01-Oct	120 days	0.94 - 0.98

Findings of a general land use survey of the microcatchment performed by the WRL researchers show that the 'veld-like' grass typical of this area grows densely on the higher lying soils of the microcatchment. The residential area present in this microcatchment exists on a very similar group of soils to those of the other land uses in the highest reaches of the microcatchment. It produces hydrological output values typical of residential areas in which soil compaction has occurred, and impervious areas exist, yet these values are curbed by the fact that it is situated on sandy soils with high hydraulic conductivities, no artificial drainage system is in place, and garden plots are largely used for alternative subsistence cropping. These plots slightly reduce community members' dependence on the Craigieburn wetland by enabling the wetland users to diversify their livelihood strategies.

The fact that large numbers of subsistence plots are comprised of maize, and that maize is believed to be a significantly different water user to other, smaller subsistence crops, warrants this subsistence crop a land use category of its own. Maize is predominantly grown in the higher, drier reaches of the wetland, as it is too wet for maize to grow on the lower lying wetland soils during the wetter season, which corresponds with the main growing season of maize in the microcatchment.

Reeds are found in the lowest parts of the wetland, and thrive in the deep, wet soils found here. Some 'veld' grows in the lower reaches of the catchment, but is in a poor condition as the lowland soils are too wet for this plant species, cattle pass through the wetland here and erosion is prominent in this part of the wetland. Mixed subsistence plots are found in these lower reaches. These mainly comprise a mixture of madumbes, ground nuts and other nuts and sweet potatoes.

A uniform area for each scenario was applied for the purpose of calculating a water balance, thereby providing an account of the effects each land use has in partitioning water within the microcatchment. The outputs evaluated were made up of interception, transpiration and evaporation from the soil, as well as stormflow, baseflow and total streamflow. Baseflow is a measure of the water that has moved downslope and down the soil profile to reach the riparian zone, where it is available to recharge shallow water tables. Stormflow is the water that runs off the surface of the soil, and the water that infiltrates the A soil horizon, commonly reappearing as surface runoff downslope. Total streamflow is made up of both the stormflow and the baseflow. A mean monthly water balance was performed using these output values and the total mean monthly rainfall values in order to determine how rainfall is partitioned for each land use. The fact that the water balance for the 'residential' land use adds up to over 100% of the total rainfall for some periods is a model irregularity, or 'bug' based on the fact that *ACRU* generates water when impervious areas are specified. This problem has been identified previously within projects that have made use of the *ACRU* model for impervious areas, but is outside of the scope of this study to address.

The results of this modelling exercise (see Table 6.5) show that water lost to evaporation is greatest from the 'residential area', followed by the 'reeds' and 'mixed subsistence plots'. This can be explained in the case of the 'reeds' as they are heavily transpiring crops growing in deep, wet soil; and evaporation from the soil is great for the 'mixed subsistence plots' as the vegetative cover is low, and the soil is wet for much of the year. Total evaporation from the 'residential area' probably comprises largely of high rates of evaporation from the large areas of bare soil present for this land use. Water pools on this bare soil as compaction has made parts of this land use area impervious to water. 'Veld in good condition' produces the lowest evaporation values as very little of the soil is left bare for this land use, and the 'veld' is growing on drier soil than those land uses on the lower slopes, and has shallower roots than the maize crops.

The values presented for the typical wet, average and dry months are those obtained in January, September and June, respectively. These values were noted in order to gauge a better understanding of the typical intra-annual variation within the output variables. This is important to note, as the impact on the local community of the hydrological effects of a particular land use may vary depending on the month in which the impact is felt.

Table 6.5 *ACRU* mean monthly results of the hypothetical land use modelling exercise

Land Use	**'Veld in Good Condition' on a Loamy Sand**						
Variable (monthly means)	Rainfall	Interception	Total Evaporation	Stormflow	Baseflow	Streamflow	Water Balance*
Typical wet month (mm)	214.52	20.08	84.34	52.11	69.35	121.45	
Typical average month (mm)	129.09	20.91	67.77	8.58	24.4	32.98	
Typical dry month (mm)	14.08	3.55	7.22	0.87	3.04	3.91	
Mean annual total (mm)	1173.87	157.07	552.63	158.68	304.24	464.92	1174.62
% rainfall per land use		13.38	47.08	13.52	26.09		
Land Use	**'Residential Area' on a Loamy Sand**						
	Rainfall	Interception	Total Evaporation	Stormflow	Baseflow	Streamflow	Water Balance*
Variable (monthly means)	214.52	17.72	119.21	97.49	50.77	148.26	
Typical wet month (mm)	129.09	12.55	102.95	39.04	14.76	53.79	
Typical average month (mm)	14.08	2.6	9.59	3.86	4.19	8.04	
Typical dry month (mm)	1173.87	128.31	828.89	429.35	253.38	682.73	1639.93
Mean annual total (mm)		10.93	70.61	36.58	21.59		

Land Use	'Maize Subsistence Plots' on a Loamy Sand						
Variable (monthly means)	Rainfall	Interception	Total Evaporation	Stormflow	Baseflow	Streamflow	Water Balance*
Typical wet month (mm)	214.52	19.04	102.53	31.82	71.57	103.38	
Typical average month (mm)	129.09	14.02	88.27	4.08	19.21	23.29	
Typical dry month (mm)	14.08	1.48	9.97	0.39	2.4	2.79	
Mean annual total (mm)	1173.87	115.13	685.04	90.63	282.88	373.75	1173.21
% rainfall per land use		9.81	58.36	7.72	24.1		
Land Use	**'Reeds' on a Sandy Clay Loam**						
Variable (monthly means)	Rainfall	Interception	Total Evaporation	Stormflow	Baseflow	Streamflow	Water Balance*
Typical wet month (mm)	214.52	9.31	107.96	70.13	23.56	93.7	
Typical average month (mm)	129.09	9.11	88.64	11.82	5.72	17.53	
Typical dry month (mm)	14.08	1.74	11.33	1.02	8.48	9.5	
Mean annual total (mm)	1173.87	68.56	736.9	211.91	155.84	367.75	1173.6
% rainfall per land use		5.84	62.78	18.05	13.28		
Land Use	**'Veld in Poor Condition' on a Sandy Clay Loam**						
Variable (monthly means)	Rainfall	Interception	Total Evaporation	Stormflow	Baseflow	Streamflow	Water Balance*
Typical wet month (mm)	214.52	12.19	94.13	98.11	16.93	115.04	
Typical average month (mm)	129.09	11.9	76.45	31.02	4.51	35.53	
Typical dry month (mm)	14.08	2.21	8.29	2.81	1.69	4.49	
Mean annual total (mm)	1173.87	89.33	621.1	379.2	83.97	463.17	1173.81
% rainfall per land use			52.91	32.3	7.15		
Land Use	**'Mixed Subsistence Plots' on a Sandy Clay Loam**						
Variable (monthly means)	Rainfall	Interception	Total Evaporation	Stormflow	Baseflow	Streamflow	Water Balance*
Typical wet month (mm)	214.52	14	101.27	68.03	36.55	104.58	
Typical average month (mm)	129.09	8.24	89.85	13.37	7.94	21.3	
Typical dry month (mm)	14.08	1.48	11.36	1	2.59	3.59	
Mean annual total (mm)	1173.87	72.28	717.12	215.58	168.83	384.41	1173.81
% rainfall per land use		6.16	61.09	18.36	14.38		
Land Use	**'Veld in Poor Condition' on on a Loamy Sand**						
Variable (monthly means)	Rainfall	Interception	Total Evaporation	Stormflow	Baseflow	Streamflow	Water Balance*
Typical wet month (mm)	214.52	11.31	98.6	18.6	69.22	82.21	
Typical average month (mm)	129.09	8.92	48.63	8.51	25.55	28.84	
Typical dry month (mm)	14.08	1.7	28.47	0.4	7.26	7.92	
Mean annual total (mm)	1173.87	66.2	702.62	60.82	344.12	405.1	1173.76
% rainfall per land use		5.62	59.85	5.18	29.3		

* Water Balance = Total Evaporation + Stormflow + Baseflow + Interception

Interception values for the 'veld in good condition' are higher than those for other land uses as a result of the comprehensive coverage and high leaf area index provided by this land use. Interception values for the 'mixed subsistence plots' and 'veld in poor condition' are low as these low-lying land uses are more sparsely distributed than their higher-lying counterparts. The total evaporation values of the lower-lying land uses are higher than those of the upland land uses, as the former will transpire at the maximum rate they are capable of for a longer period of the year. This is largely because the lower lying land uses have access to a greater water supply for more of the year as water moves downslope through the soil. The 'maize subsistence plots' lose a large amount of water to transpiration during the growing season, but this land use does not transpire all year. Maize grown in the microcatchment makes up a large part of the diet of the vast majority of the members of the local community, thus many areas have been cleared in order to plant maize crops.

The sandier texture of the shallower uplands soils means that this soil comprises larger interparticle spaces, thus infiltration into this soil is greater, as illustrated by the greater baseflow values produced by the land uses on the sandier soils. Although soils of a sandy texture are frequently subjected to great water losses as they hold water less tightly than those of a more clay-rich texture, in some cases, such as that of the Craigieburn microcatchment, water moves away from the soil surface so quickly through the sandier upland soils that little water remains to be evaporated from the soil surface, and lower evaporation losses occur from the bare sandy soils, and they retain less water than the deeper soils. The larger pore size in sandy soils also reduces capillary rise, reducing evaporative losses from the bare, sandy soils.

The total streamflow for the catchment is made up of both baseflow and stormflow for each land use. This values is of use when broken into stormflow and baseflow values, as one can establish whether land uses that seem to be beneficial to their immediate environment, in terms of producing greater streamflow values, produce a large amount of stormflow and relatively little baseflow, and are thus, based on results simulated by *ACRU*, not a beneficial land use in terms of regulating streamflows and adding to microcatchment water security.

Stormflow values for this exercise are, in part, determined by the soils on which the land uses lie, and, aside from the 'residential area', are greatest for the land uses on the deeper, wet soils which have lower hydraulic conductivities. However, the soil compaction and consequent impervious areas present in the 'residential area' lower infiltration to the degree that stormflow values are higher for this land use than for any of those on wetter, less sandy soils. The differences in stormflow values can be attributed to the differences in soil texture, and are a result of the characteristic hydraulic conductivities and water holding capacities of the two soils modelled. The stormflow values of the 'veld in poor condition' are notably high as a result of the sparse coverage and relatively shallow roots of this land cover, as well as the fact that it is growing on the wetter of the soils modelled.

The modelling results show that, of the upslope land uses, 'veld in good condition' produced the highest baseflow values. These values are determined both by the nature of the land use, and by the nature of the soil underlying this land use, as the sandier soils have a greater infiltration rate, thus more water percolates down these profiles, leading to greater baseflow values. 'Veld' is a natural vegetation of this area, thus the baseflow values obtained support literature pertaining to sustainable land use, much of which concludes that the natural vegetation of an area best regulates water movement through that area (MacKinnon and Yan, 2001). Those land uses that regulate streamflow such that flows are maintained during dry periods are frequently the natural vegetation of the area (du Plessis, 1998c). Of the land use options available for the lower lying, wetter soil areas, the 'reeds' and 'mixed subsistence plots' are the land uses that produce the greatest baseflow values, thus appearing to best increase water security for the local users. In the context of the microcatchment modelling exercise this is likely to change, however, as upslope contributions will change the water content of the soils. 'Mixed subsistence plots' do not have a great impact on baseflow, when compared with 'reeds' and 'veld in good condition'. This potentially indicates that such cultivation in the wetland does not have a significantly adverse effect on dry season flows, and that the problem may lie in overall management of the wetland.

Of the land uses based in the drier parts of the microcatchment, on the better drained, sandier soils, 'veld in good condition' appears to best encourage streamflow regulation. Although the baseflow values of this land use and those of 'maize subsistence plots' are similar, of the water making up the rest of the water balance for each of these land uses, more is lost to evaporation from the 'maize subsistence plots' than from the 'veld', a large amount of which is likely to be lost from bare soil surfaces. 'Veld in good condition' thus encourages more beneficial use of water, and consequently greater microcatchment water security than 'maize subsistence plots' do. This is consistent with the large body of literature that highlights that infiltration rates are great for undisturbed soil (Azooz and Arshad, 1996). This has lead to an international movement toward conservation tillage (Auerbach, 2000), and is thus worth considering as a 'best practice' for this area. Results of the water balances performed depicting the partitioning of water within all the abovementioned land uses are more clearly illustrated in the following water balance diagrams (see Figures 6.17, 6.18, 6.19, 6.20, 6.21 and 6.22).

Key: R = Rainfall; ET = Total Evaporation and Interception; S = Stormflow and Streamflow; D = Baseflow

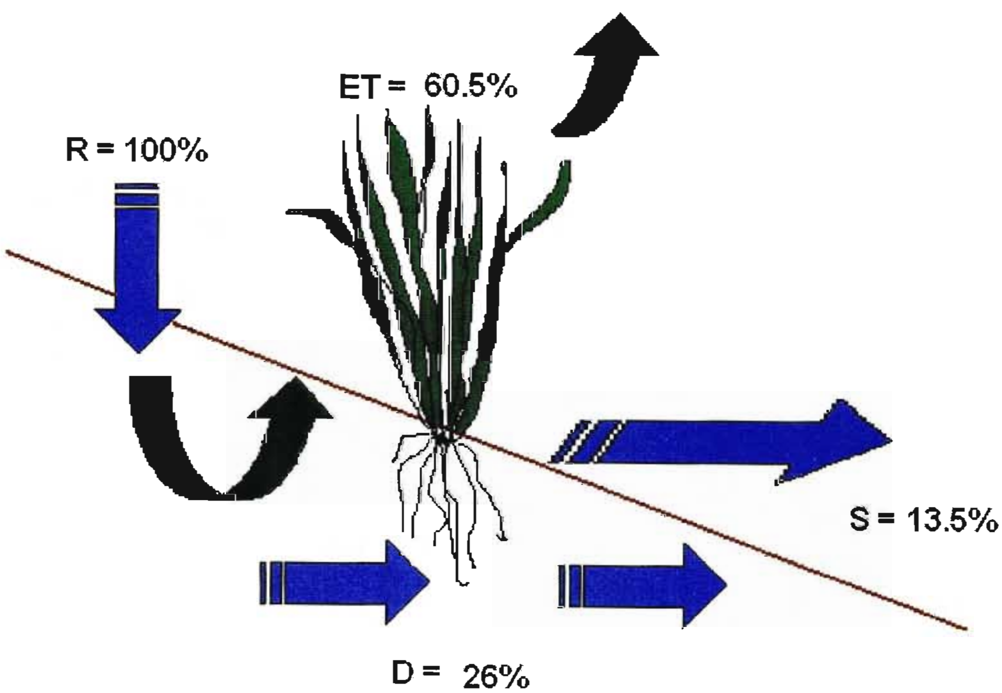


Figure 6.17 The water balance for the 'veld in good condition' simulation calculated by *ACRU*

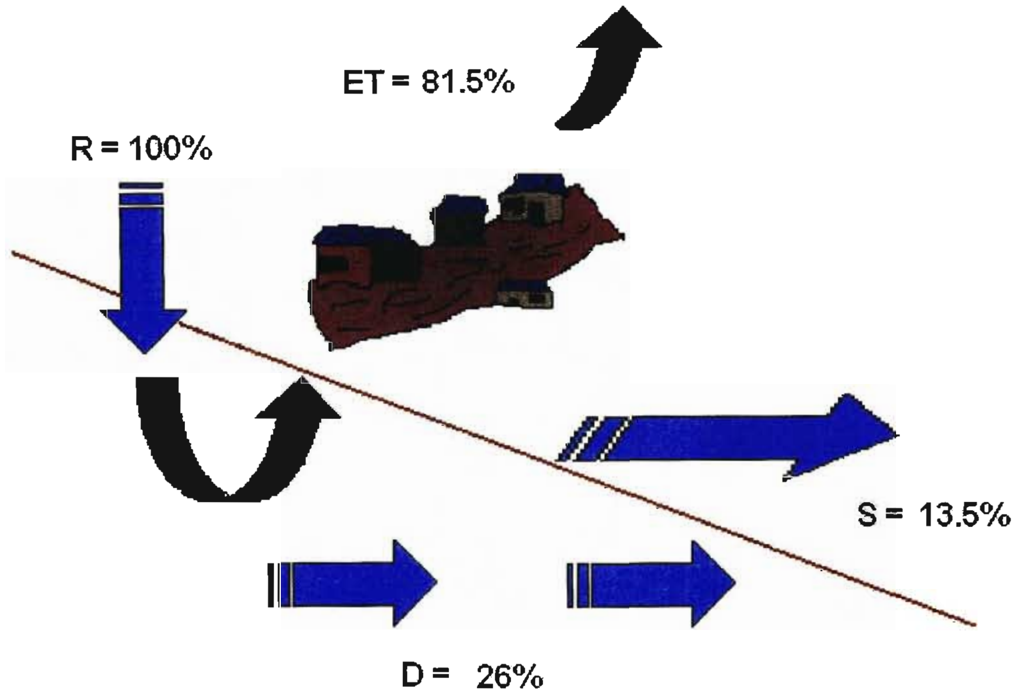


Figure 6.18 The water balance for the 'residential areas' simulation calculated by *ACRU*

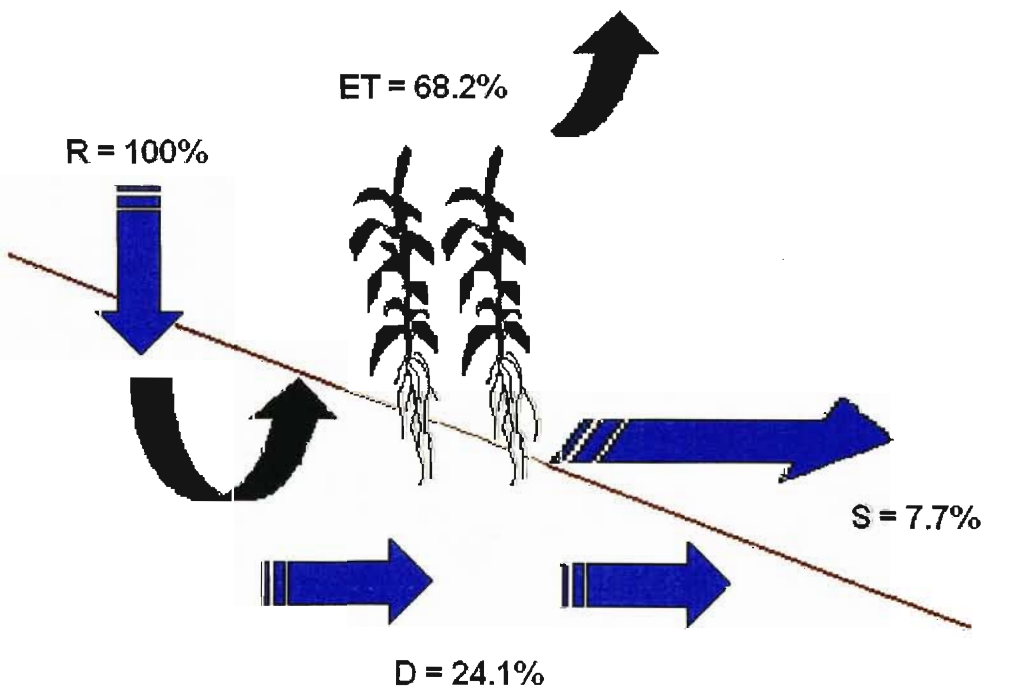


Figure 6.19 The water balance for the 'maize subsistence plots' simulation calculated by *ACRU*

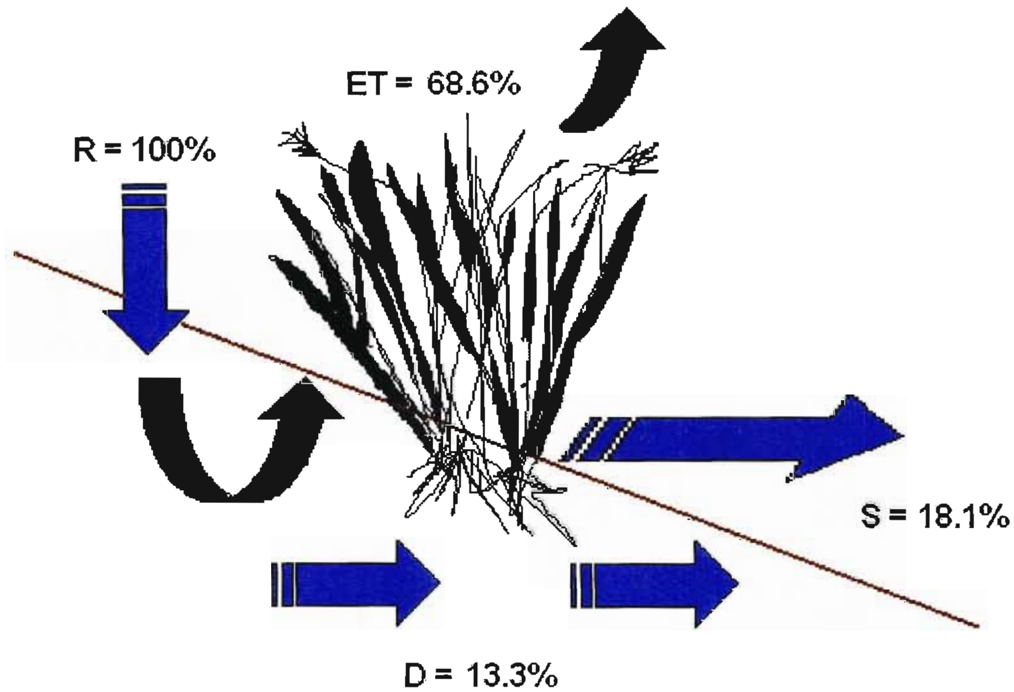


Figure 6.20 The water balance for the 'reeds' simulation calculated by *ACRU*

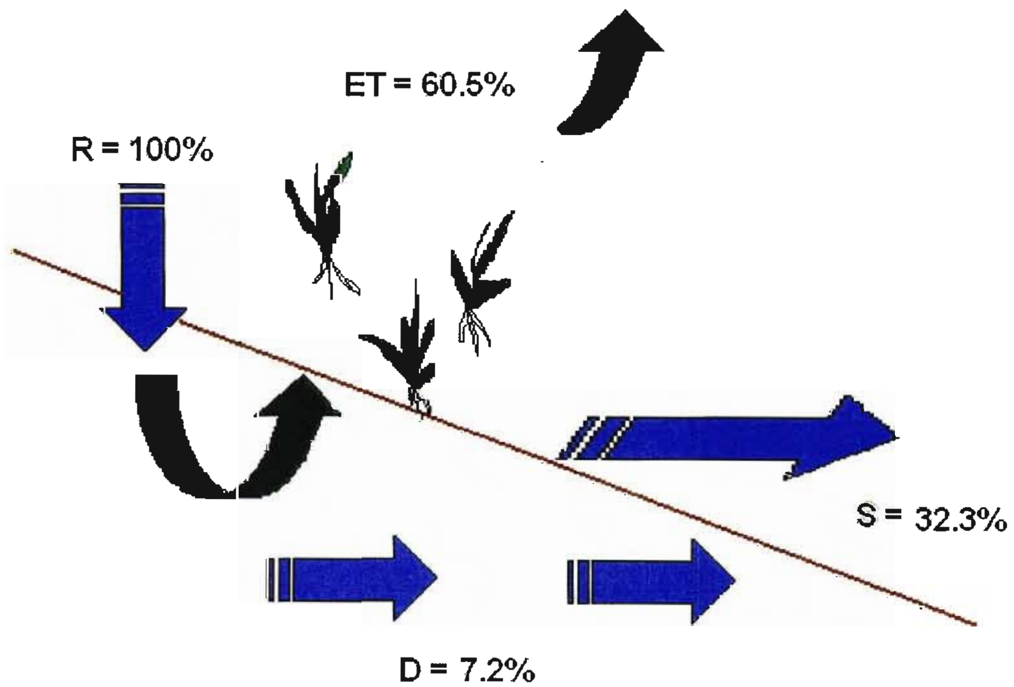


Figure 6.21 The water balance for the 'veld in poor condition' simulation calculated by *ACRU*

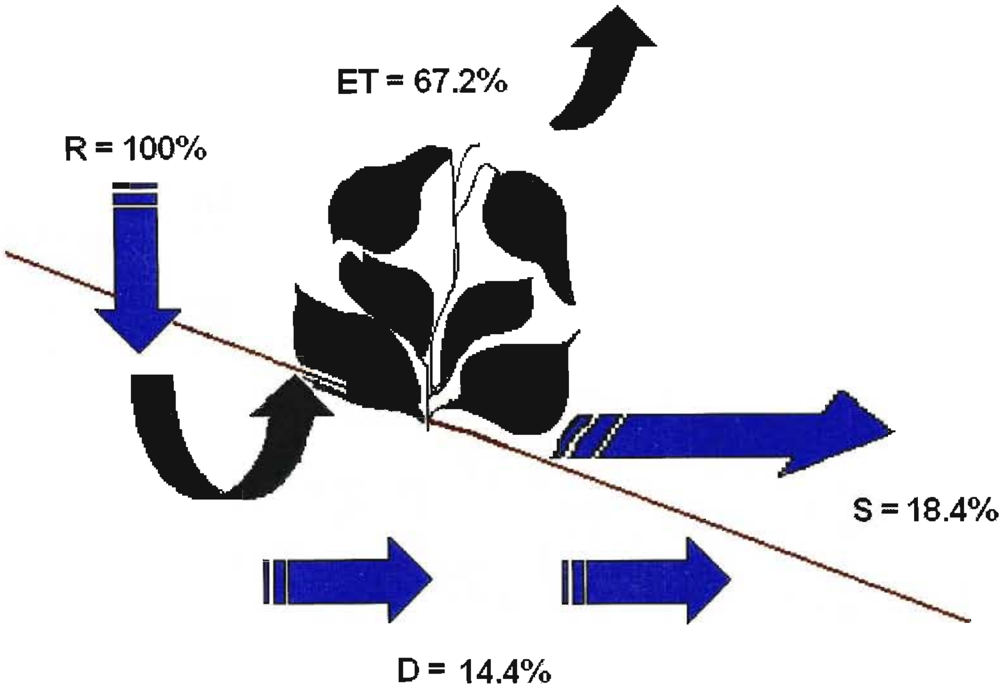


Figure 6.22 The water balance for the 'mixed subsistence plots' simulation calculated by *ACRU*

These diagrams depict the partitioning of rainfall based on the mean annual values displayed in Table 6.5. The percentages of the total water (rainfall) entering the 'system' lost to evaporation and interception, stormflow and streamflow, and to baseflow, respectively, are illustrated by arrows, and the factors determining this water partitioning are combinations of soil textures and land uses. As these figures are based on those in Table 6.5, the explanation of the effects of these land uses on water partitioning following the table holds true for these diagrams.

A land use that is less prominent than the six abovementioned land uses, but makes up a small part of the microcatchment is 'veld in poor condition' on the better-drained Loamy Sands of the microcatchment. A final scenario was performed in which these conditions were simulated, in order to establish the effects of this land use on the water balance. This provides an indication of the degree to which the soil texture influences this water balance, when compared with the influence of the land use. The results of this scenario were compared with those of the 'veld in good condition' on Loamy Sand, and 'veld in poor condition' on Sandy Clay Loam (see Table 6.6).

Table 6.6 Water balances for 'veld' under a range of vegetative and soil conditions

Land Use	**'Veld in Good Condition' on a Loamy Sand**						
Variable (monthly means)	Rainfall	Interception	Total Evaporation	Stormflow	Baseflow	Streamflow	Water Balance*
Typical wet month (mm)	214.52	20.08	84.34	52.11	69.35	121.45	
Typical average month (mm)	129.09	20.91	67.77	8.58	24.4	32.98	
Typical dry month (mm)	14.08	3.55	7.22	0.87	3.04	3.91	
Mean annual total (mm)	1173.87	157.07	552.63	158.68	304.24	464.92	1174.62
% rainfall per land use		13.38	47.08	13.52	26.09		
Land Use	**'Veld in Poor Condition' on a Sandy Clay Loam**						
Variable (monthly means)	Rainfall	Interception	Total Evaporation	Stormflow	Baseflow	Streamflow	Water Balance*
Typical wet month (mm)	214.52	12.19	94.13	98.11	16.93	115.04	
Typical average month (mm)	129.09	11.9	76.45	31.02	4.51	35.53	
Typical dry month (mm)	14.08	2.21	**8.29**	2.81	1.69	4.49	
Mean annual total (mm)	1173.87	89.33	621.1	379.2	83.97	463.17	1173.81
% rainfall per land use			52.91	32.3	7.15		
Land Use	**'Veld in Poor Condition' on on a Loamy Sand**						
Variable (monthly means)	Rainfall	Interception	Total Evaporation	Stormflow	Baseflow	Streamflow	Water Balance*
Typical wet month (mm)	214.52	11.31	98.6	18.6	69.22	82.21	
Typical average month (mm)	129.09	8.92	48.63	8.51	25.55	28.84	
Typical dry month (mm)	14.08	1.7	**28.47**	0.4	7.26	7.92	
Mean annual total (mm)	1173.87	66.2	702.62	60.82	344.12	405.1	1173.76
% rainfall per land use		5.62	59.85	5.18	29.3		

The most striking difference between the water balance values derived from this exercise is the degree to which water is lost to total evaporation for the 'veld in poor condition' land use on a Loamy Sand. The fact that these values are greater than those of the 'veld in good condition' on Loamy Sand can be attributed to the lower vegetative coverage of the 'veld in poor condition' and consequently greater water loss from increased areas of bare soil of the same, sandy texture as that underlying the 'veld in good condition'. The fact that these values are greater than those of the 'veld in poor condition' on Sandy Clay Loam cannot be attributed to the vegetative cover, as they are the same for these land uses, and one may, in fact, expect the loss of water to soil evaporation to be greater from the wetter, lower lying soil.

The reason for this difference calculated in *ACRU* becomes clearer when comparing the amounts of water lost to evaporation in a typical dry month for this scenario, with typical dry months of the other 'veld in poor condition' scenario. As a result of the difference in texture between the soils of these respective land uses, (see Table 6.7), during the typically dry months, significantly more water is lost to evaporation from the 'veld in poor condition' on a Loamy Sand than from the 'veld in poor condition' on a Sandy Clay Loam. During the drier months, in which there is little water in the soils, only the smallest interparticle soil pores are water-filled. This water is held tightly by the more clay-rich soil, as more clay-textured soils hold water tightly as a result of the greater adhesive forces the soil particles exert on the water molecules. During the wetter months, when a greater amount of water lost to soil evaporation is lost from the larger interpore spaces that offer little resistance to evaporation, these amounts are much more similar for the different textured soils.

Table 6.7 Properties of the soils underlying 'veld' in the Craigieburn microcatchment

LAND USE	TEXTURE	DEPTH 'A' (m)	DEPTH 'B' (m)	WP (m/m)	DUL (m/m)	PO (m/m)	ABRESP (m/m)
Veld in good condition	Loamy Sand	0.3	0.4	0.068	0.143	0.432	0.7
Veld in poor condition	Sandy Clay Loam	0.3	0.7	0.159	0.254	0.452	0.5
Veld in poor condition	Loamy Sand	0.3	0.4	0.068	0.143	0.432	0.7

The effects of this marked difference in behaviour of soils of different textures can be seen in the different properties these soils exhibit. As Table 6.7 displays, the soils with greater clay contents also have higher wilting point (WP) and drained upper limit (DUL) values. This WP value represents the amount of water held in the soil at the point below which vegetation growing in the soil wilts from a lack of plant available water, and the DUL is the value representing the upper water holding capacity of the soil, above which water runs off the surface of the soil. Soils with greater clay contents have a higher wilting point as more of the water held in these soils is held in small interparticle spaces and is therefore unavailable to vegetation, as it cannot break the energy barrier in order to extract this water. As Table 6.7 shows, clay-rich soils have higher porosity values. This is because, although sandier soils comprise of more macropores, the total interparticle space made up of the many micropores present in clay-rich soils is greater than the total interparticle space made up of the fewer, larger pores of more sandy soils. For this reason, the 'drained upper limit' of more clay-rich soils is also greater. The response between the 'A' and 'B' horizons of a soil, specifying the degree to which conditions in the 'A' horizon affect those in the 'B' horizon, is greater for soils with a lower clay content, as water moves more quickly down the profile in less clay-rich soils.

The stormflow values for the 'veld in poor condition' land use on a Loamy Sand are lower than those for both other 'veld' scenarios. This can be attributed to the fact that this bare, sandy soil has a very high infiltration rate, thus a very large proportion of the water falling on this land use area infiltrates into the lower portion of the soil. The baseflow values support this theory, as these are greater for this land use than for the other 'veld' land uses. This land use clearly loses the greater proportion of its water to evaporation from bare soil surfaces.

6.2.2 Microcatchment modelling

The next phase of the modelling performed within this study involved simulating the potential effects of actual land use changes over time. This phase focuses at a microcatchment scale, yet initial simulation were run at a point scale, driven by single years of rainfall data, to establish the degree to which the modelling results are determined by rainfall input values and potentially make these results more comparable with outcomes of the sociological study. The microcatchment modelling thus proceeded in two steps:

- The *ACRU* model was configured to represent 'time slices' representative of actual land uses in the Craigieburn microcatchment recorded for previous years (see Table 6.8), taken from aerial photographs of the microcatchment, presented in Section 5.1.4.10.
- Fifty years of rainfall data were used to drive the model, configured to represent actual land use areas as specified above, as well as to represent the microcatchment in 'good' and 'degraded' conditions. For this exercise the *ACRU* model was configured to represent the Craigieburn microcatchment, such that streamflow leaving each land use area was routed through the land use called 'reeds' at the outlet to the simulated microcatchment (see Figure 5.15). In this manner the streamflow values produced account for the combined effect of all the upstream land uses.

Table 6.8 Changes in land use areas in the Craigieburn microcatchment over time

	AREAS (km^2)						
Year	**VELD - GOOD**	**RESIDENTIAL**	**MAIZE PLOTS**	**REEDS**	**VELD - POOR**	**MIXED PLOTS**	**TOTAL**
1954	1.11433735	0.0468	0.00558481	0.223277839	0.01	0	1.4
1965	1.064064365	0.036	0.008213119	0.281722516	0.01	0	1.4
1974	0.652162555	0.4842	0.014607803	0.213114595	0.01	0.025915047	1.4
1984	0.80318434	0.3834	0.016552479	0.172514845	0.01	0.014348336	1.4
1997	0.887663625	0.3528	0.015535265	0.120380244	0.01	0.013620866	1.4

6.2.2.1 Time slices to represent aerial photographs

Within a modelling exercise, the effects of land use on the water balance are frequently difficult to deduce, as one cannot realistically standardise the rainfall over an area for a period of time in order to determine the effects that the land uses have on the hydrology of an area.

This also makes drawing links between the sociological and the hydrological aspects of this study difficult, especially in terms of making comparisons between what the members of the local community remember about the hydrological conditions that characterised a specific year, and what the modelling results show about the hydrological conditions of that year. This is highlighted by the results of the modelling exercise in which the *ACRU* model was configured to represent 'time slices' representative of actual land use areas in the Craigieburn microcatchment recorded for previous years (see Table 6.9), for which observed daily rainfall records for the specific year being considered were used to drive the model (see Appendix 11). The results of this exercise vary in accordance with changes in rainfall to a much greater degree than they do with changes in land use areas (see Figure 6.23).

Table 6.9 Simulated water balance components for specific years in the Craigieburn microcatchment calculated by *ACRU.*

Year	Soil Evaporation (mm)	Transpiration (mm)	Stormflow (mm)	Baseflow (mm)	Streamflow (mm)	Rainfall (mm)
1954	244.58	434.81	85.72	151.92	237.64	987.4
1965	199.91	355.40	40.52	101.42	141.94	756.1
1974	266.21	473.27	116.37	183.02	299.39	1118.3
1984	180.08	320.15	11.86	70.83	82.69	643.2
1997	241.26	428.90	57.20	149.16	206.36	990.4

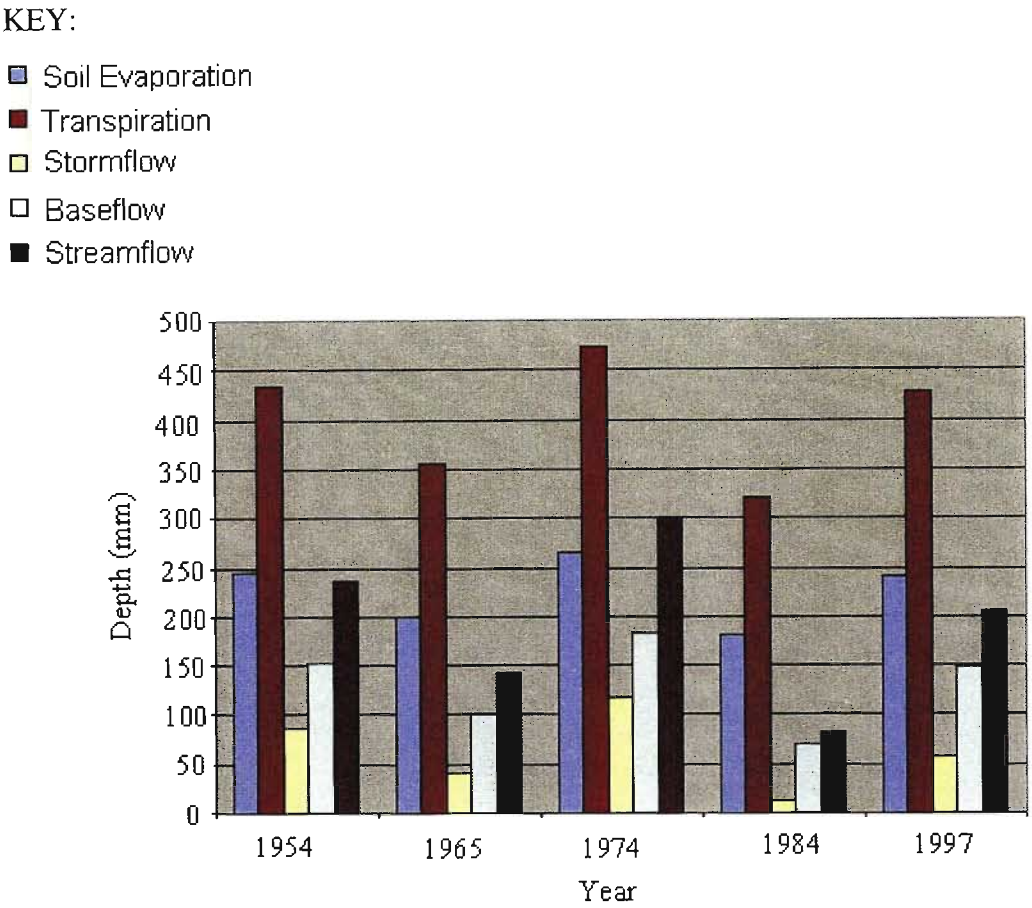


Figure 6.23 Water use partitioning of year-specific rainfall for previous land uses within the Craigieburn microcatchment calculated by *ACRU*.

The low rainfall values used to drive the scenario representing the microcatchment in 1984 result in lower streamflow values in this year than in any of the others modelled, and the comparatively high rainfall values used to drive the 1974 scenario result in higher streamflow values in this year than in the others modelled.

The results of the modelling exercises driven by single years of rainfall data are dominated by the rainfall characteristics of the year in question to such a degree that little can be gauged about the effects of the land use areas on the water balance for these scenarios. Thus, in order to evaluate the effects that the land use changes do potentially have on the various hydrological components within the microcatchment, irrespective of the rainfall values recorded for the years in question, the relative mean annual values were calculated and presented (see Figure 6.24) as percentages of the total rainfall lost to the catchment (see Table 6.10) for the respective years modelled.

Table 6.10 *ACRU* mean annual water loss partitioning for the Craigieburn microcatchment, calculated as a percentage of the total water loss

Year	Soil Evaporation	Transpiration	Stormflow	Baseflow	Streamflow	Total
1954	26.67%	47.42%	9.35%	16.57%	25.91%	100%
1965	28.67%	50.97%	5.81%	14.55%	20.36%	100%
1974	25.62%	45.56%	11.20%	17.62%	28.82%	100%
1984	30.89%	54.92%	2.03%	12.15%	14.19%	100%
1997	27.52%	48.93%	6.53%	17.02%	23.54%	100%

KEY:

- Soil Evaporation
- Transpiration
- Stormflow
- Baseflow

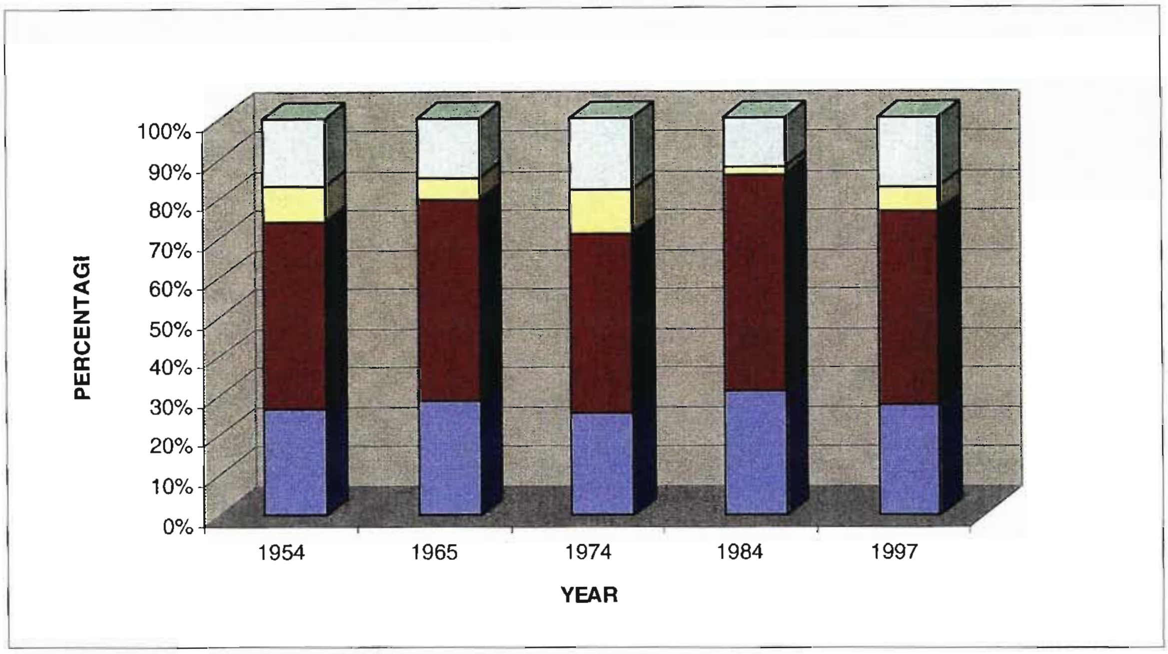


Figure 6.24 Mean annual water loss partitioning for the Craigieburn microcatchment, calculated as a percentage of the total water loss

The figures obtained show that water loss partitioning within the water balance for these land uses does not vary to a large degree. The scenario for which the 'residential area' was the largest, that of 1974, produced the largest amount of stormflow in relation to other water losses, probably as a result of the lowered transpiration from this less vegetated area, and the fact that runoff is greatly increased from this more impervious area. This relationship has been established in previous scenarios within this study. A comparatively large proportion of the water balance for the year 1984 is made up of evaporation. Of the land use data available, this is the year in which the largest area was allocated to cultivation plots (see Table 6.8). Evaporation is lost from these land use areas, as both maize plots and mixed subsistence plots lose a lot of water to transpiration during the wet months, and lose a lot to evaporation from the soil in dry months, as little vegetative coverage exists on these plots. The large degree of evaporative water loss could also be attributed to the presence of largely impervious residential areas that characterise the Craigieburn microcatchment land use areas of 1984.

As changes in hydrological outputs for the various scenarios are a result of combinations of land use changes, direct relationships pertaining to the effects of these land uses on the hydrology of the microcatchment cannot be confidently made. Despite this, insight into the effects that previous land uses have potentially had on the hydrology of the microcatchment can be gained from combinations of the results of these modelling exercises, and the results of analyses of the biophysical and sociological data collected for this study. Results such as those produced by the water balance studies presented in Section 6.2.1, in which more input variables are kept consistent, are thus necessary to determine the individual effects of each of these land uses on the hydrology of this microcatchment, and complement the results obtained from simulations at the microcatchment scale.

6.2.2.2 Simulating the effects of catchment change

Although the output variables analysed for the water balance scenarios outlined in Section 6.2.2.1 include total streamflow, baseflow, stormflow, soil evaporation and transpiration, only streamflow has been analysed for the simulations performed in order to determine the hydrological effects of catchment change. This is because the most representative of the output variables listed is total streamflow, as this variable accumulates baseflow and stormflow values from upstream land uses. In this manner the results obtained could best account for the combined effect of the various land use areas of the microcatchment on streamflow at the outlet of the microcatchment.

As elaborated upon in Section 2.2, fifty years of rainfall records were used to drive a series of modelling exercises in which realistic land use areas, presented in Table 6.8, were simulated. In addition two simulations using the same configuration and climatic input data were performed, for which hypothetical land use areas were used to represent 'baseline' and cultivation 'plots' scenarios. All scenarios were driven by the full set of daily data available from the 'Wales' rain gauge, thus any differences in output (see Table 6.11) can be attributed to differences in land use. The streamflow values typical of wet, dry and average months were investigated for each of these land use scenarios, so as to provide an indication of the regularity of streamflow under these conditions, and thus of the effects of such land use combinations on water security for the local community. Again typical wet, dry and average months refer to January, June and September, respectively. The average daily, monthly and annual values for typical wet, dry and average months were investigated in order to elucidate the degree to which streamflow volumes change within these periods. This was also intended to provide an indication of the reliability of the wetland as a water source under a variety of land use conditions.

Table 6.11 *ACRU* simulated streamflow volumes for land use area combinations in the Craigieburn microcatchment representing years for which aerial photographs are available, using 50 years of rainfall data

		1954	1965	1974	1984	1997
AVERAGE	TYPICAL WET YEAR	1903.11	1911.07	1922.62	1901.17	1901.65
ANNUAL	TYPICAL DRY YEAR	43.5	44.47	45.34	41.07	39.13
VALUES (m^3)	TYPICAL AVERAGE YEAR	271.46	279.9	289.66	264.61	263.3
OVERALL ANNUAL AVERAGE FOR ALL YEARS OF ANNALYSIS		**418**	**427.3**	**452**	**347.1**	**348.2**
AVERAGE	TYPICAL WET MONTH	37.96	38.06	38.64	37.09	36.89
MONTHLY	TYPICAL DRY MONTH	0.83	0.83	0.84	0.77	0.76
VALUES (m^3)	TYPICAL AVERAGE MONTH	7.97	8.29	8.35	7.68	7.27
TYPICAL	DURING A WET MONTH	3.07	3.07	3.09	3.05	3.05
DAILY	DURING A DRY MONTH	0.07	0.07	0.07	0.06	0.06
VALUES (m^3)	DURING AN AVERAGE MONTH	0.68	0.72	0.74	0.5	0.56

The results displayed in Table 6.11 show that average daily, monthly and annual values for typical wet, average and dry months are greatest for 1974, followed by 1965, then 1954, then 1997 and smallest for 1984, illustrating that the streamflow values are notably influenced by the size of the area making up the 'residential area' (see Table 6.12). This can be attributed to the fact that the impervious sections that characterise this area lead to greatly increased stormflow values and decreased transpiration values, thus more of the rain falling on this area makes up a part of total streamflow than that of any other area. Comparatively, of the six land uses that make up these simulations, the residential areas are also large, thereby having a great influence on the results by virtue of their size. More daily, monthly and annual streamflow volume variation is evident between the scenarios during the wetter months.

Decisive conclusions pertaining to the links between land use areas and streamflow volumes are difficult to make for scenarios such as those outlined above. The sizes of the various land use areas do not always change significantly from scenario to scenario, and there is a large variety of land uses within this small microcatchment area, making attributing hydrological effects to any one land use questionable. What can be deduced is that no single land use area determines the streamflow volume entirely. Thus, although the likely hydrological effects of the land use areas that existed for the years specified can be simulated, hypothetical scenarios in which a large number of potentially influential factors are kept consistent are essential to ones understanding of the effects of these land uses on the hydrology of this microcatchment.

Table 6.12 Actual land use areas and *ACRU* simulated streamflow values produced for 50 years of rainfall data

	AREAS (km^2)							Ave ann. (m^3)
YEAR	**VELD - GOOD**	**RESIDENTIAL**	**MAIZE PLOTS**	**REEDS**	**VELD – POOR**	**MIXED PLOTS**	**TOTAL**	**STREAMFLOW**
1954	1.114	0.047	0.006	0.223	0.010	0.000	1.4	348.734
1965	1.064	0.036	0.008	0.282	0.010	0.000	1.4	347.921
1974	0.652	0.484	0.015	0.213	0.010	0.026	1.4	452.149
1984	0.803	0.383	0.017	0.173	0.010	0.014	1.4	427.291
1997	0.888	0.353	0.016	0.120	0.010	0.014	1.4	418.094

For the final *ACRU* modelling exercise performed at the scale of the Craigieburn microcatchment, in which *ACRU* was configured to represent the microcatchment in 'good' and 'degraded' conditions, two hypothetical land use scenarios were simulated in order to determine potential values of streamflow produced by this catchment under 'non-degraded' (named 'baseline') and 'degraded' (named 'plots') conditions. The 'baseline' configuration is based on the theory that the vegetation types that naturally grow in a wetland area best sustain the wetland, elaborated upon in Section 6.2.1.2. The 'plots' scenario was performed to gauge the degree to which cultivation of the entire microcatchment would potentially impact upon the hydrology of the area, as increased cultivation of the microcatchment could occur as a reaction to the lowered yields from wetland plots noticed by the local wetland users. These areas thus comprised 'veld in good condition' and 'reeds' for the 'non-degraded' simulation, and 'maize plots' and 'mixed subsistence plots' for the 'degraded' simulation (see Appendices 12 and 13).

The 'plots' scenario produced the highest annual average, typical average month and typical dry month streamflow values (see Table 6.13). The validity of these results is verified by wetland literature referred to in Section 3 of this thesis, pertaining to the storage functions and attenuating effects wetlands, especially typical wetland vegetation types, have on streamflow. This effect can be seen more clearly when evaluating average monthly streamflow values for all months (see Table 6.14). This is elaborated upon in the following sub-section. These results are significant in light of the trend toward greater cultivation of the Craigieburn microcatchment and especially of the wetland in recent years. Greater volumes of water lost downstream will add to the desiccation of the wetland, further reducing crop yields, necessitating greater numbers of cultivation plots within the microcatchment for the same amount of yield. Without a successful alternative livelihood option, this detrimental cycle is likely to perpetuate in this manner.

The 'baseline' scenario produced higher streamflow values than the 'plots' scenario in the typical wet months, however. This is because the wet months are also the typical growing season of the maize and subsistence crops, thus water lost to transpiration is highest for these land uses during these months, and less water is consequently lost to streamflow during these months, as represented by the 'plots' scenario. During the remainder of the months, rain that falls on the sparsely vegetated soils of these plots will readily infiltrate this soil, very little of which will be lost to transpiration, thus this water makes up streamflow. The large volumes of water lost from the soil surface during the non-growing seasons could be lessened were alternative use to be made of these areas during this time. Encouraging vegetative coverage of this otherwise-bare soil during the drier months will increase interception. Rainfall intercepted by this vegetative coverage will be temporarily held by this coverage, as opposed to forming runoff from the soil, giving the water more time to infiltrate the soil. Furthermore, this coverage will shade the soil, thereby decreasing water losses to evaporation from the soil surface.

Table 6.13 *ACRU* simulated streamflow volumes for land use area combinations in the Craigieburn microcatchment, using 50 years of rainfall data

		1954	1965	1974	1984	1997	PLOTS	BASELINE
AVERAGE	TYPICAL WET YEAR	1903.11	1911.07	1922.62	1901.17	1901.65	1866	2026.5
ANNUAL	TYPICAL DRY YEAR	43.5	44.47	45.34	41.07	39.13	49	33.6
VALUES (m^3)	TYPICAL AVERAGE YEAR	271.46	279.9	289.66	264.61	263.3	546.4	148
OVERALL ANNUAL AVERAGE FOR ALL YEARS OF ANALYSIS		**418.0**	**427.3**	**452**	**347.1**	**348.2**	**568**	**140.1**
AVERAGE	TYPICAL WET MONTH	37.96	38.06	38.64	37.09	36.89	39	40.5
MONTHLY	TYPICAL DRY MONTH	0.83	0.83	0.84	0.77	0.76	0.98	0.67
VALUES (m^3)	TYPICAL AVERAGE MONTH	7.97	8.29	8.35	7.68	7.27	10.92	2.97
TYPICAL	DURING A WET MONTH	3.07	3.07	3.09	3.05	3.05	3.11	3.34
DAILY	DURING A DRY MONTH	0.07	0.07	0.07	0.06	0.06	0.08	0.06
VALUES (m^3)	DURING AN AVERAGE MONTH	0.68	0.72	0.74	0.5	0.56	0.91	0.25

Table 6.14 Monthly streamflow volumes for land use area combinations in the Craigieburn microcatchment, using 50 years of rainfall data

			AVERAGE MONTHLY STREAMFLOW VALUES (m^3)										
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1954	38	35.25	29.98	20.25	10.61	0.83	2.3	6.3	7.97	13.77	26.36	35.66	227.24
1965	38.1	36.25	33.65	19.22	10.2	0.83	2.44	6.21	8.29	18.42	28.22	36.32	238.11
1974	38.6	36.36	34.34	18.36	10.72	0.84	2.62	7.25	8.35	18.33	28.64	36.64	241.09
1984	37.1	35.25	32.87	17.3	9.56	0.77	1.55	6.24	7.68	16.95	27.89	34.58	227.73
1997	36.9	34.01	30.39	15.65	7.5	0.76	0.88	3.98	7.27	16.34	26.05	33.87	213.59

Table 6.14 shows a delayed streamflow response one may sometimes expect as a result of the wetland process of stormflow attenuation. The average streamflow values remain high in March, despite this being the start of the dry season. To a lesser, but still significant degree, the average streamflow values simulated for April also show a delayed streamflow response. The low streamflow values simulated for September, and, to a lesser extent, October, show the effect of the wetland function of water storage at the start of the wet season. Despite the fact that September and October signal the start of the wet season, the streamflow values depicted here for these months remain low, as much of the early rainfall is often stored in the wetland soils, and released in following months.

The 'baseline' and 'plots' simulations produce hydrological responses that represent extreme examples of the land use combinations of previous years. The values produced by the simulations representing land uses for the years specified thus generally fall between those produced for the 'baseline' and 'plots' scenarios. The values of the variables simulated tend to more closely represent those of the 'plots' scenario, and the trends of which tend to more closely mimic the 'baseline' scenario. These trends can be identified in the underlying graph (see Figure 6.25).

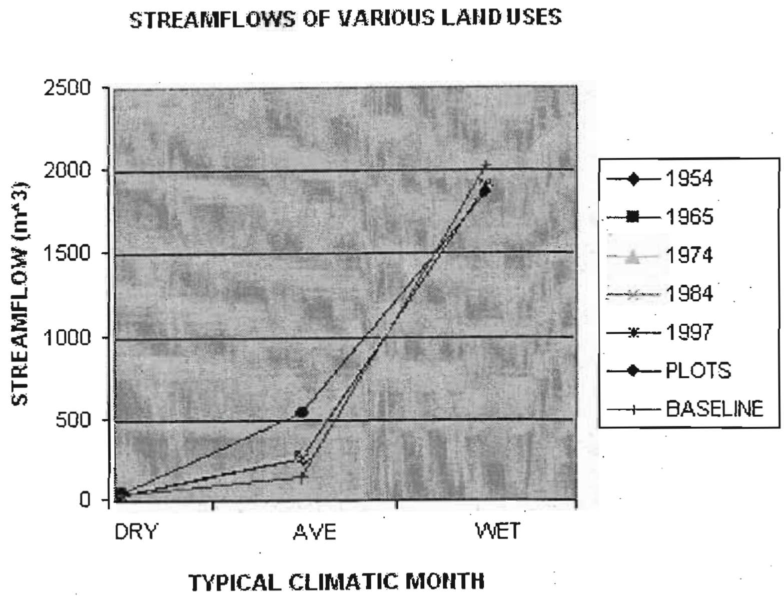


Figure 6.25 Simulated mean annual streamflow values for a variety of land uses

In this context the streamflow values of the 'baseline' scenario represent conditions under which the microcatchment and wetland are not in a state of degradation, and the streamflow values of the 'plots' scenario represent conditions under which the microcatchment and wetland are in a severe state of degradation. Although the resulting trends of previous land use scenarios are more like those of the 'baseline' scenarios than those of the 'plots' scenarios, they deviate from these trends in favour of the trends of the 'plots' scenario. Furthermore, the average annual streamflow values of previous land use area simulations are much more like those of the 'plots' simulation than those of the 'baseline' simulation. These results to a degree verify the wetland users' and research teams' suspicions that this area is in a degraded condition.

6.2.3 Sand River Catchment Modelling

The final step in the hydrological modelling exercise, the simulation catchment scale modelling exercise described in Section 5.2, again made use of the *ACRU* model, but at the scale of the Sand River catchment. The results of the Sand River catchment modelling exercises produced by *ACRU* (see Appendices 14 to 17) show slight decreases in streamflow values with increased total catchment wetland areas for the period 1 January 1930 to 31 December 1997 (see Table 6.15).

Table 6.15 *ACRU* simulated Sand River catchment streamflow values for changes in total wetland area over the period 1 January 1930 to 31 December 1997

TYPICAL *ACRU* STREAMFLOW VALUES (m^3) FOR THE SAND RIVER CATCHMENT				
MONTHLY AVERAGE	20% WETLANDS	10% WETLANDS	5% WETLANDS	0% WETLANDS
WET MONTH	28.43	28.44	28.45	28.48
AVERAGE MONTH	9.34	9.35	9.36	9.37
DRY MONTH	1.71	1.71	1.71	1.72
ANNUAL AVERAGE	**116.04**	**116.12**	**116.18**	**116.32**

The average annual and monthly streamflow values, as well as those of both typically dry and typically wet months decrease slightly with increased wetland areas. Here again, typically wet, dry and average months are represented by January, June and September, respectively. Although these results appear to highlight the attenuating effect that wetlands potentially have on streamflow at a catchment scale, and could be explained by the tendency of wetlands to store water within the catchment, as elaborated upon in Section 3.2, the magnitude of the change in these values is too slight to confidently make such deductions. From the results of the simulations at the catchment scale one can thus only conclude that the impact is not significant.

It has been shown that wetlands do, in some cases, generate flood-runoff, thereby exacerbating water management problems (Bullock and Acreman, 2003). Despite this, as emphasised in Section 3.2, a hydrological role wetlands can play in a landscape, identified by many researchers (Williams, 1991; Brinson, 1993; Kence, 1995, Thompson, 1998), is to decrease streamflow variability, thereby storing more water for use during dry periods, and lessening streamflow values at the catchment outlet, and thus lessening water losses downstream. At both the catchment and microcatchment scale the scenario simulation results appear to suggest that the hydrological effects of water retention and storage are taking place as a result of areas simulating wetland functions, highlighted by results of the dry season, and the long term results for the hypothetical scenarios of wetland areas. One cannot draw any conclusions about the effects of wetlands at different scales from these results, however, as the differences between the configurations at the microcatchment scale and the catchment scale vary too greatly to conclude that such small variations in the results are significant.

When the Sand River catchment scale results are evaluated as a percentage of the annual average streamflow volumes (see Table 6.16), the typically wet months show a reverse trend to that of the typically dry months. It could be hypothesised that, as a result of the attenuating effect of the wetlands on streamflow, a comparatively larger proportion of the average annual streamflow is made up of low flows (streamflow released in the dry months) as the wetland area increases. Conversely, proportionately lower contributions of average annual streamflow are derived from typically wet month streamflows as the wetland area increases. Although the trends do suggest that the wetlands store some rainfall and some upstream water contributions during the high rainfall months, and release this water slowly throughout the drier months, and that in such a manner streamflow becomes more regular, and water is available to the immediate wetland environment during these drier months, the relatively minor differences and uncertainty in the modelling process mean that these results are in fact inconclusive.

Table 6.16 *ACRU* simulated monthly Sand River catchment streamflow volumes as percentage contributions of total annual average streamflow volumes

PERCENTAGE OF ANNUAL TOTAL OF MONTHLY STREAMFLOW VOLUMES (%)				
TYPICAL MONTHLY AVERAGE	0% WETLANDS	5% WETLANDS	10% WETLANDS	20% WETLANDS
WET MONTH	24.50	24.49	24.49	24.48
AVERAGE MONTH	8.05	8.05	8.05	8.06
DRY MONTH	1.47	1.47	1.47	1.48

When assessing the variability of the average monthly streamflow values, it becomes evident that little, if any change in streamflow occurs on a monthly basis (see Table 6.17). Some variation is seen in December, January and February, as these are typically wetter months than the others.

Table 6.17 Average monthly *ACRU* simulated streamflow values for changes in wetland areas

MONTH	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
0%	21.42	28.48	16.84	9.37	4.6	3.13	3.01	1.72	3.3	3.02	6.54	14.88
5%	21.4	28.45	16.82	9.36	4.59	3.12	3.01	1.71	3.3	3.02	6.53	14.86
10%	21.39	28.44	16.81	9.35	4.59	3.12	3.01	1.71	3.3	3.02	6.53	14.85
20%	21.38	28.43	16.8	9.34	4.58	3.11	3.01	1.71	3.3	3.01	6.53	14.84

What Tables 6.14, 6.15 and 6.16 do show is that the magnitude of the changes in input variables is not great enough to produce output that varies significantly in magnitude. This means that either the areas of the wetlands simulated within the Sand River catchment configuration are too small to have a significant effect on the simulated streamflow calculated at the exit to the final subcatchment in the configuration, or that the model is insufficiently set up to simulate such impacts, or that the model does not represent processes well enough to simulate such impacts. The land uses aside from wetland areas therefore determine the streamflow results of these simulations (Pike, 2000). Relatively low hydrological impacts between the different scenarios simulated for previous research using this configuration have also been seen. As the same configuration and input data that was used for the 2000 study of the Sand River catchment (Pike and Schulze, 2000) was used for the catchment-scale modelling exercise performed within this study, some of the reasons given for these low hydrological impacts also apply to this study.

A reason for low hydrological impacts between different scenarios given for previous research using this configuration is that the hydrological contributions of certain subcatchments offsets the impacts of the changes in other subcatchments. A further reason is that the presence of impoundments upstream of the point at which the simulated streamflow was calculated within this study, have the effect of reducing the impacts of land use changes made in upstream subcatchments. The resulting low hydrological impacts of the land use when impoundments are present occur because the impoundments are first filled to full capacity by high flow events before overflow occurs, thereby cancelling out impacts upstream land uses would otherwise have had on the yield of the impoundments. This additional storage is then available to supplement the flows in the dry season. Furthermore, these reservoirs provide controlled releases from the impoundments, which again serve to supplement low flows during the dry season (Pike and Schulze, 2000).

6.3 Sociological Implications of Results

Results of the integrated hydrological, geomorphological and sociological research conducted in the Craigieburn wetland microcatchment and the 'control' wetland point toward a number of inter-related factors acting in conjunction with each other. These factors have lead to changes in and consequent degradation of the Craigieburn microcatchment wetland, and the consequent decrease in reliability of food and water sources for the local communities. Reasons for such links have been established in Section 4. Deductions about the sociological implications of hydrological and geomorphological results necessitated a comparison between qualitatively assessed sociological data (see Section 2.3.1) and quantitatively assessed hydrological and geomorphological data (see Sections 2.3.2, 2.3.3 and 2.3.4).

At the microcatchment scale, in-depth study of the Craigieburn microcatchment and the point scale study of the Craigieburn and 'control' wetlands, changes in soil and water conditions occur at spatial and temporal scales small enough to be detected by, and to severely impact upon the lives of local community members. Owing to this, information about the microcatchment and these wetlands gathered from the local community is comparable with information gathered from geomorphological tests performed in these areas, and with the results of hydrological models used for the modelling of these areas, as they operate at this scale, and use this geomorphological information as input data.

The results of the hydrological modelling exercises, especially those performed at the scale of the Craigieburn microcatchment, are more applicable and potentially beneficial to this study when viewed in conjunction with the results of the geomorphological and sociological studies incorporated within this thesis.

6.3.1 Changes in water content

The most notable hydrological aspect of the Craigieburn wetland identified during the WRL researchers' first visit to the catchment in January 2003 was the lack of water flowing through the wetland, especially as this was in one of the higher rainfall months. There were also indications that degradation had occurred throughout the microcatchment, such as a visible erosion donga nick point (see Figure 2.3) at the base of the Craigieburn wetland, and the extent of atypical wetland vegetation. A large number of cultivation plots within the wetland close to the main wetland channel indicated that water shortages had been experienced on the plots further from the wetland that had been more extensively cultivated previously. Such indicators serve to highlight the degree to which the hydrology and the sociology of the wetland are inextricably linked, as detailed in Section 2.2.1. The management practices evident included the remains of shallow drains dug into these plots, clearly designed to efficiently drain the plots. This may indicate that at some time in the recent past the plots had received too much water for the crops growing on them, despite the dryness of the area and the coarse, thus easily drained, texture of the soils.

Wetland users encountered during this early visit mentioned that they had experienced increased drying of the wetland. A local farmer mentioned that madumbes (*Colocasia esculenta*) used to be grown on a larger scale in and around the Craigieburn wetland, but that the soil had become too dry for madumbes. As a result farmers further drained their plots, and grew maize in the wetland instead. The farmers pointed out that the conditions of these plots had since become too dry for maize, and that management decisions made pertaining to cultivation of the wetlands are largely made in order to counteract starvation. According to the few farmers present in the Craigieburn wetland area at this time, maize and madumbes are among the most abundant crops grown here. These initial signs of and comments pertaining to wetland desiccation lead to more thorough investigation into the degree of and reasons for such effects, under a different component of the WRL project.

The geomorphological and soil texture analyses of the wetlands confirm the users' suspicions that there has been desiccation of the Craigieburn wetland. Two key on-site factors that contribute to the desiccation are the soil texture, as this determines the hydraulic conductivity of the soils, and the presence of erosion gullies. Wetland erosion gullies exert a drying out effect over an extensive area of the wetland, as fine particles such as clay particles are lost via the preferential flowpath that the gully creates (Ellery, 2004). The predominantly sandy soil that remains has a very high hydraulic conductivity, thus water is not readily retained within the wetland soils and desiccation occurs. Erosion results from several interacting factors, including the runoff characteristics of the wetland's micro-catchment, properties of the soil, the wetland's topography, particularly the slope, and the extent of on-site vegetation cover and on-site mechanical disturbance.

According to the WRL project geomorphology specialist's in-field interpretation, the recent lowering of the water table in the Craigieburn wetland, as indicated by the presence of soils typical of an environment wetter than that of the present, the drains dug into wetland plots and the comments of the local wetland users, can largely be attributed to the presence of gully erosion at the base of the wetland. If no erosion were present, the contribution of fine particles in the wetland would build up, lowering the hydraulic conductivity of the wetland soil. As a result of the erosion, and the consequently high hydraulic conductivity of the soil, the wetland water table drops quickly, despite recharge from upstream and rain inputs. This results in great variations in water table heights, and an overall lowering of the water table (Ellery, 2004), the sociological implications of which are that the wetland cannot provide a reliable supply of water to the wetland users' crops.

As the *ACRU* modelling exercise driven by 50 years of rainfall data and based on observed land use areas shows, large volumes of water are potentially lost downstream from the catchment to streamflow. This streamflow is made up, in part, of stormflow occurring from residential areas (see Table 6.18), yet the single land use, point-based modelling exercise (see Table 6.5) shows that water is also potentially lost to stormflow from mixed subsistence crops (see Figure 6.22) and areas in which 'veld in poor condition' grows (see Figure 6.21). Methods that the local wetland users could adopt in an attempt to reduce such losses include changes in cultivation practices, and efforts to retain and collect water running off the land before it is lost downstream. These are elaborated upon in Chapter 7. When asked about cultivation practices and difficulties experienced, a female member of the local community who cultivates subsistence crops and harvests reeds in the Craigieburn wetland, commented that the most difficult time of the year to grow crops is during the winter months. She further stated that there is seldom enough food produced during this time to feed her household, thus alternative livelihood strategies are more intensively adopted during winter. This can be attributed to the fact that the sandy texture of the Craigieburn wetland leads to severe desiccation in the winter months, during which the rate of water loss from the wetland to stormflow and especially evaporation is very much greater than the rate of water input from rainfall.

Table 6.18 Observed residential areas at different times and *ACRU* simulated catchment streamflow values produced for 50 years of rainfall data

	Area (km^2)	Ave ann. (m^3)
YEAR	**RESIDENTIAL**	**STREAMFLOW**
1954	0.047	348.734
1965	0.036	347.921
1974	0.484	452.149
1984	0.383	427.291
1997	0.353	418.094

The close correlation between the size of the residential areas and volume of runoff produced in many of the modelling exercises described within this chapter have sociological implications for local Craigieburn community members. This potential correlation implies that the local community would be well advised to adopt methods of redirecting and containing this water on site, before it is lost to streamflow downstream. Again this is discussed in Chapter 7.

6.3.2 Inconsistencies in data and results

A Craigieburn microcatchment visit characterised by much drier conditions than those observed in January 2003 took place in April of the same year. The fact that the reeds were still thriving, despite the main channel having dried up, indicated that some water was still present in the wetland, and the vegetation within and surrounding the perimeter of the wetland was denser than it had previously been. Members of the local community who farm in the Craigieburn wetland were again (see Section 6.3.1) in agreement that the wetland had become progressively drier in recent years.

The inconsistencies that exist between the type of environment indicated by the soils and by the vegetation, respectively, indicate that this wetland has become progressively drier in the past decade. The gleyed, mottled soils found in the lowest parts of the microcatchment wetland are indicative of an environment that is a lot wetter than the environment needed to sustain the current vegetation of the wetland. Mottling within the soils indicated the existence of an alternating water table height, present as a result of the natural cycle of wet and dry periods. During dry periods oxidation of the soils produces an orange layer in the soil, and in the wet periods, during which time the soil is in an anoxic state, a grey layer is left within the soil (Hillel, 1998).

The characteristics and composition of soils change in response to changes in the degree of wetness of their environment over a period of about a decade, whereas vegetation responds to far more immediate changes in its environment than soil does. Thus, although the soil indicated a certain degree of wetness of the Craigieburn wetland, the vegetation present in the wetland indicated much drier current conditions, verifying that the wetland has become progressively drier in the past decade. The sociological implications of the potential perpetuation of such a trend are that alternative water supplies and cultivation area will have to be found, and more intensive use will have to be made of alternative livelihood strategies.

The local Craigieburn wetland community commented on their memories of past periods of wetter and drier conditions. Four historic climatic and anthropogenic events relevant to the use of the wetland were considered by members of the local community to be especially significant. These include the drought of 1992, the flood of February/March 2000, the clearing of natural vegetation for plantation trees in the 1950s, and the washing away of a large number of the surrounding hills in 1939. The rainfall records collected at the 'Wales' rain gauge show evidence of the drought of 1992 and the flood of early 2000, as noted in Section 2.3.3. Comments made by some of the community members contradicted what others had to say, however. These members considered the drought of 1992 to have had a considerable impact on wetland production, but although the drought was seen to negatively affect the production of *Leshago*, other natural items including water sources were described as being largely unaffected. It was further mentioned that sand covered the *Leshago* after the floods of 2000, which contradicted the indication that production of *Leshago* was still high in this year. A further contradiction was the generally high year round crop production estimate for 2000 gained from local community members, despite that fact that these wetland users said that crops were washed away in the 2000 floods.

Assessments of the hydrological condition of the Craigieburn microcatchment in previous years are made difficult by the lack of hydrological, land use and sociological data that overlaps temporally. A few members of the community recall large-scale clearing of vegetation in the Craigieburn microcatchment and elsewhere in the 1950s. Although land use information (see Section 5.1.4.10) and rainfall records pertaining to the year 1954 (MAP = 1097.5mm) (see Appendix 3) have been available and studied for the purpose of this research, no links between the comments of the community members and the streamflow volumes produced for modelling exercises that make use of this data can be made. These streamflow values largely correspond with the average values calculated for the five respective land use scenarios (see Table 6.19).

Table 6.19 *ACRU* streamflow values for past land use conditions in the Craigieburn microcatchment, simulated using 50 years of rainfall data

		1954	**1965**	**1974**	**1984**	**1997**
AVERAGE	**TYPICAL WET MONTH**	1903.11	1911.07	1922.62	1901.17	1901.65
ANNUAL	**TYPICAL DRY MONTH**	43.5	44.47	45.34	41.07	39.13
TREAMFLOW	**TYPICAL AVERAGE MONTH**	271.46	279.9	289.66	264.61	263.3
VALUES (m^3)	**AVERAGE ANNUAL VALUE**	**418**	**427.3**	**452**	**347.1**	**348.2**

Few community members appeared to have any memory of the 1950s, thus the validity of the production statements for this time are somewhat in question. When questioned about the causes of the observed changes in the wetland, the wetland users responded that it was largely a result of a lack of rain and excess heat from the sun.

Some of the data collected seemed to contradict other data, such as the comments made pertaining to rainfall amounts and crop production in previous years. At times, however, apparent contradictions produced a clearer picture of the processes at play within the wetlands. This can be seen in the Craigieburn wetland vegetation and soil characteristics, as the vegetation is indicative of drier wetland conditions than are indicated by the wetland soils. Representative results were difficult to obtain from contradictory sociological data, but some of the more in-depth and easily quantifiable geomorphological and hydrological data (see Sections 2.3.2 and 2.3.3) lent itself to derivation of verifiable results, much of which did compliment the sociological data collected (see Section 2.3.1).

6.3.3 Changes in Soil Fertility

Results of the geomorphological and hydrological analyses of the Craigieburn microcatchment; including nitrate accumulation results of the 'HOWWET?' model (see Section 6.2.1.1), soil texture, wetness and topographic data as well as relationships between these properties; suggest a decrease in the fertility of the Craigieburn microcatchment. To a degree these results thus verify the wetland users' suspicions that the fertility of the wetland is decreasing. This is of great significance to these users, as, of the sixty wetland users who attended the participatory processes organised by the WRL research team and were involved in the household interviews (see Section 2.3.1), all declared that at least one member of each of their households uses the wetland for either harvesting of reeds (*Schoenoplectus*) or for small-scale subsistence agriculture (see Section 4.4). A decrease in the fertility of the wetland will impact negatively on the agricultural production potential of the wetland, lessening the ability of the wetland to provide produce to meet the household subsistence needs of the community. This emphasises the community members' dependence on the wetlands for their livelihoods, as well as the importance of the condition of the wetland to these users.

Low fertility levels of the Craigieburn wetland are indicated by the comments of the wetland users and 'HOWWET?' results that show a significantly lower gain in soil nitrogen in the Craigieburn wetland than the 'control' wetland. 'HOWWET?' does not account for nitrogen losses, thus the magnitude of this depicted increase is not necessarily accurate, but does account for the fact that a severely lesser nitrogen gain occurs in the Craigieburn wetland than in the 'control' wetland. Low fertility levels can be directly linked to the increased erosion of the wetland area. As, according to the WRL geomorphology specialist, erosion has contributed significantly to the fact that there is minimal organic matter and clay remaining in the wetland soils, the Cation Exchange Capacity (CEC) of the soil is severely reduced, and nutrients are quickly leached from the soil. The clay and organic matter found within a soil accounts for the vast majority of the cation exchange that occurs within the soil, as nutrients adhere to clay and organic matter particles and not to sand particles. This is because, as a result of their mineralogy, clay and organic matter are comprised of charged particles that are able to enter into reactions with nutrients (ions) in the soil water, yet sand particles do not enter into these reactions (Kamprath, 1999). As the 'control' wetland has a higher percentage of clay particles in its soil than the Craigieburn wetland does, greater nitrogen gains are expected in this wetland.

Nutrient levels sufficient to sustain the subsistence cropping that ensues in these wetland soils is of great importance to the wetland users, especially as this area is extensively used in the dry seasons, and by the poorest members of the Craigieburn community. Lowered fertility of the wetland soils could thus negate the effect of the wetland acting as a buffer against starvation for members of the local community. In an attempt to improve the fertility of the cultivation plots within the Craigieburn microcatchment, all the farming community members practice application of cattle manure in both wetland and non-wetland plots (see Figure 6.26). There is, however, a lack of understanding of the negative effects of exposing the manure to direct sunlight. This action causes nitrogen volatilisation, thus large quantities of nitrogen are lost before entry into the soil or plants.

Figure 6.26 A manure pile on a Craigieburn microcatchment plot

Field visits to the Craigieburn microcatchment revealed that the crops grown in the Craigieburn wetland comprise of some large, healthy-looking crops, but also of a predominance of small crops whose leaves are dying, even in the wetter areas where, according to wetland users, these same crop types have thrived previously. This could be attributed to the lack of fertility of the soil, highlighting the degree of degradation of this wetland. It is well known that wetlands can potentially make up some of the most fertile, productive features of a landscape when performing typical wetland functions (Maltby, 1998).

Removal of some of the vegetative cover that was present in the microcatchment has occurred progressively over the past decade in order to clear areas for cultivation plots, leading to changes in topography and soil loss from the catchment. This has occurred and is continuing to occur in an unregulated manner as a result of the lack of effective governance in the Sand River catchment that has continued since 1994. The lack of regulatory conservation measures accompanied by an increase in microcatchment and especially in wetland user numbers has resulted in many changes in microcatchment practices, increasing wetland and livelihood vulnerability. In the past access to wetland-use was controlled by local-level institutions. Currently access to wetland and non-wetland plots is gained through inheritance or simply clearing a necessary field. This unregulated manner of access provides little scope to implement soil conservation techniques, and leads to a large amount of traffic moving through the wetlands. Realisation of the importance of regulation of wetland access does appear to be becoming more apparent in the microcatchment, however, and progressively more of the plots in the wetland are being crudely fenced, mostly to exclude cattle. The success of these fences, most of which are made of mixtures of wire, poles and thorny branches, is questionable.

7. DISCUSSION AND CONCLUSIONS

This chapter comprises a section in which conclusions drawn from all aspects of the study and related wetland literature have been presented, including problems that may be encountered if implementation of remedial action is attempted based on the conclusions drawn from the study as a whole. This is followed by a section that considers the study limitations encountered, and is concluded by suggestions for further research, as research gaps and useful information provided by further studies became evident throughout the research performed within this thesis. In the same manner in which conclusions drawn from the hydrological results are influenced when viewed in conjunction with those of the geomorphological and sociological studies of the Craigieburn microcatchment, conclusions drawn from the results produced within this study are influenced by general wetland literature and results of previous studies. The limitations imposed upon, and conditions governing this study further influence the conclusions one is able to draw.

7.1 Conclusions Drawn from the Research

'Political action is the way of securing change. If you do not engage in political parties you are not actually engaging in political decisions. You may think you are, but you're not' (Blair, 1987).

'We cannot wait for governments to do it all. Globalization operates on Internet time. Governments tend to be slow moving by nature, because they have to build political support for every step' (Annan, 2002).

Research-based projects aimed at understanding and improving the condition of wetlands and the livelihood conditions of wetland users in impoverished communities in South Africa are characterised by the lack of an environmental policy to guide the use and development of, and to regulate access to and exclusion from wetlands and their resources. As the above quotes emphasise, the past fifteen years have seen a change in society's outlook on how best to ensure change. A worldwide trend toward use of Non-Governmental Organisations (NGOs), and proactive community-based initiatives in order to solve problems that would previously have been directed toward governmental agencies has been established, with significant success (Bailey, 1998; McConnel, 1998; Diem, 1998).

There are mixed views regarding who is ultimately responsible for the wise use of wetlands in South Africa, however, and how useful such a body will be in this regard. In light of the potential consequences of governmental inefficiency in terms of both drafting and implementing an environmental policy for wetlands in rural areas in South Africa, NGO-based approaches to wetland use in these areas may be worth adopting. Much South African literature that spans the past fifteen years mentions initiatives in which the South African government and development agencies are in the process of assessing the use of the environment and investigating new approaches to the management thereof (Dugan, 1990; Johnson, 2003; Swanson, 2004), yet the lack of an effective wetland policy, commonplace in developing countries such as South Africa, has continued throughout this period. Wetland degradation and loss has also been supported in the past by governmental agents distributing development assistance funds, oblivious to the fact that negative impacts on a wetland environment are often incomparable with the benefits of the development of the wetland area (Dugan, 1990; Bergkamp, 1998; Kotze, 2002; Swanson, 2004).

Aside from political complications, communities that rely on wetland resources for their livelihoods encounter further difficulties that place them in a vulnerable position. Wetlands in South Africa are subject to climatic, geomorphological and other unpredictable changes in their immediate environment, making encompassing programmes that guide sustainable land management practices thereof necessary. Owing to their vulnerability, wetland environments tend to become scarce, precipitating exploitation of the resources they offer, making them more susceptible to environmental damage. Ideally communities should make use of wetland resources in a manner sustainable to the community and to the resource itself (Bergkamp, 1998). This is highlighted by the extensive degree to which erosion is becoming prominent in the Sand River catchment (see Figure 2.4), worsening the wetland's storage capacity (see Section 6.2.1.2), and in turn negatively impacting those who are dependent on the wetland for their daily livelihoods (see Section 4.1).

The degradation of the Craigieburn wetland highlights the sensitivity of the Sand River catchment wetlands to disturbance, in turn highlighting the need for equilibrium to be maintained within wetlands. As a result of the dominance of sandy soils in these wetlands, the consequently high hydraulic conductivities and ongoing cultivation, gully erosion is likely to further lower the water table over a larger area, eventually drying out the wetland completely (see Section 6.3.1). Those local community members who will be the most severely affected by complete drying of the wetland are likely to be members of the poorest households, as outcomes of discussions held with the Craigieburn wetland and microcatchment users show (see Section 2.3.1). These wetland users' vulnerability is emphasised by the fact that the wetland acts as a barrier to starvation for these households, and that livelihoods within all wealth categories move easily from one category to another. As is typical of lower income, rural households, most adopt multiple livelihood strategies, in many of which wetlands play an important role (May, 2000).

The literature pertaining to the link between wetlands and rural livelihoods tends to agree on certain points, despite the fact that the precise definition of a wetland is not always one of these. Modelling or pure science-based studies, those that concentrate on wetland functions and processes, show that although there is limited consensus in the scientific community over the important functions that wetlands perform (Bullock and Acreman, 2003), some references agree that under certain conditions these include water storage, flood attenuation, erosion control, toxin and nutrient retention and groundwater recharge (see Section 3.5). The study of the Craigieburn microcatchment and wetland highlights the effects that the soil texture and the land use of the microcatchment have on these hydrological processes. The origin of the link between wetlands and impoverished communities lies in the fact that these processes enable wetlands to provide a source of water and are fertile enough to support a variety of plants. Hydrological modelling helps to establish this link by mimicking the functions that wetlands provide by simulating the processes that occur within them. These processes may include lateral water flows, inflows, losses, outflows and storage functions, many of which are determined by the properties of the soils within the wetland and the uses being made of the wetland. In this way hydrological models are proving to be useful tools for improving ones understanding of the processes that occur within wetlands, and how these are both affected by, and affect their environment. Much work is still needed in this field, however, as elaborated upon in Section 7.2.

As has been emphasised, processes leading to degradation of the Craigieburn wetland do not occur in isolation, and establishing the links between these processes highlights the degree to which a problematic effect of one process may exacerbate the detrimental effects of other. The following series of established links serve to illustrate this. Increased population numbers in the Craigieburn microcatchment has placed pressure on the resources of the Craigieburn wetland. The lack of effective governance and extension in the area prevents the implementation of cultivation practices that minimise the effects of this pressure and are essential to conservation of sand-dominated soil such as those of the Craigieburn wetland, but would be particularly difficult to implement in an area in which plots are fenced off and access is regulated in so haphazard a manner. The resulting absence of established vegetation increases the rate at which water and fine soil particles are lost downstream, and the lack of clay particles present in the Craigieburn wetland soil results in a lack of exchange sites for cations that may be present in the immediate environment. This causes organic matter that may be present in the wetland to pass through the wetland unhindered, further reducing the cation exchange capacity of the soil. The non-cohesive soil is particularly vulnerable to erosion, and once erosion starts, it moves very quickly in sandy soils such as those of the Craigieburn wetland.

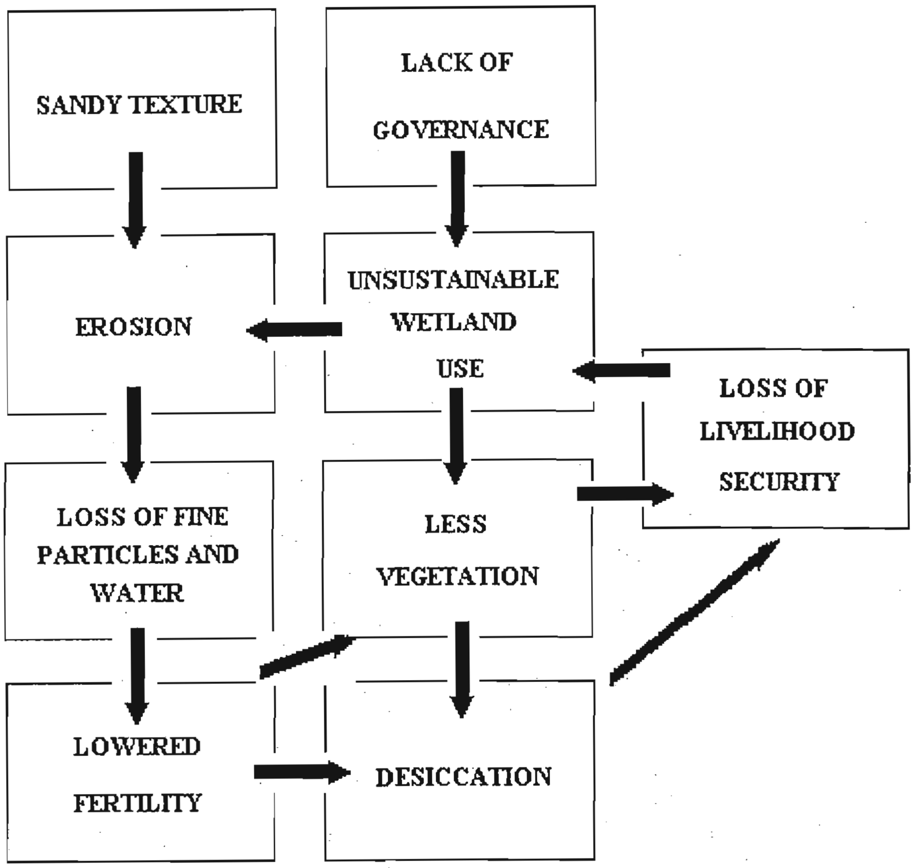
Over-population of the area increases human traffic and thus also the number of cattle inhabiting the wetland area, greatly increasing mechanical disturbance of the wetland, and also aiding the erosion process. The erosion provides paths for rapid water flow through the profile, drying the soil and adding to soil loss. The reduction in vegetation also reduces the ability of the wetland to physically hinder the path of water through the wetland, leading to further desiccation thereof. Although rainfall is sparse and runoff thus minimal in the Sand River catchment, a large amount of soil-water is lost as the large inter-particle spaces of the bare, sandy soils ensure that water is not tightly held within the soil matrix.

The drying of the wetland is likely to also have a drying effect on the area surrounding the wetland. This is because soil water will move from wetter to drier areas as a result of matric soil water potential gradients, and will move from higher to lower areas as a result of gravitational forces. This may force the community members to move cultivated areas closer and closer to the centre of the wetland, increasing the vulnerability of the wetland to erosion, and further drying the wetland and microcatchment. With a severely limited amount of clay and organic matter present in the soil, plant nutrient retention also becomes very limited, rendering the soil infertile, and limiting the types and amount of vegetation that can grow in the wetland. The reduction in vegetation leads to a lowering of organic matter inputs to the soil, perpetuating the cycle. Reduction in the crop production potential of the wetland increases the area of the wetland in which subsistence cropping takes place, placing further pressure on the wetland resources, and further encouraging erosion. Under such impoverished conditions competition for the scarce wetland resources can become fierce, detracting from wetland users' motivation to use the wetland more sustainably, and to implement a collective action wetland use programme.

In the Craigieburn wetland erosion manifests itself in the form of an erosion donga at its outlet, and the erosion donga leads to a marked loss in retention of fine particles within the wetland. As shown in the above example, this, in turn, leads to an increase in hydraulic conductivity of the soils, and a decrease in the water table of the wetland, leading to desiccation. Under conditions in which the water table is lowered, previously anoxic soils become aerated areas, causing the organic matter in this area to be used up by the life forms that this oxygenated area enables. This is a rapid process, whereas reintroducing organic matter to an environment is a markedly slower process, thus a decrease in fertility results.

Some of the processes leading to the degradation of the Craigieburn wetland can be attributed to its inherent properties. The inherent geomorphological properties of the Craigieburn wetland microcatchment are its soils, its oversteepened gradient and its vegetation (see Section 6.1). Properties of most moderately erodible, sandy soils are a high hydraulic conductivity and low level of fertility. In the Craigieburn wetland a high hydraulic conductivity has led to rapid groundwater recharge and a consequent lowering of the water table locally and regionally. The use and consumption of the wetland vegetation leads to mechanical disturbance at the hands of local people and animals, and a reduction of both on-site and more general vegetation. As mentioned previously (see Section 6.2.1.1), this leads to an increase in sediment availability, leading to erosion, and thus also to desiccation of the wetland and a consequently lowered fertility. In this inter-related manner, the inherent properties of the Craigieburn wetland lead to its erosion, and to a loss of livelihood security for the local community (see Figure 7.1).

Figure 7.1. The inter-related manner in which aspects of the Craigieburn wetland are linked



Potentially beneficial changes in cultivation practices include retaining a vegetative cover on the wetland plots year-round and potentially increasing baseflow by encouraging the growth of 'veld in good condition' in the microcatchment (see Figure 6.17). A vegetative cover will potentially reduce water loss to stormflow as the roots of the vegetation will bind the soil, providing a physical barrier to stormflow. This will potentially retain water on the land for a longer period, encourage this water to percolate into deeper soil horizons, making up baseflow. The benefits thereof are discussed in Section 3.2.

Methods of redirecting and containing the water that runs off the 'residential areas' (see Table 6.17) and makes up a component of the streamflow, are likely to be beneficial to the local community members in this water scarce area. The majority of this water runs off roofs, cemented courtyard areas, animal enclosures, dirt roads and footpaths within the 'residential area'. The infiltration capacity of these areas is unlikely to increase, as high volumes of human and other traffic moving through these areas will ensure that the soils of these areas remains compacted. A method in which this water can be captured and contained within a vessel that does not impart toxins to the water will enable this water to be treated and used. In light of the economic circumstances that characterise this area, a manner in which to implement such a plan without the use of expensive infrastructure would have to be devised. Ideally such a project should be devised and maintained by members of the community, thereby encouraging self-sufficiency of the community.

Literature pertaining to the value that wetlands provide is more wide-ranging that that based on the hydrological aspects thereof (see Section 4.1), and emphasises the degree to which wetland value is not only determined by the hydrological, geomorphological and ecological characteristics of the wetland, but also by the social dynamics of the local communities for whom the wetlands hold value. There is general consensus that in order to comprehensively understand and value a wetland, initiatives must be wetland-specific, multi-disciplinary and take full cognisance of all stakeholders (Oellerman and Darroch, 1994; Maltby, 1998; Kotze, 2002; Pollard, 2002). The importance of the Craigieburn wetlands to its users is particularly great as no aid structures are in place in this impoverished area. It is the responsibility of each household to fend for itself, and in this respect the wetland enables users to diversify the wetland resources they harvest for the variety of livelihood strategies they adopt. The wetland also enables many farmers to continue to practice subsistence farming at the driest times of the year. Even once stakeholder involvement within such a project has been achieved, assigning value to a wetland is particularly difficult (see Section 4.6.3). Wetlands are subjectively valued resources to which environmental economists have long been attempting to assign more objective value, and a universal manner in which to value them (Kotze, 2002).

Scarcity of resources is only one of the problematic dynamics that arise in many rural South African communities. Household and gender inequalities are apparent, and communities struggle to fight against the legacy of poverty left by apartheid. Not only do wetlands provide livelihood resources for local communities, wetlands are often of great historic and cultural value to the communities. The financial resources that wetlands offer these marginalized communities, and the value that they hold are potentially available to communities living in and around the wetlands, but as highlighted in Section 4.2, rights of access, exclusion and use are governed by both *de facto* laws that operate within the community, and commonly antagonistic *de jure* rights that operate nationally. Were local communities to be better integrated into the decision-making processes related to wetlands, it is likely that the incentives for these members to more sustainably utilise the wetlands would be greater. Once the Craigieburn wetland users with whom the WRL team interacted were aware of what the intention of the 'Wetland and Rural Livelihoods' project was, they questioned the members of the project team about what was likely to be done in order to improve the condition of the wetland. This illustrated an awareness of and an interest in the functioning of the wetland, highlighting the possibility for local participation in potential implementation of conservation cropping methods or other wetland use management schemes. Problems are typically encountered in natural resource management projects that involve the local community, as such projects require monitoring that ideally should occur in a sensitive manner so as not to 'police' the community members, yet implementation of a plan of action is commonly the most difficult part of a management process and can require stringent monitoring (Ainslie, 1999).

The concept of community-based natural resource management is of particular importance in rural wetland management, but as highlighted in Section 4.3, few examples of successful implementation thereof exist. The variety of interactions that community members have with wetlands means that collective management is more important to some community members than to others. Thus discovering ways in which all members benefit optimally from combined wetland resource management initiatives will contribute substantially to both the well being of the community members and the wetland. This was illustrated by the greater degree of use and dependence upon the Craigieburn wetland of the poorest members of the community local to the Craigieburn wetland. Despite underdeveloped rural regions of South Africa receiving priority status in terms of poverty alleviation, including steps toward resource rehabilitation, management models often prove inappropriate in areas in which a lack of infrastructure is commonplace and traditional land tenure systems dominate. Wetland-oriented programmes require unique guidelines and monitoring systems, in which appropriate management policies and incorporation of local and external expertise are essential. A lack of understanding of the norms, values and livelihood strategies of the local communities leads to inappropriate wetland programmes being implemented in rural areas. The local communities express aversion to these policies as a result, and their valuable inputs and needs thus remain unheard (Schlager and Ostrom, 1992).

Approaches such as Integrated Water Resource Management, and multidisciplinary approaches to wetlands and other resource programmes that involve the local community in rural areas are proving beneficial, as the project based in the Waza-Logone region of Cameroon (see Section 4.6.3) highlights. The success of this project can be attributed to the fact that expertise in the fields of hydrology and biosciences were integrated with local knowledge and stakeholder input, creating a project with a broad scope, and a wide field of expertise (Braunt, 2003). The need for effective wetland policies, stakeholder participation and community awareness are also becoming more obvious to wetland project developers (Hanson, 1997).

On a broader scale, as the economy of many countries depends on their natural resource base, developing countries are under pressure to encourage social and environmental development in a sustainable manner. As highlighted in Section 4.6, scarcity of resources leads to economic decline, which leads to exploitation of resources, thus case-specific ways in which to manage wetlands are necessary, such that both the local community and the natural resources benefit. Correctly pricing natural resources is a manner in which to curb their exploitation. This gives wetland users and wetland initiative stakeholders an accurate indication of how much of the resource can be used in order that the initiative remains sustainable. Assigning prices to wetland resources, and especially to the value wetlands hold is difficult as quantifying abstract values involves subjective opinions. Some standard methods to quantify wetland value do exist however (see Section 4.6.3).

Despite the conflicting views that literature pertaining to wetlands does hold, there is concurrence that wetland-oriented projects necessitate a multi-disciplinary approach in which all stakeholders play a role. Thus, when initiating such a project, the geomorphological, hydrological, ecological, sociological and economic considerations thereof need to be accounted for.

7.2 Problems Incurred During the Study

As was to be expected, some problems were experienced during the formulation of this thesis. From the onset, the lack of gauge networks in the upper Sand River catchment posed problems to the intricate wetland-modelling component of the research. Although reliable rainfall and temperature data were available for this area, gauged streamflow data were not available. This provided a challenge, as hydrological modelling is central to the hydrological research component of this thesis. When applying a hydrological model to an area, a useful manner in which to calibrate the model for the area in which one is working, and to verify that output from the model is representative of the area, is to compare the output with gauged streamflow data. As calibration was not possible, output values obtained for the Craigieburn microcatchment scenarios can be used comparatively, but cannot be assumed to necessarily replicate volumes of water moving through and out of the microcatchment and wetland accurately. The trends simulated do reflect conceptual understanding developed from observations at sites where such data are available, and the models used have been well tested in similar conditions elsewhere. Model output can thus be assumed to be representative of the effects that changes in land use have on the hydrology of the Craigieburn wetland, and the effects that the different geomorphological conditions have on the hydrology of the Craigieburn and 'control' wetlands.

The scenario-based modelling of the Craigieburn wetland uses the well-established *ACRU* model. It is considered that the model has a sound conceptual basis, and that adequate verification of the soil water and vegetation processes in the model have been performed to deem the scenario-based modelling outputs of the Craigieburn wetland an adequate representation of the likely effects of changes in land use on the hydrology of these wetlands. The differences between the output values obtained from the 'HOWWET?' simulations of the Craigieburn and of the 'control' wetland are to be expected, based on the hydrological, soil science and wetland literature reviewed.

Despite what appears to be a positive final account of the modelling component of this thesis, this was indisputably the most trying constituent of the research. A range of problems were encountered that prevented many of the models investigated from being used to simulate the Craigieburn wetland, including problems of data availability, differences in model emphasis, and a lack of user support. Furthermore, the lack of wetland-scale models developed for typically South African climatic, geomorphological and sociological conditions necessitated adaptation of a variety of other models in attempts to represent the Sand River catchment wetlands accurately for use within these models. To exacerbate this already-testing situation, literature pertaining to wetlands in South Africa tends to focus on the social, political and economic aspects of wetlands, resulting in a lack of scientific, and especially hydrological literature in this field. As highlighted in Chapter 3, where wetland literature specific to southern Africa does exist, a lack of consensus pertaining to the hydrological functioning and processes that occur within these wetlands is evident. This may be attributed to the small number of quantitative studies performed in this region (Bullock and Acreman, 2003), and to the fact that site-specific characteristics of the wetland environment greatly affect wetland responses. General wetland functions are thus inferred to a number of wetlands that do not necessarily exhibit these characteristics (Cowan, 1995).

A logistical problem encountered was the distance between the various research institutions from which the 'Wetland and Rural Livelihoods' project was conducted. The distance between the Pietermaritzburg office where this research was based, and the wetland study area made frequent visits impractical from a financial perspective. Coordinating meetings between all the researchers involved with the 'Wetlands and Rural Livelihoods' project was also difficult, as all the other members were involved in a number of other projects simultaneously, as well as performing lecturing and administrative duties. Furthermore, the researchers are based at various institutions between Pietermaritzburg and Cape Town.

The scales at which discipline-specific research applicable to the 'Wetlands and Rural Livelihoods' project was performed varied among the disciplines. This raised questions pertaining to the validity of upscaling information, and drawing conclusions from information gathered at a variety of both spatial and temporal scales. For the purpose of research pertaining to the Craigieburn microcatchment, this hurdle was overcome as it was agreed that the geomorphological data, although collected at a point scale in space and time, is an accurate representation of the soils that have been prominent in the area over an extended period of time, as the process of soil formation is slow. The plant communities, although more variable than the soils of the area, are unlikely to vary to a degree that invalidates the use of this data for the purpose of this project. Alterations in vegetation that are known to be more frequent, specifically alterations in subsistence cropping, was one of the scenarios modelled, thus this alteration was accounted for. Extensive geomorphological data was collected for the Craigieburn microcatchment, and used as input values for the microcatchment-scale *ACRU* modelling exercises.

In the consideration of different temporal scales, inter-annual rainfall and temperature data variations have been accounted for as results have been reported as monthly averages for the entire period of record. Information gathered from the local community pertaining to events outside of this time frame have been discarded, or included for interest, but specified as information outside of the time frame of the modelling exercise. Upscaling is generally perceived to be constrained by fewer problems than downscaling (Schulze, 2004; Jewitt and Gorgens, 2000).

'HOWWET?' operates spatially at a point scale, thus there was no discrepancy between this and the geomorphological samples collected at various points used to drive this model. 'HOWWET?' produced hydrological output at a point for a year, although soils and vegetation data were not collected throughout the year for which this modelling was performed. It was accepted, however, that in 1999 the wetlands are likely to have had soils, vegetation and a slope similar enough to those that presently characterise the wetlands for these values to provide input enabling a useful comparison to be made between the wetlands' hydrological responses.

Incorporating some of the research, methodology and objectives of this thesis with those of the 'Wetlands and Rural Livelihoods' project made some aspects of this Masters research difficult. The intention of this thesis has been to investigate and develop an understanding of the hydrology, geomorphology and sociology of the Craigieburn microcatchment, and the links between the various sections of the research, whereas the intention of the project was to develop a management plan for the wetlands, over and above gaining an understanding of these aspects of the wetland. Certain aspects of this thesis, such as the analyses of a variety of models that could not be utilised within this study, while very important to this thesis, were found not to be of major importance to the greater project. Certain aspects of the research that were essential to the rather more results-driven larger project were of limited importance to this thesis. Working as a part of this larger interdisciplinary group, however, had far more benefits than disadvantages for the purpose of this thesis. The research benefited from the experience of the other project members, all of whom are experts in their various fields, and gained broad knowledge of and a variety of skills within all of these fields, including those of data gathering, modelling, project and meeting coordination, and general research practices and methods.

Political issues played less of a role than initially expected in this research. Initial assumptions based on the fact that the social study was based in a deeply rural part of the country, and that rural areas of South Africa are frequently fraught with political upheaval, were that external researchers would encounter significant barriers (Ainslie, 1999; Carter and May, 1999; TAU, 2003). The Witness newspaper articles referred to in Section 4.7 of this document, in which the precarious political climate of the area in which the study is based is highlighted, verify this. As is elaborated on in Section 2.3.1, the collection of social data did incur some resistance, but not enough to prevent the research team from performing research in the majority of this area. The WRL research team were barred from certain areas, however, one of which comprised a hollow in the side of hill that houses the area in which an initiation ceremony ritualistically takes place.

A political barrier that did impact upon the progress of the research team, specifically the hydrological research, was a split in management between the government agencies responsible for the Working for Water and Working for Wetlands programmes, respectively. This split made accessing certain resources difficult, for example, plans to attain images of the Sand River catchment did not materialise before the completion of this document. These images would have enabled inclusion of the areas and position of actual wetlands present in the Sand River catchment in the *ACRU* configuration thereof. Consequently this exercise was performed using hypothetical wetland extents of 5%, 10% and 20%, as described in Sections 5.2 and 6.2.3. Although this still provided useful results, the adapted configuration could easily be manipulated to include these wetland areas, were these images to become available in the future.

Political influences of the past, specifically the legacy of apartheid left in the former-homeland area in which the research was based, did impact upon the research, and underpin the implementation of the project. As is elaborated on throughout this thesis, a lack of governance and infrastructure exacerbate the poverty incurred in the area, which can be attributed to inequitable allocation of resources in the past.

Certain assumptions made in the proposal stage of the research were shown to be inaccurate. This slowed progress to a degree, as many steps forming the research design for this thesis lead on from previous steps, some of which were deemed unachievable as a result of these false assumptions. One such assumption was that small-scale hydrological models that can accurately account for water movement through a wetland are readily available. Changes made within one of the disciplines involved with the larger project affected the other disciplines, thus problems encountered in one discipline slowed progress within the others.

7.3 Suggestions for Further Research

Based on the advantages of multi-disciplinary research evident in the study phases involved in the 'Wetlands and Rural Livelihoods' project, further research based on links between wetlands and rural livelihoods should continue with a multi-disciplinary approach to the research. The areas in which the hydrological, geomorphological and sociological aspects of wetland research are inextricably linked became clear throughout the duration of this project, and the manner in which conclusions drawn about these separate entities fed into each other was particularly successful. This enabled broader explanations to questions posed by the research.

Further research into the field of wetland hydrology specific to South Africa is essential. As climatic and other environmental conditions vary widely among wetlands, area-specific information is essential to an accurate understanding of the processes undergone in the wetland under inspection. It is strongly recommended that research into the development of a wetland hydrology model specific to South African conditions be performed, that accounts for all lateral and vertical flows typical of wetland soil water movement, and for a variety of soils, climates and vegetation types. Further research in this area will require careful monitoring of critical hydrological processes. The sociological impacts of and on wetlands will also be site-specific, thus a guide specifying suggested best management practices for wetlands should be area specific.

There is a moment in every dawn when…there is the possibility of magic.
The moment passed as it regularly did… without incident.
The mist clung to the surface of the marshes. The swamp trees were grey with it, the tall reeds indistinct. It hung motionless like held breath. Nothing moved. There was silence. The sun struggled feebly with the mist, tried to impart a little warmth here, shed a little light there, but clearly today was going to be just another long haul across the sky.
Nothing moved.
Again, silence.
Nothing moved.
Silence.
Nothing moved.
Very often whole days would go on like this, and this was indeed going to be one of them.
Fourteen hours later the sun sank hopelessly beneath the opposite horizon with a sense of totally wasted effort (Adams, 1996).

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9. APPENDICES

Appendix 1. Craigieburn Wetland User Questionnaire

Wetlands Research
Household Interviews September 10th 2003

Materials to have on hand:

- Household name card, maps of homestead and fields
- Map
- A3 sheets
- Koki pens
- Beans

Introduce the interview team, say we expect to spend about 45 minutes, make it clear all household members present are welcome to join in, or anyone else who is around. Check if people are ok with this, and if they have anything they would like to say or ask about.

PART ONE

Lay out the maps and name card. Check information we have on them. Capture information in the **Household Information** section. Some of this is checking information we already have, some of it is new information.

Significant events ask this by referring to the categories – we are asking about events that have been very important – these events may have had good effects or bad ones for the household members – e.g. things that moved the household from one category to another, or that caused great change of some sort.

Household category Check where we have them, and if they agree with this.

PART TWO: DISCUSSION ON WETLAND

PART THREE : SOURCES exercise: or "where does this come from?"

NOTE: write in English but also use either Sotho or even better simple pictures or codes to illustrate.

Explain that we will be asking about where the household gets some of the things it needs in order to live, for we are looking at how big or small a part the wetlands plays in this households livelihood.

FOOD

Lay down an A3 sheet and draw a plate of food at the top.

Ask: Where do you get your food from, in this last year?(from October last year to now) Make boxes below this and note the answers eg shop – or we buy it and for the fields/ garden, we grow it.

Ask: what proportion do you grow, and what do you buy: (using beans, or asking which was more?)
Now ask if this was different the year before (which was a wetter year).
Note the answers on the boxes, and on the SOURCES sheet.

Where does the food you grow come from?
Possibilities: Wetland field, other field, homestead garden. Show with the beans how much food came from each source in the last year. Write the answer. Then ask if this was different the previous year. Write down the number of beans on the diagram, and on the SOURCES sheet.

Say we know people use money for many things, not only food. Where does the money you use come from? Write down sources of income: ask about sale of crops, employment, pension, sale of reeds or mats, own business…
Allocate beans to show proportion of each source to overall income – for this past year. Then ask about if it was different the previous year. Fill in on the SOURCES sheet

Of the crops you sell, where do those crops come from? Wetlands, other fields, garden. Show with beans what proportion of what is sold come from which source, for this year, then for last year. Write down answers on the diagram and the SOURCES sheet.

NATURAL RESOURCES

People use natural resources for many things: we want to know about those from the wetlands – what are the other things that come form the wetland that you use? Write them down, each in its own box.
How important these are to your household? You can use the beans to score if there are many

Where do they get leshago from? If more than one source, ask how much they get from the different places. (Use the map to get clear on where if not certain). Ask here about how easy or difficult access for themselves or for others is.

How are the reeds used: for home use, for selling as raw materials, for selling as mats
Ask what proportion (use beans if this is helpful)

WATER

Where does water for your household come from – for people –and how much comes from where. Explore if this changes at certain times.
Then do this for animals.
Interviewers name ________________________ Date __________

PART 1. **Household Information**

Name ____(*check*)

No: ___________ (*check*)

Respondents name/s ____

Household head ____

Number of people in household ___________ (*check*)

Adults ______________

Children _______________ School-going ___________________

No of animals: cattle_____________ Goats ___________ Pigs _______ (*check*)

When this household came to Craigieburn ______________________________

When the respondent came to this homestead __________________________

Who in this household uses the wetland, what for, what is their age

________________________ __________________________ _______

________________________ __________________________ _______

________________________ __________________________ _______

Significant events in this household

____

____

____

____

____

____

____

Household category __1 ___2___3___4 _________________________________

PART TWO: SOURCES exercise: or "where does this come from?"

FOOD

Food

	This year	Last year
Bought		
Grown		

Where food we ate was grown

	This year	Last year
Wetland		
Other field/s_		
Home garden		

Where money comes from

	This year	Last year
Sale of crops		
Employment		
Pension		
Sale of reeds or mats		
Business		

Crops sold come from

	This year	Last year
Wetland		
Other field/s_		
Home garden		

NATURAL RESOURCES

What resources

	How important: scoring
Leshago	

Sources of reeds

	How important: scoring

Access for self and others:

Uses of reeds

	Use scoring
Mats for home use	
Selling reeds	
Selling mats	

WATER

Sources of water for people

	Use scoring	Comments

Sources of water for cattle and goats

	Use scoring	Comments

Grazing sources

	Use scoring	Comments
Wetland		

PART THREE: DISCUSSION ON WETLAND

When did this respondent start to use the wetlands here; for cultivating, harvesting reeds etc? How did they come to get this piece of land? Why did they?

(Lead in by noting that the soil sampling done recently by other team members indicates that these wetlands used to look quite different.)

If you go back in your mind to when you first came here – what can tell us has changed? What did it used to be like, how is it different?

If you think of the wetland being like a person, who may be healthy or weak and sick: how healthy do you think the wetlands are now? What tells you if a wetland is healthy?

What do you think can and should be done to make your wetlands healthier?

Appendix 2. Rain Gauges Identified in the Craigieburn Microcatchment Vicinity

0594511 W,30.8000,-24.5167,HOEDSPRUIT - SWADINI
0594550 W,30.8167,-24.6667,GRASKOP - BOURKE'S LUCK
0594609 W,30.8333,-24.6500,BELVEDERE (POW)
0594635 W,30.8667,-24.5833,MARIEPSKOP (BOS)
0594640 W,30.8667,-24.6667,BELVEDERE
0594696 W,30.9000,-24.6000,SALIQUE (BOS)
0594760 W,30.9333,-24.6667,HEBRON (BOS)
0594781 W,30.9333,-24.5167,MADRID
0594783 W,30.9500,-24.5667,GLEN LYDEN
0594817 W,30.9667,-24.6167,FOUR CORNERS
0594819 W,30.9667,-24.6500,WALES
0637720 W,30.8833,-24.5167,BEDFORD

Appendix 3. Example of Rainfall Data from the 'Wales' Rain Gauge (0594819W)

DAY	AMOUNT (mm)
594	**819 W**
1954	**1**
1	10
2	1.1
3	0
4	98.4
5	1
6	0
7	0
8	0
9	0
10	25.5
11	0.2
12	0
13	0
14	44.8
15	5.8
16	1.1
17	0
18	0
19	0
20	0
21	0
22	1.6
23	6.4
24	0
25	5.8
26	1.7
27	3.9
28	7.2
29	0.4
30	0
31	4.9
594	
1954	**2**
1	4.9
2	4
3	7.1
4	0
5	10.2
6	0
7	5.3
8	0.3
9	0
10	0
11	0

12	0
13	4
14	0
15	50.5
16	54.8
17	9.1
18	0
19	1.6
20	18.4
21	3.9
22	0
23	3
24	67.6
25	13.8
26	0
27	1.1
28	0
594	
1954	**3**
1	1.8
2	0
3	0
4	57.2
5	3.1
6	0
7	0.3
8	0
9	0.7
10	0
11	0
12	0
13	1.8
14	20.7
15	7.8
16	12
17	0
18	0
19	0
20	0
21	0
22	0
23	0
24	0
25	2.1
26	0
27	0
28	0
29	0
30	0
31	0
594	
1954	**4**

1	0
2	0
3	0
4	0
5	0
6	3.8
7	8.2
8	0
9	0
10	27.7
11	2.3
12	0.7
13	0
14	15.9
15	0
16	0
17	0
18	0
19	1.1
20	30
21	0
22	0
23	0
24	0
25	0
26	2.8
27	9.2
28	0.9
29	1.3
30	0
594	
1954	**5**
1	0
2	0
3	0
4	0
5	0
6	0
7	4.1
8	0
9	0
10	0
11	0
12	0
13	0
14	0
15	0
16	0
17	0
18	0
19	18.6
20	0.6

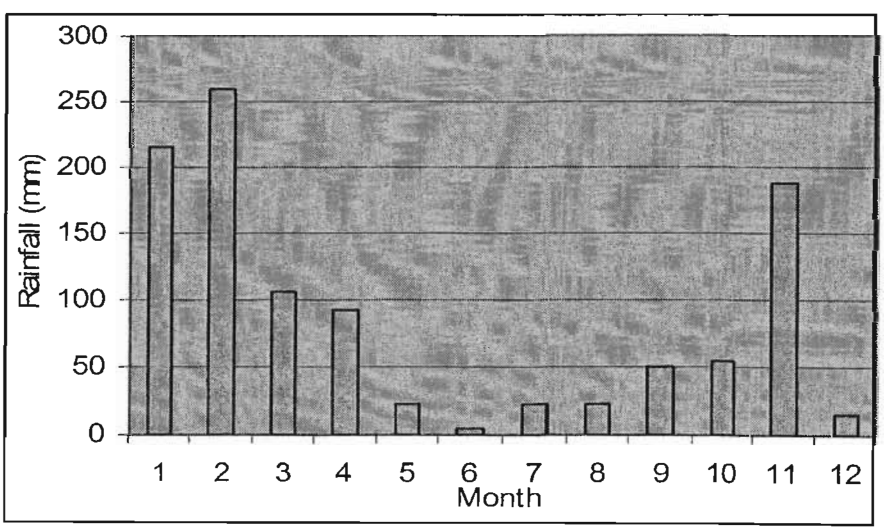
21	0
22	0
23	0
24	0
25	0
26	0
27	0
28	0
29	0
30	2.8
31	0
594	
1954	**6**
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0
11	0
12	0
13	0
14	0
15	0
16	4.1
17	0
18	0
19	0
20	0
21	0
22	0
23	0
24	0
25	0
26	0
27	0
28	0
29	0
30	0
31	0
594	
1954	**7**
1	0
2	0
3	0
4	0
5	0
6	0

7	0
8	0
9	0
10	0
11	0
12	0
13	0
14	0
15	0
16	0
17	0
18	0
19	0
20	0
21	0
22	0
23	0
24	0
25	0
26	0
27	0
28	0
29	0
30	0
31	0
594	
1954	**8**
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	3.2
11	4.1
12	14.2
13	1.8
14	0
15	0
16	1.6
17	2.5
18	9.9
19	1.2
20	0
21	0
22	0
23	3.4
24	0
25	0

26	0
27	0
28	0
29	2.5
30	1.2
31	0
594	
1954	**9**
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0.4
10	0
11	0
12	0
13	0
14	0.2
15	0.1
16	0.9
17	0
18	0
19	1
20	0
21	0
22	0
23	0
24	0
25	0
26	0
27	0
28	0.9
29	4
30	0
594	
1954	**10**
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0
11	7.8
12	0

13	0
14	0
15	0
16	20
17	10.9
18	1.5
19	5.2
20	0
21	0
22	0
23	0
24	1.4
25	0
26	3.5
27	0
28	0.3
29	0.2
30	2.9
31	0
594	
1954	**11**
1	0.2
2	13.9
3	6.5
4	0
5	0
6	0
7	0
8	0
9	0
10	3.2
11	5
12	4.4
13	2.8
14	2.7
15	0.6
16	3.4
17	1
18	0
19	0
20	0
21	0
22	1.8
23	0
24	14.1
25	19.9
26	2.6
27	3.8
28	11.8
29	1.5
30	29.6
594	

1954	12
1	8.6
2	13.6
3	2.2
4	0
5	0
6	0
7	12.5
8	11
9	14.3
10	29.7
11	6
12	1.2
13	0
14	0
15	0
16	0
17	0
18	7.3
19	4.1
20	4.3
21	0
22	0
23	0
24	4.6
25	1
26	8.4
27	0
28	2.5
29	0
30	0
31	9.6
MAP	**1097.5**



Appendix 4. Example of Temperature Data Obtained for the Craigieburn Microcatchment Area

MAXIMUM AND MINIMUM TEMPERATURES				
YEAR	MONTH	DAY	MAX	MIN
1950	1	1	28.1	17.1
1950	1	2	28.1	17.1
1950	1	3	28.1	17.2
1950	1	4	28.2	17.2
1950	1	5	28.2	17.3
1950	1	6	28.3	17.3
1950	1	7	28.3	17.4
1950	1	8	28.4	17.5
1950	1	9	28.4	17.5
1950	1	10	28.5	17.6
1950	1	11	28.6	17.7
1950	1	12	28.7	17.8
1950	1	13	28.8	17.8
1950	1	14	28.9	17.9
1950	1	15	29.1	18
1950	1	16	29.2	18.1
1950	1	17	29.4	18.2
1950	1	18	29.5	18.3
1950	1	19	29.6	18.4
1950	1	20	29.8	18.5
1950	1	21	30	18.6
1950	1	22	30.1	18.7
1950	1	23	30.3	18.8
1950	1	24	30.4	18.9
1950	1	25	30.6	19.1
1950	1	26	30.7	19.2
1950	1	27	30.8	19.3
1950	1	28	30.9	19.4
1950	1	29	31.1	19.4
1950	1	30	31.2	19.5
1950	1	31	31.4	19.6

MAXIMUM AND MINIMUM TEMPERATURES				
YEAR	MONTH	DAY	MAX	MIN
1950	2	1	31.5	19.7
1950	2	2	31.6	19.8
1950	2	3	31.7	19.9
1950	2	4	31.8	20
1950	2	5	31.9	20
1950	2	6	32	20.1
1950	2	7	32.1	20.1
1950	2	8	32.2	20.2
1950	2	9	32.2	20.2
1950	2	10	32.2	20.2
1950	2	11	32.2	20.3
1950	2	12	32.3	20.3
1950	2	13	32.3	20.3
1950	2	14	32.3	20.3
1950	2	15	32.2	20.3
1950	2	16	32.2	20.3
1950	2	17	32.2	20.3
1950	2	18	32.2	20.2
1950	2	19	32.2	20.2
1950	2	20	32	20.2
1950	2	21	32	20.1
1950	2	22	31.9	20.1
1950	2	23	31.8	20
1950	2	24	31.7	19.9
1950	2	25	31.6	19.8
1950	2	26	31.5	19.7
1950	2	27	31.4	19.6

Appendix 5. Examples of Soil Texture Analysis Results for the Craigieburn and 'control' Wetlands

CRAIGIEBURN WETLAND

0 - 10 CM						
Sample Plot	Coarse Sand	Medium Sand	Fine Sand	Total Sand	Silt	Total
A 6	37.87	40.71	9.17	87.75	11.79	
B 3	30.62	50.41	8.24	89.27	10.14	
C 2	32.44	46.14	10.84	89.42	9.73	
D 2	41.40	43.34	7.71	92.45	7.01	
E 2	46.05	46.41	4.82	97.28	2.26	
F 4	45.10	36.57	8.56	90.23	9.02	
ave	25.94	29.29	5.48	60.71	5.55	66.26
percentage	39.15	44.20	8.27	**91.62**	**8.38**	100.00
B 0	42.20	38.71	9.88	90.79	8.57	
B 1	32.58	42.08	11.45	86.11	13.72	
B 3	30.62	50.41	8.24	89.27	10.14	
D 6	33.50	50.18	9.31	92.99	6.68	
D 4	34.84	32.84	10.19	77.87	21.66	
D 2	41.40	43.34	7.71	92.45	7.01	
F 2	26.91	46.87	15.26	89.04	10.78	
F 3	28.60	45.26	15.36	89.22	10.16	
F 4	45.10	36.57	8.56	90.23	9.02	
ave	30.39	38.62	9.56	78.58	9.91	88.48
percentage	34.35	43.64	10.81	**88.80**	**11.20**	100.00
40 - 50 CM						
Sample Plot	Coarse Sand	Medium Sand	Fine Sand	Total Sand	Silt	
A 6	40.70	39.48	8.71	88.89	10.55	
B 3	16.50	55.13	15.80	87.43	11.91	
C 2	37.25	43.95	9.72	90.92	8.59	
D 2	30.52	59.88	5.37	95.77	3.91	
E 2	63.35	33.11	1.35	97.81	1.31	
F 4	41.03	38.21	9.68	88.92	10.72	
ave	28.67	33.72	6.33	68.72	5.87	74.59
percentage	38.43	45.21	8.48	**92.13**	**7.87**	100.00
B 0	42.44	39.44	8.84	90.72	8.62	
B 1	53.96	29.58	6.78	90.32	9.31	
B 3	16.50	55.13	15.80	87.43	11.91	
D 6	31.36	34.85	11.51	77.72	21.64	
D 4	35.43	32.06	11.35	78.84	20.63	
D 2	30.25	59.88	5.37	95.50	3.91	

F 2	28.89	45.26	15.73	89.88	14.02	
F 3	32.72	38.42	15.98	87.12	12.34	
F 4	41.03	38.21	9.68	88.92	10.72	
ave	34.73	41.43	11.23	87.38	12.57	99.95
percentage	34.75	41.45	11.23	**87.43**	**12.57**	100.00

'CONTROL' WETLAND

Site	Depth	Grain size	Packet (g)	Packet + sample	Sample (g)	Percent	
J1	0-10	>2	1.202	4.0767	2.8747	1.904359	
		1	1.225	34.107	32.882	21.78284	
		0.5	1.223	43.569	42.346	28.05231	51.73951
		0.25	1.235	36.349	35.114	23.26144	
		0.125	1.222	26.278	25.056	16.59847	
		0.053	1.23	12.71	11.48	7.604981	47.46488
		<0.053	1.229	2.43	1.201	0.795608	0.795608
					150.9537	100	
J2	0-10	>2	1.24	2.875	1.635	1.049631	
		1	1.23	38.872	37.642	24.16527	
		0.5	1.272	44.46	43.188	27.72567	52.94057
		0.25	1.241	31.194	29.953	19.22911	
		0.125	1.217	23.983	22.766	14.61523	
		0.053	1.236	19.089	17.853	11.4612	45.30555
		<0.053	1.269	4.001	2.732	1.753879	1.753879
					155.769	100	
J3	0-10	>2	1.306	4.291	2.985	1.94701	
		1	1.297	33.583	32.286	21.05902	
		0.5	1.262	45.519	44.257	28.86728	51.8733
		0.25	1.282	31.467	30.185	19.68861	
		0.125	1.245	22.825	21.58	14.07587	
		0.053	1.244	19.926	18.682	12.18561	45.95009
		<0.053	1.238	4.575	3.337	2.176607	2.176607
					153.312	100	
J4	0-10	>2	1.269	4.051	2.782	1.792376	
		1	1.263	28.421	27.158	17.49725	
		0.5	1.245	40.162	38.917	25.07329	44.36291
		0.25	1.254	40.373	39.119	25.20343	
		0.125	1.251	27.584	26.333	16.96572	
		0.053	1.233	19.225	17.992	11.59181	53.76096
		<0.053	1.261	4.173	2.912	1.876132	1.876132
					155.213	100	
J5	0-10	>2	1.206	4.162	2.956	1.908611	
		1	1.208	34.876	33.668	21.73854	
		0.5	1.246	40.495	39.249	25.34205	48.9892

		0.25	1.224	29.629	28.405	18.34036	
		0.125	1.262	24.941	23.679	15.28891	
		0.053	1.227	21.196	19.969	12.89346	46.52272
		<0.053	1.242	8.193	6.951	4.488078	4.488078
					154.877	100	
J6	0-10	>2	1.266	8.221	6.955	4.529056	
		1	1.245	34.163	32.918	21.43601	
		0.5	1.269	34.93	33.661	21.91985	47.88492
		0.25	1.238	33.817	32.579	21.21526	
		0.125	1.242	29.917	28.675	18.673	
		0.053	1.198	15.22	14.022	9.131046	49.0193
		<0.053	1.213	5.967	4.754	3.095778	3.095778
					153.564	100	

Appendix 6. XRF analysis data

PLOT	DEPTH (CM)	SiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	TiO2	P2O5	Cr2O3	NiO	TOTAL	L.O.I.
BO	0-10	75.5	17.19	4.16	0	0.48	0.1	0.38	1.7	0.62	0.05	0	0	100.1	8.82
BO	40-50	70.3	20.26	5.01	0	0.62	0	1.33	1.9	0.58	0.04	0	0	100.1	8.33
BO	80-90	76.3	16.46	1.46	0	0.44	0.2	2.17	2.3	0.61	0.02	0	0	100	5.16
B1	0-10	85.9	9.14	1.14	0	0.28	0.1	1.26	1.5	0.68	0.03	0	0	99.99	4.02
B1	40-50	78.3	13.31	0.83	0	0.19	0.1	4.59	2.2	0.34	0.02	0	0	99.94	1.84
B1	80-90	72.7	17.08	1.89	0	0.42	0.2	5.47	1.6	0.53	0.04	0	0	99.95	3.35
B1	110-120	71.4	16.58	3.32	0	0.8	0.3	5.91	1.3	0.46	0.07	0	0	100.2	3.57
B3	0-10	86.6	8.53	1.74	0	0.26	0.1	0.7	1.5	0.58	0.04	0.01	0	100	4.88
B3	40-50	88.5	7.46	1.1	0	0.2	0.1	0.94	1.3	0.48	0.02	0	0	100.1	5.38
B3	80-90	93.8	3.46	0.64	0	0.06	0.1	0.4	0.7	0.48	0.02	0	0	99.71	1.14
B3	110-120	93.9	3.82	0.43	0	0.09	0.1	0.46	0.8	0.3	0.02	0	0	99.81	1.25
D2	0-10	85.7	10.03	2.08	0	0.17	0.1	0.22	1.3	0.35	0.03	0	0	100.1	5.55
D2	40-50	85.6	10.09	1.79	0	0.15	0.1	0.32	1.6	0.33	0.03	0	0	100.1	4.37
D2	80-90	92	5.39	1	0	0.08	0.1	0.42	1	0.26	0.03	0	0	100.2	2.25
D2	110-120	58.3	32.37	5.33	0	0.68	0.2	0.44	2	0.65	0.1	0	0	100	13.9
D4	0-10	63	24.91	5.24	0.1	0.97	0.6	1.73	2.3	0.61	0.05	0	0	99.4	11.7
D4	40-50	69.3	21.26	3.13	0	0.71	0.3	1.19	3	0.5	0.03	0	0	99.44	7.74
D4	80-90	85.2	8.89	0.92	0	0.11	0.1	0.67	3.8	0.2	0.02	0.01	0	100	1.64
D4	110-120	71.2	19.76	2.78	0	0.84	0.3	0.93	3.4	0.58	0.02	0	0	99.88	6.05
D6	0-10	81.5	13.34	3.08	0	0.14	0.1	0.11	1.4	0.49	0.04	0	0	100.2	7.26
D6	40-50	71.1	19.55	3.25	0	0.7	0.4	1.54	2.9	0.52	0.03	0	0	100	6.45
D6	80-90	80.6	11.33	2.07	0	0.3	0.3	1.39	3.5	0.36	0.02	0	0	99.91	2.41
D6	110-120	76.9	14.25	2.85	0	0.51	0.3	0.9	3.5	0.49	0.02	0	0	99.74	4.08
F2	0-10	71.4	20.87	5.33	0	0.21	0.1	0.15	1.3	0.62	0.05	0	0	100.1	10.4
F2	40-50	67.7	24.35	5.59	0	0.17	0	0	1	0.64	0.04	0	0	99.54	10.3
F2	80-90	64.5	26.59	6.04	0	0.23	0.1	0.04	1.1	0.78	0.04	0	0	99.34	10.8
F2	110-120	66.8	24.79	5.75	0	0.21	0	0.13	1.1	0.76	0.03	0	0	99.56	10
F3	0-10	77.7	15.69	4.49	0	0.19	0.1	0	1.4	0.52	0.05	0	0	100.2	8.3
F3	40-50	80.1	13.52	4.71	0	0.1	0.1	0.11	1.1	0.39	0.02	0	0	100.2	5.75
F4	0-10	80	13.36	3.11	0	0.32	0.2	0.54	2	0.42	0.04	0	0	100	7.17
F4	40-50	77.9	14.58	4.22	0	0.31	0.2	0.57	1.8	0.44	0.03	0	0	100.1	5.83
F4	80-90	62.4	28.66	3.51	0	0.64	0.3	1.4	2.2	0.64	0.03	0	0	99.75	9.54
F4	110-120	78.1	15.64	2.72	0	0.32	0.2	0.5	2	0.65	0.04	0.01	0	100.1	5.55

Appendix 7. Cligen Input File for the WEPP Model

```
0.00
  1  1  0

Latitude Longitude Elevation (m) Obs. Years   Beginning year  Years simulated
  31.00   24.66        700         1        2000          1
Observed monthly ave max temperature (C)
27.55 27.09 28.10 26.93 24.17 21.91 44.00  0.00  0.00  0.00  0.00  0.00
Observed monthly ave min temperature (C)
18.18 19.14 18.20 14.87  9.83  8.11 14.00  0.00  0.00  0.00  0.00  0.00
Observed monthly ave solar radiation (Langleys)
497.5 500.4 373.5 458.8 353.8 375.6 360.2 458.8 500.2 578.9 554.5 533.9
Observed monthly ave rainfall (mm)
320.1 717.2 509.9 63.0  30.2  52.0  13.0   0.0   0.0   0.0   0.0   0.0
 day mon year nbrkpt tmax  tmin    rad  w-vel  w-dir   dew
             (mm)    (C)   (C) (ly/day) m/sec   deg    (C)
  1   1 2000  0   33.00  19.00 497.5   1.50  225.0  16.4
  2   1 2000  0   30.00  20.00 497.5   1.50  225.0  16.4
  3   1 2000  0   30.00  20.00 497.5   1.50  225.0  16.4
  4   1 2000  0   25.00  19.00 497.5   1.50  225.0  16.4
  5   1 2000  0   24.00  19.00 497.5   1.50  225.0  16.4
  6   1 2000  0   29.00  19.00 497.5   1.50  225.0  16.4
  7   1 2000  0   30.00  20.00 497.5   1.50  225.0  16.4
 10   1 2000  0   27.00  17.00 497.5   1.50  225.0  16.4
 11   1 2000  0   30.00  18.00 497.5   1.50  225.0  16.4
 12   1 2000  0   29.00  19.00 497.5   1.50  225.0  16.4
 14   1 2000  0   26.00  18.00 497.5   1.50  225.0  16.4
 15   1 2000  0   23.00  17.00 497.5   1.50  225.0  16.4
 16   1 2000  0   23.00  16.00 497.5   1.50  225.0  16.4
 17   1 2000  0   22.00  17.00 497.5   1.50  225.0  16.4
 18   1 2000  0   24.00  15.00 497.5   1.50  225.0  16.4
 23   1 2000  0   29.00  16.00 497.5   1.50  225.0  16.4
 25   1 2000  0   28.00  16.00 497.5   1.50  225.0  16.4
 26   1 2000  0   30.00  16.00 497.5   1.50  225.0  16.4
 27   1 2000  0   28.00  20.00 497.5   1.50  225.0  16.4
 29   1 2000  0   29.00  20.00 497.5   1.50  225.0  16.4
 30   1 2000  0   28.00  20.00 497.5   1.50  225.0  16.4
 31   1 2000  0   29.00  19.00 497.5   1.50  225.0  16.4
  3   2 2000  0   30.00  20.00 500.4   1.50  225.0  17.3
  4   2 2000  0   29.00  19.00 500.4   1.50  225.0  17.3
  5   2 2000  0   27.00  18.00 500.4   1.50  225.0  17.3
  6   2 2000  0   25.00  18.00 500.4   1.50  225.0  17.3
  7   2 2000  0   25.00  20.00 500.4   1.50  225.0  17.3
  8   2 2000  0   25.00  19.00 500.4   1.50  225.0  17.3
  9   2 2000  0   25.00  19.00 500.4   1.50  225.0  17.3
 10   2 2000  0   25.00  19.00 500.4   1.50  225.0  17.3
 11   2 2000  0   26.00  20.00 500.4   1.50  225.0  17.3
```

12	2	2000	0	29.00	20.00	500.4	1.50	225.0	17.3
13	2	2000	0	29.00	19.00	500.4	1.50	225.0	17.3
14	2	2000	0	28.00	20.00	500.4	1.50	225.0	17.3
15	2	2000	0	30.00	20.00	500.4	1.50	225.0	17.3
16	2	2000	0	31.00	21.00	500.4	1.50	225.0	17.3
17	2	2000	0	22.00	18.00	500.4	1.50	225.0	17.3
22	2	2000	0	30.00	20.00	500.4	1.50	225.0	17.3
23	2	2000	0	28.00	19.00	500.4	1.50	225.0	17.3
24	2	2000	0	26.00	20.00	500.4	1.50	225.0	17.3
25	2	2000	0	23.00	18.00	500.4	1.50	225.0	17.3
26	2	2000	0	28.00	18.00	500.4	1.50	225.0	17.3
27	2	2000	0	26.00	17.00	500.4	1.50	225.0	17.3
28	2	2000	0	29.00	19.00	500.4	1.50	225.0	17.3
1	3	2000	0	28.00	17.00	373.5	1.50	225.0	13.5
2	3	2000	0	30.00	20.00	373.5	1.50	225.0	13.5
5	3	2000	0	27.00	20.00	373.5	1.50	225.0	13.5
7	3	2000	0	30.00	17.00	373.5	1.50	225.0	13.5
8	3	2000	0	28.00	18.00	373.5	1.50	225.0	13.5
10	3	2000	0	28.00	17.00	373.5	1.50	225.0	13.5
11	3	2000	0	30.00	19.00	373.5	1.50	225.0	13.5
12	3	2000	0	25.00	19.00	373.5	1.50	225.0	13.5
14	3	2000	0	30.00	17.00	373.5	1.50	225.0	13.5
15	3	2000	0	30.00	18.00	373.5	1.50	225.0	13.5
16	3	2000	0	27.00	19.00	373.5	1.50	225.0	13.5
17	3	2000	0	27.00	19.00	373.5	1.50	225.0	13.5
18	3	2000	0	31.00	19.00	373.5	1.50	225.0	13.5
19	3	2000	0	29.00	21.00	373.5	1.50	225.0	13.5
20	3	2000	0	26.00	19.00	373.5	1.50	225.0	13.5
21	3	2000	0	29.00	19.00	373.5	1.50	225.0	13.5
26	3	2000	0	29.00	16.00	373.5	1.50	225.0	13.5
28	3	2000	0	26.00	17.00	373.5	1.50	225.0	13.5
29	3	2000	0	28.00	16.00	373.5	1.50	225.0	13.5
30	3	2000	0	24.00	17.00	373.5	1.50	225.0	13.5
1	4	2000	0	27.00	18.00	458.8	1.50	225.0	12.2
3	4	2000	0	28.00	14.00	458.8	1.50	225.0	12.2
4	4	2000	0	30.00	15.00	458.8	1.50	225.0	12.2
5	4	2000	0	31.00	16.00	458.8	1.50	225.0	12.2
6	4	2000	0	18.00	14.00	458.8	1.50	225.0	12.2
14	4	2000	0	29.00	14.00	458.8	1.50	225.0	12.2
15	4	2000	0	27.00	16.00	458.8	1.50	225.0	12.2
16	4	2000	0	22.00	16.00	458.8	1.50	225.0	12.2
18	4	2000	0	28.00	13.00	458.8	1.50	225.0	12.2
20	4	2000	0	26.00	14.00	458.8	1.50	225.0	12.2
22	4	2000	0	24.00	15.00	458.8	1.50	225.0	12.2
23	4	2000	0	28.00	13.00	458.8	1.50	225.0	12.2
26	4	2000	0	30.00	15.00	458.8	1.50	225.0	12.2
27	4	2000	0	30.00	14.00	458.8	1.50	225.0	12.2
28	4	2000	0	26.00	16.00	458.8	1.50	225.0	12.2
3	5	2000	0	27.00	10.00	353.8	1.50	225.0	5.2
4	5	2000	0	23.00	11.00	353.8	1.50	225.0	5.2

5	5	2000	0	23.00	12.00	353.8	1.50	225.0	5.2
6	5	2000	0	19.00	12.00	353.8	1.50	225.0	5.2
10	5	2000	0	24.00	10.00	353.8	1.50	225.0	5.2
11	5	2000	0	24.00	8.00	353.8	1.50	225.0	5.2
18	5	2000	0	25.00	8.00	353.8	1.50	225.0	5.2
19	5	2000	0	26.00	8.00	353.8	1.50	225.0	5.2
22	5	2000	0	27.00	9.00	353.8	1.50	225.0	5.2
23	5	2000	0	27.00	8.00	353.8	1.50	225.0	5.2
25	5	2000	0	23.00	12.00	353.8	1.50	225.0	5.2
26	5	2000	0	22.00	10.00	353.8	1.50	225.0	5.2
3	6	2000	0	24.00	5.00	375.6	1.50	225.0	2.5
4	6	2000	0	23.00	4.00	375.6	1.50	225.0	2.5
6	6	2000	0	19.00	9.00	375.6	1.50	225.0	2.5
7	6	2000	0	18.00	8.00	375.6	1.50	225.0	2.5
17	6	2000	0	25.00	8.00	375.6	1.50	225.0	2.5
18	6	2000	0	24.00	12.00	375.6	1.50	225.0	2.5
19	6	2000	0	24.00	11.20	375.6	1.50	225.0	2.5
20	6	2000	0	19.00	11.00	375.6	1.50	225.0	2.5
23	6	2000	0	24.00	7.00	375.6	1.50	225.0	2.5
25	6	2000	0	19.00	11.00	375.6	1.50	225.0	2.5
30	6	2000	0	22.00	3.00	375.6	1.50	225.0	2.5
2	7	2000	0	21.00	8.00	360.2	1.50	225.0	3.6
11	7	2000	0	23.00	6.00	360.2	1.50	225.0	3.6

Appendix 8. An Example of an *ACRU* Input Menu

```
     Mode of simulation (point/lumped vs distributed)
    ------------------------------------------------
ICELL
,,,,I
   1

     Distributed model specifications
    ---------------------------------
 ISUBNO MINSUB MAXSUB LOOPBK
,,,,III,,,,III,,,,III,,,,,,I
    6    1    6    0

     Hydrograph routing options
    ---------------------------
 IROUTE DELT
,,,,,,I,FFFF.F
     0 1440.0

     Subcatchment configuration information
    ---------------------------------------
ICELLN IDSTRM PRTOUT
,,,III,,,,III,,,,,,F
    1     4     0                                 1
    2     4     0                                 2
    3     4     0                                 3
    4     4     0                                 4
    5     4     0                                 5
    6     6     0                                 6

     Rainfall file organisation
    ---------------------------
IRAINF
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAA
me                                                1
me                                                2
me                                                3
me                                                4
me                                                5
me                                                6

     Rainfall information
    ---------------------
FORMAT PPTCOR   MAP
,,,,,,F,,,,,,F,,IIIII
    1      0    700                               1
    1      0    700                               2
    1      0    700                               3
    1      0    700                               4
    1      0    700                               5
    1      0    700                               6

     Monthly rainfall adjustment factors, CORPPT(i)
    ----------------------------------------------
JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
```

```
,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF
 1.08 1.08 1.08 1.11 1.11 1.11 1.11 1.11 1.11 1.11 1.08 1.08      1
 1.08 1.08 1.08 1.11 1.11 1.11 1.11 1.11 1.11 1.11 1.08 1.08      2
 1.08 1.08 1.08 1.11 1.11 1.11 1.11 1.11 1.11 1.11 1.08 1.08      3
 1.08 1.08 1.08 1.11 1.11 1.11 1.11 1.11 1.11 1.11 1.08 1.08      4
 1.08 1.08 1.08 1.11 1.11 1.11 1.11 1.11 1.11 1.11 1.08 1.08      5
 1.08 1.08 1.08 1.11 1.11 1.11 1.11 1.11 1.11 1.11 1.08 1.08      6
```

Availability of observed streamflow data

```
    ------------------------------------------
IOBSTQ IOBSPK IOBOVR
,,,,,I,,,,,,I,,,,,,I
   0    0    0                     1
   0    0    0                     2
   0    0    0                     3
   0    0    0                     4
   0    0    0                     5
   0    0    0                     6
```

Streamflow file organisation

```
    ------------------------------
ISTRMF
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAA
                                  1
                                  2
                                  3
                                  4
                                  5
                                  6
```

Dynamic file option

```
    --------------------
DNAMIC
F
0                                 1
0                                 2
0                                 3
0                                 4
0                                 5
0                                 6
```

Dynamic file organisation

```
    --------------------------
IDYNFL
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAA
                                  1
                                  2
                                  3
                                  4
                                  5
                                  6
```

General heading of simulation

```
    ------------------------------
HEAD
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
VELD IN GOOD ON SAND                       1
RESIDENTIAL AREA ON SAND                     2
```

```
SUBSIST PLOTS MAIZE ON SAND                              3
REEDS ON GLEYED                                     4
VELD IN POOR ON GLEYED                                 5
SUBSIST PLOTS MIXED ON GLEYED                             6

   Locational information
   -----------------------
 CLAREA  ELEV  ALAT ALONG IHEMI IQUAD
FFFFF.FF,FFFF.F,FF.FF,FF.FF,,,,,I ,,,,I
  1.00  700.0 24.67 31.00   2   1              1
  1.00  700.0 24.67 31.00   2   1              2
  1.00  700.0 24.67 31.00   2   1              3
  1.00  700.0 24.67 31.00   2   1              4
  1.00  700.0 24.67 31.00   2   1              5
  1.00  700.0 24.67 31.00   2   1              6

   Period of record for simulation
   --------------------------------
IYSTRT IYREND
,,IIII,,,IIII
 1950  2000                          1
 1950  2000                          2
 1950  2000                          3
 1950  2000                          4
 1950  2000                          5
 1950  2000                          6

   Simulation printout options
   ----------------------------
WRIDY WRIMO
,,,,F,,,,,F
  0   1                          1
  0   1                          2
  0   1                          3
  0   1                          4
  0   1                          5
  0   1                          6

   Statistical output options (I)
   --------------------------------
SUMMRY ICOMPR
,,,,FF,,,,,I
  1   0                          1
  1   0                          2
  1   0                          3
  1   0                          4
  1   0                          5
  1   0                          6

   Statistical output options (II)
   --------------------------------
ICOMPV LOGVAL
,,,,,,I,,,,,,I
  0   0                          1
  0   0                          2
  0   0                          3
  0   0                          4
  0   0                          5
  0   0                          6
```

Monthly means of daily max temperature, TMAX(i)

```
-----------------------------------------------
 JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F
 24.3 24.1 23.4 21.8 19.8 18.1 18.3 20.1 21.5 21.7 22.6 23.8    1
 24.3 24.1 23.4 21.8 19.8 18.1 18.3 20.1 21.5 21.7 22.6 23.8    2
 24.3 24.1 23.4 21.8 19.8 18.1 18.3 20.1 21.5 21.7 22.6 23.8    3
 24.3 24.1 23.4 21.8 19.8 18.1 18.3 20.1 21.5 21.7 22.6 23.8    4
 24.3 24.1 23.4 21.8 19.8 18.1 18.3 20.1 21.5 21.7 22.6 23.8    5
 24.3 24.1 23.4 21.8 19.8 18.1 18.3 20.1 21.5 21.7 22.6 23.8    6
```

Monthly means of daily min temperature, TMIN(i)

```
-----------------------------------------------
 JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F
 13.3 13.2 12.8  9.7  5.8  3.2  2.9  5.1  7.7  9.8 11.3 13.9    1
 13.3 13.2 12.8  9.7  5.8  3.2  2.9  5.1  7.7  9.8 11.3 13.9    2
 13.3 13.2 12.8  9.7  5.8  3.2  2.9  5.1  7.7  9.8 11.3 13.9    3
 13.3 13.2 12.8  9.7  5.8  3.2  2.9  5.1  7.7  9.8 11.3 13.9    4
 13.3 13.2 12.8  9.7  5.8  3.2  2.9  5.1  7.7  9.8 11.3 13.9    5
 13.3 13.2 12.8  9.7  5.8  3.2  2.9  5.1  7.7  9.8 11.3 13.9    6
```

```
#    Reference potential evaporation control variables
-----------------------------------------------
EQPET
,,FFF
 109                                    1
 109                                    2
 109                                    3
 109                                    4
 109                                    5
 109                                    6
```

Evaporation input availability control flags

```
---------------------------------------------
 IEIF ILRF IWDF IRHF ISNF IRDF IPNF
,,,,,I,,,,,I,,,,,I,,,,,I,,,,,I,,,,,I,,,,,I
  0    0    0    0    0    0    0          1
  0    0    0    0    0    0    0          2
  0    0    0    0    0    0    0          3
  0    0    0    0    0    0    0          4
  0    0    0    0    0    0    0          5
  0    0    0    0    0    0    0          6
```

Means of monthly totals of pan evaporation, E(i)

```
-----------------------------------------------
 JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F
100.9 154.0 129.9 131.0 116.8  99.5  97.4 109.2 130.2 139.5 140.6 140.2    1
100.9 154.0 129.9 131.0 116.8  99.5  97.4 109.2 130.2 139.5 140.6 140.2    2
100.9 154.0 129.9 131.0 116.8  99.5  97.4 109.2 130.2 139.5 140.6 140.2    3
100.9 154.0 129.9 131.0 116.8  99.5  97.4 109.2 130.2 139.5 140.6 140.2    4
100.9 154.0 129.9 131.0 116.8  99.5  97.4 109.2 130.2 139.5 140.6 140.2    5
100.9 154.0 129.9 131.0 116.8  99.5  97.4 109.2 130.2 139.5 140.6 140.2    6
```

Temperature adjustment for altitude

```
------------------------------------
 TELEV LRREG
FFFF.F,,,,II
1040.0    0                             1
```

```
1040.0   0                          2
1040.0   0                          3
1040.0   0                          4
1040.0   0                          5
1040.0   0                          6
```

Mean lapse rates for min and max temperatures

```
-------------------------------------------
TMAXLR TMINLR
FFFF.FF,FFFF.FF
  7.00  5.50                        1
  7.00  5.50                        2
  7.00  5.50                        3
  7.00  5.50                        4
  7.00  5.50                        5
  7.00  5.50                        6
```

Mean daily windspeed (m/s)

```
--------------------------
WNDSPD
,,FF.F
  1.6                          1
  1.6                          2
  1.6                          3
  1.6                          4
  1.6                          5
  1.6                          6
```

Windspeed region number

```
------------------------
LINWIN
,,,III
   0                           1
   0                           2
   0                           3
   0                           4
   0                           5
   0                           6
```

Monthly means of daily windrun (km/day), WIND(i)

```
-------------------------------------------------
 JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F,FFF.F
 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0   1
 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0   2
 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0   3
 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0   4
 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0   5
 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.0   6
```

Monthly means of daily average relative humidity, RH(i)

```
-------------------------------------------------------
 JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
,FF.F,FF.F,FF.F,FF.F,FF.F,FF.F,FF.F,FF.F,FF.F,FF.F,FF.F,FF.F
55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0      1
55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0      2
55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0      3
55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0      4
55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0      5
55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0 55.0      6
```

Penman equation control variables

```
----------------------------------
ALBEDO ICONS ISWAVE
,,F.FF,,,,,I,,,,,I
 .25   0   0                          1
 .25   0   0                          2
 .25   0   0                          3
 .25   0   0                          4
 .25   0   0                          5
 .25   0   0                          6
```

Monthly means of daily hours of sunshine, ASSH(i)

```
-------------------------------------------------
 JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
,FF.F,FF.F,FF.F,FF.F,FF.F,FF.F,FF.F,FF.F,FF.F,FF.F,FF.F,FF.F
 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0        1
 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0        2
 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0        3
 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0        4
 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0        5
 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0 2.0        6
```

"A" coefficient in Penman equation, ACONS(i)

```
---------------------------------------------
 JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF
 .27 .27 .28 .24 .24 .25 .24 .21 .23 .23 .22 .24        1
 .27 .27 .28 .24 .24 .25 .24 .21 .23 .23 .22 .24        2
 .27 .27 .28 .24 .24 .25 .24 .21 .23 .23 .22 .24        3
 .27 .27 .28 .24 .24 .25 .24 .21 .23 .23 .22 .24        4
 .27 .27 .28 .24 .24 .25 .24 .21 .23 .23 .22 .24        5
 .27 .27 .28 .24 .24 .25 .24 .21 .23 .23 .22 .24        6
```

"B" coefficient in Penman equation, BCONS(i)

```
---------------------------------------------
 JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF
 .52 .49 .52 .52 .51 .50 .51 .55 .57 .56 .58 .54        1
 .52 .49 .52 .52 .51 .50 .51 .55 .57 .56 .58 .54        2
 .52 .49 .52 .52 .51 .50 .51 .55 .57 .56 .58 .54        3
 .52 .49 .52 .52 .51 .50 .51 .55 .57 .56 .58 .54        4
 .52 .49 .52 .52 .51 .50 .51 .55 .57 .56 .58 .54        5
 .52 .49 .52 .52 .51 .50 .51 .55 .57 .56 .58 .54        6
```

Monthly means of daily incoming radiation, RADMET(i)

```
---------------------------------------------------
 JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
,FF.F,FF.F,FF.F,FF.F,FF.F,FF.F,FF.F,FF.F,FF.F,FF.F,FF.F,FF.F
12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0        1
12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0        2
12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0        3
12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0        4
12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0        5
12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0        6
```

Penman equation option for either S-tank or A-pan equivalent evaporation

```
-------------------------------------------------------------------------
SAPANC
,,,,,I
```

```
  0                                  1
  0                                  2
  0                                  3
  0                                  4
  0                                  5
  0                                  6

   Smoothed mean monthly A-pan/S-pan ratios, SARAT(i)
   --------------------------------------------------
 JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF
 1.26 1.25 1.26 1.27 1.30 1.34 1.36 1.37 1.35 1.32 1.28 1.27        1
 1.26 1.25 1.26 1.27 1.30 1.34 1.36 1.37 1.35 1.32 1.28 1.27        2
 1.26 1.25 1.26 1.27 1.30 1.34 1.36 1.37 1.35 1.32 1.28 1.27        3
 1.26 1.25 1.26 1.27 1.30 1.34 1.36 1.37 1.35 1.32 1.28 1.27        4
 1.26 1.25 1.26 1.27 1.30 1.34 1.36 1.37 1.35 1.32 1.28 1.27        5
 1.26 1.25 1.26 1.27 1.30 1.34 1.36 1.37 1.35 1.32 1.28 1.27        6

   Pan adjustment option
   ---------------------
PANCOR
,,,,,F
  0                                  1
  0                                  2
  0                                  3
  0                                  4
  0                                  5
  0                                  6

   Monthly pan adjustment factors, CORPAN(i)
   -----------------------------------------
 JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF
 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00        1
 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00        2
 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00        3
 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00        4
 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00        5
 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00        6

#  Level of soils information
   ---------------------------
PEDINF
,,,,,F
  1                                  1
  1                                  2
  1                                  3
  1                                  4
  1                                  5
  1                                  6

   Soils texture information
   -------------------------
ITEXT
,,,,II
  4                                  1
  4                                  2
  4                                  3
  7                                  4
  7                                  5
```

```
  7                                  6

  Soil physics based infiltration/soil water redistribution option
  ---------------------------------------------------------------
REDIST
,,,,,F
  0                                  1
  0                                  2
  0                                  3
  0                                  4
  0                                  5
  0                                  6

  Rainfall intensity distribution type
  -------------------------------------
IRDIST
,,,,,I
  2                                  1
  2                                  2
  2                                  3
  2                                  4
  2                                  5
  2                                  6

  Soil thickness information
  ---------------------------
 PEDDEP
,,,,,,F
  2                                  1
  2                                  2
  2                                  3
  1                                  4
  1                                  5
  1                                  6

  Soils information (adequate)
  -----------------------------
DEPAHO DEPBHO  WP1  WP2  FC1  FC2  PO1  PO2 ABRESP BFRESP
,FF.FF,,FF.FF,.FFF,.FFF,.FFF,.FFF,.FFF,.FFF,,FF.FF,,FF.FF
  .30   .40 .068 .068 .143 .143 .432 .432   .70   .70         1
  .30   .40 .068 .068 .143 .143 .432 .432   .70   .70         2
  .30   .50 .068 .068 .143 .143 .432 .432   .70   .70         3
  .30   .90 .159 .159 .254 .254 .402 .402   .50   .50         4
  .30   .70 .159 .159 .254 .254 .402 .402   .50   .50         5
  .30   .70 .159 .159 .254 .254 .402 .402   .50   .50         6

  Shrink-swell soils option
  --------------------------
ICRACK
,,,,,I
  0                                  1
  0                                  2
  0                                  3
  0                                  4
  0                                  5
  0                                  6

  Initial values of soil water retention constants
  ------------------------------------------------
 SMAINI SMBINI
```

```
,FFF.FF,FFF.FF
  8.00  20.00                                  1
  8.00  20.00                                  2
  8.00  20.00                                  3
 13.00  70.00                                  4
 13.00  70.00                                  5
 13.00  70.00                                  6

     Option for statistical analysis of soil water regime
     ----------------------------------------------------
SWLOPT
,,,,,F
    0                                     1
    0                                     2
    0                                     3
    0                                     4
    0                                     5
    0                                     6

     Soil water content thresholds for A horizon, SWLAM(i)
     -----------------------------------------------------
  1     2     3     4     5     6
,,F.FFF,,F.FFF,,F.FFF,,F.FFF,,F.FFF,,F.FFF
  .018  .050  .100  .150  .200  .300                  1
  .018  .050  .100  .150  .200  .300                  2
  .018  .050  .100  .150  .200  .300                  3
  .018  .050  .100  .150  .200  .300                  4
  .018  .050  .100  .150  .200  .300                  5
  .018  .050  .100  .150  .200  .300                  6

     Soil water content thresholds for B horizon, SWLBM(i)
     -----------------------------------------------------
  1     2     3     4     5     6
,,F.FFF,,F.FFF,,F.FFF,,F.FFF,,F.FFF,,F.FFF
  .018  .050  .100  .150  .200  .300                  1
  .018  .050  .100  .150  .200  .300                  2
  .018  .050  .100  .150  .200  .300                  3
  .018  .050  .100  .150  .200  .300                  4
  .018  .050  .100  .150  .200  .300                  5
  .018  .050  .100  .150  .200  .300                  6

#    Level of land cover information
     --------------------------------
LCOVER
,,,,,I
    0                                     1
    0                                     2
    0                                     3
    0                                     4
    0                                     5
    0                                     6

     Land cover number information
     ------------------------------
  CROPNO
,,,FFFFFFF
  2030104                                  1
  1040201                                  2
  3040201                                  3
  4040101                                  4
```

```
2030102                    5
3040101                    6
```

Determination of canopy interception loss

```
-----------------------------------------
INTLOS
,,,,,I
 1                         1
 1                         2
 1                         3
 1                         4
 1                         5
 1                         6
```

Leaf area index information

```
----------------------------
LAIND
,,,,,I
 0                         1
 0                         2
 0                         3
 0                         4
 0                         5
 0                         6
```

Monthly means of crop coefficients, CAY(i)

```
-------------------------------------------
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF
 .75 .75 .75 .65 .40 .20 .20 .20 .30 .60 .65 .70        1
 .65 .65 .65 .55 .30 .20 .20 .20 .30 .50 .55 .65        2
 .80 .80 .60 .40 .20 .20 .20 .20 .20 .40 .65 .80        3
 .80 .80 .80 .70 .60 .50 .40 .40 .40 .50 .60 .70        4
 .55 .55 .55 .45 .20 .20 .20 .20 .30 .40 .50 .55        5
 .80 .70 .30 .30 .30 .30 .30 .30 .30 .30 .35 .60        6
```

Monthly means of leaf area index, ELAIM(i)

```
-------------------------------------------
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF
1.30 1.30 1.30 .90 .21 .20 .20 .20 .10 .74 .90 1.09        1
 .90 .90 .90 .59 .31 .10 .10 .10 .23 .45 .59 .90        2
 .00 .00 .00 .00 .00 .00 .00 .00 .00 .00 .00 .00        3
3.00 3.00 3.00 3.00 2.50 2.50 2.00 2.00 2.50 2.50 3.00 3.00        4
 .59 .59 .59 .33 .10 .00 .00 .00 .01 .21 .45 .59        5
 .00 .00 .00 .00 .00 .00 .00 .00 .00 .00 .00 .00        6
```

Canopy interception loss (mm) per rainday, VEGINT(i)

```
----------------------------------------------------
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF
1.50 1.50 1.50 1.50 1.50 1.50 1.50 1.50 1.50 1.50 1.50 1.50        1
1.20 1.20 1.20 1.20 1.20 1.20 1.20 1.20 1.20 1.20 1.20 1.20        2
1.30 1.30 1.30 1.30 1.10 .50 .50 .50 .50 .50 .90 1.30        3
 .60 .60 .60 .60 .60 .60 .60 .60 .60 .60 .60 .60        4
 .80 .80 .80 .80 .80 .80 .80 .80 .80 .80 .80 .80        5
1.00 1.00 .60 .50 .50 .50 .50 .50 .50 .00 .50 .80        6
```

Fraction of active root system in topsoil horizon, ROOTA(i)

```
------------------------------------------------------------
```

```
  JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
 ,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF
  .90 .90 .90 .94 .94 .94 .94 .94 .92 .92 .90 .90          1
  .90 .90 .90 .94 .94 .94 .94 .94 .92 .92 .90 .90          2
  .85 .85 .85 .90 1.00 1.00 1.00 1.00 1.00 1.00 .90 .85       3
 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00        4
  .90 .90 .90 .94 .94 .94 .94 .94 .92 .92 .90 .90          5
  .74 .78 .91 1.00 1.00 1.00 1.00 1.00 1.00 1.00 .92 .79       6

    Effective total rooting depth
   ------------------------------
 EFRDEP
 FFF.FF
   .50                                     1
   .00                                     2
   .60                                     3
   .40                                     4
   .30                                     5
   .40                                     6

    Total evaporation control variables
   -----------------------------------
 EVTR FPAW
 ,,,,F,,,,F
   2   0                                   1
   2   0                                   2
   2   0                                   3
   2   0                                   4
   2   0                                   5
   2   0                                   6

    Fraction of PAW at which plant stress sets in
   ---------------------------------------------
 CONST
 FF.FF
  .30                                      1
  .30                                      2
  .30                                      3
  .40                                      4
  .40                                      5
  .40                                      6

    Critical leaf water potential
   ------------------------------
 CRLEPO
 FFFFF.F
   .0                                      1
   .0                                      2
   .0                                      3
   .0                                      4
   .0                                      5
   .0                                      6

    Option for enhanced wet canopy evaporation
   ------------------------------------------
 FOREST
 ,,,,,F
   0                                       1
   0                                       2
   0                                       3
```

```
  0                                      4
  0                                      5
  0                                      6
```

Option for simulation under enhanced atmospheric CO2 levels

```
 ----------------------------------------------------------
CO2TRA
,FFF.F
  .0                                     1
  .0                                     2
  .0                                     3
  .0                                     4
  .0                                     5
  .0                                     6
```

Mean temperature threshold (øC) for active growth to take place

```
 --------------------------------------------------------------
TMPCUT
,,FF.F
 10.0                                    1
 10.0                                    2
 10.0                                    3
 10.0                                    4
 10.0                                    5
 10.0                                    6
```

Unsaturated soil moisture redistribution

```
 ----------------------------------------
IUNSAT
,,,,,I
  0                                      1
  0                                      2
  0                                      3
  0                                      4
  0                                      5
  0                                      6
```

Option for lysimeter routine

```
 ------------------------------
LYSIM
,,,,I
  1                                      1
  1                                      2
  1                                      3
  1                                      4
  1                                      5
  1                                      6
```

Streamflow simulation control variables

```
 ------------------------------------------
QFRESP  COFRU SMDDEP IRUN ADJIMP DISIMP STOIMP
,FF.FF,,,F.FFF,FFF.FF,,,,I,,F.FFF,,F.FFF,,,F.FF
 .30  .030  .00  1  .000  .000  1.00           1
 .70  .005  .00  1  .250  .300  1.00           2
 .40  .030  .00  1  .000  .000  1.00           3
 .21  .050  .00  1  .000  .000  1.00           4
 .50  .020  .00  1  .000  .000  1.00           5
 .50  .020  .00  1  .000  .000  1.00           6
```

Coefficient of initial abstraction, COIAM(i)

```
 ---------------------------------------------
  JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
 ,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF
  .30 .30 .30 .30 .30 .30 .30 .30 .30 .30 .30 .30          1
  .05 .05 .05 .05 .05 .05 .05 .05 .05 .05 .05 .05          2
  .20 .20 .20 .20 .20 .20 .20 .20 .20 .20 .20 .20          3
  .40 .40 .40 .40 .40 .40 .40 .40 .40 .40 .40 .40          4
  .10 .10 .10 .10 .10 .10 .10 .10 .10 .10 .10 .10          5
  .10 .10 .10 .10 .10 .10 .10 .10 .10 .10 .10 .10          6

#    Peak discharge : option
     -------------------------
 PEAK
 ,,,F
  1                                  1
  1                                  2
  1                                  3
  1                                  4
  1                                  5
  1                                  6

     Peak discharge : control variables (I)
     ---------------------------------------
 LAG SLOPE
 ,,,I,FFF.F
  2  1.2                             1
  2  1.2                             2
  2  1.2                             3
  2  1.2                             4
  2  1.2                             5
  2  1.2                             6

     Peak discharge : control variables (II)
     ---------------------------------------
 HYLEN CNII
FFFFF.F,,FF.
 200.0  68.                          1
 200.0  87.                          2
 200.0  79.                          3
 200.0  57.                          4
 200.0  83.                          5
 200.0  77.                          6

#    Sediment yield : option
     -------------------------
MUSLE
,,,,I
  0                                  1
  0                                  2
  0                                  3
  0                                  4
  0                                  5
  0                                  6

     Means of monthly cover factors, COVER(i)
     -----------------------------------------
 JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF,F.FF
```

```
.07 .07 .07 .07 .07 .07 .07 .07 .07 .07 .07 .07        1
.05 .05 .05 .05 .05 .05 .05 .05 .05 .05 .05 .05        2
.20 .20 .20 .20 .20 .20 .20 .20 .20 .20 .20 .20        3
.03 .03 .03 .03 .03 .03 .03 .03 .03 .03 .03 .03        4
.30 .30 .30 .30 .30 .30 .30 .30 .30 .30 .30 .30        5
.01 .01 .01 .01 .01 .01 .01 .01 .01 .01 .01 .01        6


     Wetland input options
    ----------------------
 IVLEI   CAPM3S
,,,,I,,,,,,FF.F
   0      1.2                        1
   0      1.2                        2
   0      1.2                        3
   0      1.2                        4
   0      1.2                        5
   0      1.2                        6

#    Shallow groundwater : analysis option
    --------------------------------------
IGWATR
,,,,,I
   0                                 1
   0                                 2
   0                                 3
   0                                 4
   0                                 5
   0                                 6


#    Irrigation : option
    --------------------
IRRIGN WRIRR
,,,,,I,,,,,F
   0   0                             1
   0   0                             2
   0   0                             3
   0   0                             4
   0   0                             5
   0   0                             6


     Option for domestic abstractions
    ---------------------------------
IDOMR
,,,,,I
   0                                 1
   0                                 2
   0                                 3
   0                                 4
   0                                 5
   0                                 6


#    Reservoir yield analysis : option
    ----------------------------------
RESYLD
,,,,,F
   0                                 1
```

```
0                                        2
0                                        3
0                                        4
0                                        5
0                                        6

#    Crop yield : option
     ---------------------
 CROP WRTYLD
,,,,,F,,,,,,F
   0    0                                1
   0    0                                2
   0    0                                3
   0    0                                4
   0    0                                5
   0    0                                6
```

MENUBUILDER VERSION 2.22 Output created on 21/ 4/2004

Appendix 9. An Example of an *ACRU* Output File

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
AET	Sum	5659.35	5075.43	4446.40	2576.70	964.05	440.16	422.55	453.26	1145.11	2506.69	4200.11	5576.95	33464.59
Scenario: 6 april 005	Mean	113.19	101.51	88.93	51.53	19.28	8.80	8.45	9.07	22.90	49.15	82.36	109.35	669.29
Monthly Stats	Minimum	0.53	0.14	0.04	0.01	0.00	0.00	0.00	0.00	0.16	0.78	0.90	0.51	142.03
Start Month:	Maximum	171.22	163.07	154.11	114.25	77.75	62.49	34.13	31.84	63.26	105.30	131.49	172.21	890.43
	No. Data Poin	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	51.00	51.00	51.00	50.00
	5%	49.80	28.64	39.83	11.09	0.70	0.00	0.01	0.27	1.39	18.96	30.96	41.62	484.11
	10%	70.19	54.64	44.03	17.73	4.64	0.00	0.01	0.97	3.56	24.51	45.38	68.23	537.62
	20%	83.90	64.16	68.11	27.19	7.97	0.60	0.76	2.20	10.51	30.24	52.09	78.75	590.11
	33%	103.33	89.73	71.79	37.59	13.42	1.39	2.82	4.37	15.40	37.50	71.94	99.90	630.62
	50%	122.10	107.61	88.47	50.08	17.74	4.08	5.61	8.84	21.27	53.06	83.38	117.03	671.64
	67%	132.73	118.99	102.39	67.20	21.84	9.05	8.03	11.10	26.52	59.77	98.67	128.90	705.14
	80%	141.00	139.28	121.49	76.48	29.44	16.16	13.05	14.31	33.46	63.99	108.35	134.12	790.74
	90%	152.49	144.17	131.30	79.99	35.42	24.17	22.18	16.39	44.57	69.70	122.72	140.91	823.41
	95%	157.39	152.98	149.99	89.64	37.87	31.38	29.38	23.13	52.13	84.91	125.36	158.77	848.70
	Standard Devi	36.24	38.22	34.61	26.98	13.98	11.90	9.17	7.27	15.06	21.25	31.64	36.15	134.07
	Variance	1313.39	1460.94	1198.16	727.66	195.40	141.72	84.13	52.90	226.86	451.54	1001.07	1306.64	17973.57
	Coefficient o	32.02	37.65	38.92	52.34	72.50	135.23	108.53	80.23	65.77	43.23	38.42	33.06	20.03
	Skewness	-1.02	-0.63	-0.11	0.15	1.58	2.41	1.40	1.05	0.69	0.17	-0.57	-0.91	-1.24
	Kurtosis	1.06	-0.09	-0.11	-0.51	4.99	7.63	1.15	1.21	0.18	0.09	0.00	0.96	3.89
	No. Values <	1.00	1.00	1.00	1.00	3.00	12.00	11.00	5.00	3.00	1.00	1.00	1.00	41.00
QUICKF	Sum	3518.98	4333.05	2319.40	732.31	135.93	134.31	117.15	68.25	319.56	610.46	1292.81	2739.75	16321.97
Scenario: 6 april 005	Mean	70.38	86.66	46.39	14.65	2.72	2.69	2.34	1.37	6.39	11.97	25.35	53.72	326.44
Monthly Stats	Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	34.65
Start Month:	Maximum	257.81	426.57	269.17	112.07	36.36	25.12	34.99	12.05	107.33	50.29	110.08	322.31	916.38
	No. Data Poin	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	51.00	51.00	51.00	50.00
	5%	2.49	2.33	3.69	0.07	0.00	0.00	0.00	0.00	0.00	0.10	0.96	4.12	91.38
	10%	4.36	4.06	6.39	0.16	0.00	0.00	0.00	0.00	0.00	0.82	1.86	8.14	149.52
	20%	16.21	15.20	9.67	0.59	0.03	0.00	0.00	0.00	0.00	2.87	6.24	15.93	180.93
	33%	28.47	23.88	20.00	4.22	0.16	0.00	0.00	0.00	0.01	4.73	9.42	23.37	212.26
	50%	56.28	56.47	31.81	9.85	1.00	0.00	0.00	0.02	0.31	7.50	14.41	43.22	262.84
	67%	82.71	93.66	45.38	15.72	1.85	0.02	0.04	0.53	1.48	12.33	23.75	53.86	382.94
	80%	112.91	138.59	69.42	20.15	3.07	0.93	0.77	2.14	7.43	19.04	36.23	68.33	486.94

90% 152.58 239.43 102.98 38.24 6.54 12.06 5.98 4.57 14.02
32.65 67.19 108.51 567.64
95% 220.23 259.27 129.80 45.23 9.05 20.38 10.43 6.77 25.11
37.81 98.65 164.39 640.25
Standard Devi 65.25 91.72 50.98 19.50 5.64 6.49 7.09 2.70 17.58
12.42 28.73 59.29 186.21
Variance 4257.42 8413.25 2599.02 380.34 31.82 42.12 50.31 7.28
308.95 154.14 825.52 3515.49 34672.66
Coefficient o 92.71 105.84 109.90 133.16 207.49 241.60 302.73 197.72
275.01 103.72 113.34 110.37 57.04
Skewness 1.39 1.63 2.44 2.99 4.67 2.55 4.02 2.53 4.58
1.46 1.79 2.74 0.93
Kurtosis 1.65 2.93 7.58 12.18 26.36 5.48 16.47 6.45 23.59
1.40 2.43 9.08 0.79
No. Values < 2.00 2.00 2.00 12.00 25.00 40.00 41.00 36.00 31.00
6.00 3.00 2.00 202.00

RUN Sum 717.34 974.99 928.22 517.86 258.26 125.39 77.18 51.30
47.60 107.42 202.87 419.45 4427.20
Scenario: 6 april 005 Mean 14.35 19.50 18.56 10.36 5.17 2.51 1.54 1.03 0.95
2.11 3.98 8.22 88.54
Monthly Stats Minimum 0.00 0.01 0.01 0.00 0.00 0.00 0.00 0.00 0.00
0.00 0.00 0.01 0.39
Start Month: Maximum 52.04 91.03 83.04 54.72 22.36 12.51 7.78 10.39
10.50 19.42 24.08 27.14 343.29
No. Data Poin 50.00 50.00 50.00 50.00 50.00 50.00 50.00 50.00 50.00
51.00 51.00 51.00 50.00
5% 0.26 0.32 0.24 0.41 0.20 0.09 0.05 0.02 0.02 0.04
0.03 0.07 6.34
10% 0.84 0.73 0.51 0.73 0.78 0.36 0.18 0.08 0.05 0.06
0.04 0.23 24.76
20% 2.03 3.05 3.51 2.10 1.46 0.80 0.43 0.20 0.11 0.08
0.13 0.71 30.41
33% 4.59 5.22 5.46 4.47 2.47 1.19 0.69 0.33 0.17 0.15
0.74 1.61 42.55
50% 7.47 9.87 11.74 6.64 3.48 2.02 1.06 0.50 0.35 0.37
2.62 5.22 69.07
67% 16.74 21.67 18.59 10.46 5.66 2.93 1.81 0.90 0.57
1.40 4.40 10.05 93.86
80% 25.44 35.89 31.27 15.03 8.15 3.82 2.07 1.12 1.31
3.86 6.26 17.09 140.58
90% 35.73 55.64 53.47 26.62 10.22 5.13 3.69 2.08 2.15
5.73 8.90 21.65 192.21
95% 46.51 63.44 55.42 30.69 15.97 5.98 4.86 3.87 4.04
9.90 13.64 26.18 220.46
Standard Devi 14.46 22.07 19.54 11.22 4.87 2.29 1.58 1.66 1.74
3.71 4.89 8.64 73.00
Variance 209.03 487.11 381.77 125.99 23.74 5.22 2.51 2.76 3.04
13.78 23.91 74.63 5329.03
Coefficient o 100.77 113.18 105.25 108.38 94.33 91.13 102.58 162.03
183.05 176.22 122.93 105.04 82.45
Skewness 1.17 1.43 1.39 1.98 1.62 2.03 1.99 4.11 3.88
2.84 2.01 0.93 1.31
Kurtosis 0.52 1.41 1.43 4.49 2.72 6.44 4.64 20.75 18.48
9.50 4.99 -0.39 1.77
No. Values < 6.00 7.00 6.00 6.00 8.00 12.00 23.00 38.00 38.00
30.00 18.00 13.00 205.00

SIMSQ Sum 4236.32 5308.04 3247.62 1250.17 394.19 259.70 194.32 119.55
367.16 717.89 1495.68 3159.20 20749.16
Scenario: 6 april 005 Mean 84.73 106.16 64.95 25.00 7.88 5.19 3.89 2.39 7.34
14.08 29.33 61.95 414.98
Monthly Stats Minimum 0.61 0.27 0.14 0.07 0.00 0.00 0.00 0.04 0.00
0.07 0.18 0.09 41.49
Start Month: Maximum 306.95 517.60 352.21 123.28 52.81 28.27 42.77 14.18
108.53 61.17 134.15 348.53 1259.67
No. Data Poin 50.00 50.00 50.00 50.00 50.00 50.00 50.00 50.00 50.00
51.00 51.00 51.00 50.00
5% 4.71 2.78 6.51 2.68 0.52 0.40 0.05 0.08 0.05 0.32
2.41 5.85 99.98
10% 10.43 4.82 11.24 4.01 1.16 0.50 0.19 0.11 0.09
1.09 4.88 9.52 187.25
20% 24.77 22.52 20.19 5.64 2.74 0.99 0.52 0.33 0.17
3.88 8.28 17.10 221.09

33%	48.99	35.82	27.03	13.73	3.53	1.58	0.81	0.55	0.45	6.34	12.57	25.71	255.51
50%	61.60	67.93	43.30	22.63	5.56	2.72	1.46	0.94	0.94	7.84	16.33	48.65	332.14
67%	88.12	123.19	76.48	28.50	8.21	3.73	2.04	2.07	2.30	15.70	25.41	62.60	494.72
80%	137.92	178.55	95.84	36.92	11.19	6.55	3.48	3.81	9.18	26.05	40.64	80.46	616.23
90%	192.05	281.80	139.94	45.17	15.58	13.22	9.15	5.90	16.77	34.13	73.33	124.09	749.82
95%	247.47	306.72	185.30	60.44	22.12	21.92	12.61	11.00	28.16	44.98	110.92	187.71	846.24
Standard Devi	76.29	108.24	66.37	22.00	8.77	6.97	7.92	3.36	17.86	14.68	32.15	64.69	253.65
Variance	5819.55	11715.04	4404.86	483.88	76.89	48.59	62.73	11.26	319.05	215.57	1033.33	4184.82	64339.01
Coefficient o	90.04	101.95	102.18	87.98	111.22	134.21	203.78	140.35	243.25	104.31	109.61	104.43	61.12
Skewness	1.39	1.61	2.22	2.08	3.14	2.14	3.88	2.17	4.39	1.64	1.89	2.55	1.06
Kurtosis	1.56	3.14	6.50	7.04	13.55	3.89	16.04	4.29	22.14	2.32	2.93	8.06	1.19
No. Values <	1.00	1.00	1.00	2.00	4.00	10.00	18.00	28.00	27.00	4.00	1.00	2.00	99.00

Appendix 10. Vegetation Found in the Craigieburn and 'control' Wetlands

SPECIES
Aristida diffusa
Schizachyrium jefferysii
Syzygium cordatum
Dichrostachys cineria
Melinis repens
Athrixia elata
Parinari capensis
Rhoicissus tridentate
Themeda triandra
Hyperthelia dissoluta
Setaria sphacelata
Hyparrhenia hirta
Sporobolus pyramidalis
Vernonia sp
Psidium quajave
Helichrysum kraussii
Pteridium aquilinium
Cymbopogon plurinodis
Diospyros lyciodes
Antidesma venosum
Cassia sp
Eragrotis planta
Indigofera sp
Panicum sp
Phragmites mauritianus
Cynodon dactylon
Caentella asiatica
Sida cordifolia
Ageratum houstonianum
Leersia hexandra
Thelypteris sp
Fimbristylis complanata
Crassocephalum sp
Cyperus Latifolius

Appendix 11. Results of the Modelling Exercise for which Rainfall Data Specific to the Land Use Year was Used

AVERAGE MONTHLY VARIABLE VALUES DRIVEN BY DIFFERENT CLIMATIC YEARS

1954 Monthly Variables							
	Soil Evap	Transpiration	Streamflow	Peak	Stormflow	Rainfall	Baseflow
Jan	47.53011	84.49798	55.2307	1.523867	37.17528	219.8	24.903801
Feb	43.62125	77.5489	59.3134	1.601647	32.70902	259.6	33.759143
Mar	40.66941	72.30118	57.14672	0.433339	13.7331	122.7	53.326307
Apr	33.22796	59.07193	17.91569	0.029074	0.036338	103.9	11.335446
May	0.0036	0.0064	0.15391	0.000164	0.01	2.8	0.0629368
Jun	2.051999	3.647998	2.769085	0.002692	0.01	4.1	1.0666282
Jul	0.0036	0.0064	0.033864	1.41E-05	0.01	0	0.0054356
Aug	0.699131	1.2429	0.022431	3.99E-06	0.01	1.2	0.0015341
Sep	1.002247	1.781772	0.01249	1.17E-06	0.01	0	0.0004515
Oct	0.730988	1.299534	0.008573	3.3E-07	0.01	0.2	0.0001281
Nov	28.66527	50.96049	3.059647	0.02479	0.229731	137.2	0.4934674
Dec	46.38332	82.45923	20.46489	0.125097	1.836311	135.9	26.968394
Total	244.5817	434.8119	216.1314	3.74069	85.77977	987.4	151.92367

1965 Monthly Variables							
	Soil Evap	Transpiration	Streamflow	Peak	Stormflow	Rainfall	Baseflow
Jan	48.91445	86.95902	31.21929	0.778144	15.19657	220.9	23.497376
Feb	44.63913	79.35845	47.78912	1.230837	20.90915	219.2	36.24162
Mar	29.43064	52.32114	16.93431	0.069795	3.568056	58	21.685723
Apr	16.19038	28.78289	5.207388	0.016239	0.001934	50.8	5.0545733
May	0.108	0.192	0.047968	8.18E-05	0.1	0.5	0.0247252
Jun	0.647999	1.151998	1.035824	0.001346	0.1	2.4	0.4190412
Jul	0.036	0.064	0.013209	7.07E-06	0.1	0	0.002136
Aug	0.036	0.064	0.012113	0.000002	0.1	1.5	0.0006032
Sep	0.85639	1.522472	0.212059	0.001588	0.051522	0	0.4974446
Oct	3.64E-07	6.46E-07	0.119555	0.000505	0	0	0.1527866
Nov	35.8628	63.75609	6.186298	0.064426	0.809649	145.4	5.922275
Dec	23.1889	41.22471	4.829987	0.025495	0.192021	57.4	7.920357
Total	199.9107	355.3968	113.6071	2.188466	41.1289	756.1	101.41866

1974 Monthly Variables							
	Soil Evap	Transpiration	Streamflow	Peak	Stormflow	Rainfall	Baseflow
Jan	58.57082	104.1259	113.5988	3.283873	75.106	381.7	33.31029
Feb	44.39281	78.92054	81.38376	1.096175	29.5638	219.2	63.166772
Mar	28.7109	51.0416	53.41073	0.324302	7.286506	106.6	48.739034
Apr	32.03439	56.95002	26.72154	0.056707	2.68721	82.6	23.502048
May	0.0036	0.0064	0.207726	0.00024	0	0	0.0966678
Jun	0.107997	0.191994	4.831746	0.003947	0	0.9	1.638282
Jul	0.0036	0.0064	0.12304	0.000228	0.000132	0	0.0920157
Aug	0.0036	0.0064	0.074866	6.44E-05	0	0	0.0259586
Sep	0.0036	0.0064	0.062319	1.89E-05	0	0	0.0076288
Oct	0.0036	0.0064	0.869547	5.34E-06	0	13.7	0.0021528

Nov	46.36568	82.42787	12.51328	0.011031	0.13045	152.7	2.3990319
Dec	56.01306	99.57878	19.02992	0.087282	1.597866	160.9	10.039103
Total	266.2136	473.2687	312.8273	4.863874	116.372	1118.3	183.01898

1984 Monthly Variables							
	Soil Evap	Transpiration	Streamflow	Peak	Stormflow	Rainfall	Baseflow
Jan	26.92898	47.87373	3.498939	0	0	92.2	0
Feb	24.44194	43.45234	2.565088	0	0	66.7	0
Mar	25.53528	45.39606	24.04242	0.417819	9.241734	183.9	15.576237
Apr	24.3505	43.28978	28.67543	0.073239	2.508946	56.4	37.406766
May	0.0036	0.0064	0.19832	0.000266	0	0	0.1322439
Jun	2.124002	3.776003	4.498456	0.004377	0	7.7	2.241205
Jul	0.904195	1.607458	0.975563	0.002557	0.092512	0	1.2700291
Aug	0.093155	0.165609	0.463836	0.000516	0	4.8	0.2570247
Sep	0.321254	0.571118	0.159037	0.000152	0	0.8	0.0755293
Oct	1.329819	2.364124	2.209354	0.001024	0.00387	28.9	0.2300662
Nov	42.11122	74.86438	18.07619	0.017882	0.014135	112	9.209574
Dec	31.93854	56.77963	11.03206	0.008662	0	89.8	4.4316312
Total	180.0825	320.1466	96.3947	0.526493	11.8612	643.2	70.830306

1997 Monthly Variables							
	Soil Evap	Transpiration	Streamflow	Peak	Stormflow	Rainfall	Baseflow
Jan	48.44513	86.12467	14.56982	0.021581	0.004449	183.5	15.744558
Feb	36.94076	65.67246	34.34067	0.396942	10.89756	185.7	27.607802
Mar	58.52344	104.0417	89.75548	1.157589	42.45244	266.6	64.246144
Apr	33.76439	60.02559	37.64588	0.075248	1.859048	99.5	30.751727
May	0.3264	0.580267	0.298876	0.000224	0	0	0.1582034
Jun	1.642565	2.920115	6.883703	0.003692	0	5.8	2.6811521
Jul	0.524422	0.932305	0.100501	1.94E-05	0	0.4	0.0136621
Aug	3.2E-07	5.7E-07	0.056064	5.47E-06	0	0	0.0038548
Sep	5.58E-07	9.92E-07	0.426703	0.000554	0.000422	0	0.39068
Oct	0.635664	1.13007	0.173367	0.000156	0	0	0.110214
Nov	23.07539	41.02292	8.373688	0.002981	0	96.2	2.2192441
Dec	37.37906	66.45166	14.48004	0.249128	1.923339	152.7	5.2366034
Total	241.2572	428.9017	207.1048	1.90812	57.13725	990.4	149.16385

Appendix 12. Input Table Specifying Land Use Areas of the 'Baseline' Scenario

BASELINE SCENARIO	
LAND USE	**AREA (km^2)**
veld in good condition	0.68
residential area	0.01
subsistence maize plots	0.01
subsistence mixed plots	0.01
veld in poor condition	0.01
Reeds	0.68

Appendix 13. Input Table Specifying Land Use Areas of the 'Plots' Scenario

PLOTS SCENARIO	
LAND USE	**AREA (km^2)**
veld in good condition	0.01
residential area	0.01
subsistence maize plots	0.68
subsistence mixed plots	0.68
veld in poor condition	0.01
reeds	0.01

Appendix 14. Annual Values of Monthly Average Streamflow Values for 20% Wetland Areas

	January	February	March	April	May	June	July	August	September	October	November	December
1930	7.66	4	40.49	17.95	6.97	4.47	3.37	2.44	1.68	1.23	1.21	35.94
1931	21.23	12.44	11.93	16.53	4.31	2.97	6.79	1.95	1.38	1.22	2.89	11.75
1932	1.54	2.74	21.27	1.26	0.8	0.45	0.33	0.26	0.28	0.32	0.88	2.45
1933	25.8	10.43	24.44	5.33	3.79	2.51	1.84	1.22	0.86	0.74	6.76	14.55
1934	40.85	6.67	11.09	6.5	1.94	1.46	0.96	0.7	2.49	0.58	22.6	14.17
1935	11.89	21.67	4.18	2.57	2.23	1.26	0.88	0.63	0.55	0.39	0.98	1.08
1936	10.22	16.55	9.16	6.63	2.86	1.77	1.32	0.8	32.3	4.04	10.88	29.55
1937	43.81	185.49	30.54	19.08	12.04	8.47	6.46	4.69	3.27	2.17	3.28	3.63
1938	2.83	6.66	4.16	21.83	2.65	2.52	2.83	0.99	16.26	3.81	3.56	64.61
1939	82.27	150.27	43.37	30.07	16.86	10.75	8.61	5.98	5.05	2.97	16.53	27.74
1940	9.41	8.56	14.96	7.5	5.8	10.98	3.01	2.01	2.04	1.62	27.41	10.66
1941	6.84	4.52	14.44	35.08	4.13	2.81	2.29	1.52	1	1.51	0.7	12.97
1942	23.8	6.09	46.97	5.66	5.11	11.85	2.81	2.05	2.08	1.59	7.87	4.32
1943	4.94	1.3	7.31	14.65	5.64	3.16	4.63	2.7	2.07	1.75	30.04	3.77
1944	5.02	11.77	4.41	1.78	1.3	1.17	0.7	0.49	0.59	6.86	2.7	3.39
1945	44.03	32.56	12.73	6.21	3.67	2.55	1.78	1.29	0.95	2.35	0.79	1.63
1946	45.7	68.12	23.34	11.35	8.18	5.7	4.15	2.88	1.93	1.5	12.14	8.86
1947	6.05	10.83	8.67	12.99	2.14	1.62	1.06	0.71	0.57	0.91	7.85	16.16
1948	12.89	5.99	64.54	9.46	5.33	3.54	2.72	1.93	2.05	2.22	1.83	1.4
1949	16.2	11.08	4.39	3.38	5.67	1.42	1.1	0.76	0.64	0.46	13.2	21.48
1950	7.91	3.29	8.13	5.98	1.77	0.59	1.17	0.56	0.39	0.36	2.38	15.95
1951	7.36	2.76	4.48	15.3	2.17	0.68	2.83	3.63	3.62	1.78	1.06	3.76
1952	2.56	2.92	4.07	2.12	0.23	0.24	0.26	0.1	0.06	0.77	10.46	3.72
1953	16.36	26.33	10.97	18.65	3.36	2.23	1.62	1.17	0.92	0.69	6.63	14.19
1954	15.35	10.87	2.91	5.57	0.98	0.58	0.41	0.32	0.42	0.25	4.05	2.23
1955	21.11	42.29	44.34	14.37	8.06	4.22	3.03	2.14	1.37	7.28	30.72	25.79
1956	22.8	96.94	39.96	17.55	12.6	8.39	6.03	4.11	4.47	2.35	1.89	5.03
1957	1.66	13.13	16.51	4.8	5.06	1.01	1.19	0.85	0.57	4.95	0.75	9.03
1958	135.68	21.55	13.78	12.65	6.82	4.86	3.48	2.36	4.33	1.37	5.54	14.77
1959	14.73	36.46	3.96	2.24	2.27	1.19	1.73	0.68	5.17	0.92	3.87	8.9
1960	3.31	108.01	20.87	13.79	6.82	4.07	3	2.11	2.11	1.19	10.97	30.06
1961	20.52	39.98	28.17	8.36	5.21	8.58	3.93	2.49	4.22	2.31	2.97	7.27
1962	8.2	14.5	1.64	1.12	0.51	0.3	0.25	0.29	0.13	0.2	30.14	12.64
1963	7.44	5.38	4.11	13.75	1.72	3.39	3.15	0.89	0.59	0.61	1.83	3.12
1964	17.47	13.61	2.64	4.59	1.4	0.89	0.57	0.45	0.23	5.2	2.1	7.28
1965	7.74	3.15	2.36	1.27	0.63	0.42	0.29	0.19	0.64	0.73	1.89	1.14
1966	33.33	39.2	3.74	2.16	1.75	1.14	0.84	0.65	0.47	6.38	0.94	7.38
1967	16.54	29.74	12.7	16.1	5.26	2.73	2.13	1.32	0.89	1	1.75	4.26
1968	2.15	15.66	14.25	4.1	0.85	0.84	0.52	0.46	0.31	0.42	3.57	2.18
1969	9.78	16.01	9.74	4.98	1.98	1.16	0.9	0.55	1.22	18.13	4.81	14.86
1970	3.38	10.75	3.54	1.05	0.71	0.89	0.5	0.43	0.32	0.34	1.08	8.78
1971	56.17	8.4	14.68	11.28	2.27	1.42	1.03	0.69	2.54	0.98	4.51	11.71
1972	36.28	27.32	53.31	15.57	12.42	7.03	5.08	3.52	2.39	5.73	3.75	2.49
1973	2.99	4.4	1.36	7.39	0.58	0.38	0.32	0.27	41.69	35.45	8.14	61.92
1974	79.02	25.3	14.09	15.73	6.56	3.88	18.68	2.98	2.11	2.26	3.57	30.21
1975	13.51	14.74	12.18	4.73	9.48	1.82	1.14	0.72	0.53	0.37	0.44	36.57
1976	60.95	93.83	34.36	18.4	12.86	8.23	5.91	4.32	2.74	2.15	5.79	14.47

1977	18.81	50.13	32.84	13.63	11.13	6.74	4.96	3.53	14.89	7.17	4.05	10.21
1978	53.59	57.36	33.39	22.7	9.84	6.94	5.31	3.7	2.43	2.52	8.99	15.76
1979	22.96	13.94	15.67	3.03	4.83	1.4	1.06	1.55	1.27	6.24	2.36	9.87
1980	5.82	29.59	9.98	3.85	2.09	1.42	1.05	1.03	1.15	0.8	5.86	43.59
1981	28.96	42.08	22.06	8.28	5.97	3.92	2.85	2.14	4.67	2.02	3.62	5.3
1982	27.49	3.7	3.24	5.95	1.77	0.99	1.77	1.09	0.49	0.7	0.64	4.54
1983	3.8	2.86	5.39	2.95	1.6	0.22	0.05	0.14	0.02	0.39	6.04	12.75
1984	19.5	29.85	22.59	9.21	4.27	3.08	37.23	11.05	11.11	6.02	10.89	11.8
1985	25.01	121.07	13.75	8.28	7.44	4.35	3.1	2.16	1.56	3.88	8.74	6.82
1986	9.53	8.19	5.68	13.83	2.04	1.24	0.82	0.73	0.5	0.59	0.39	2.31
1987	6.57	4.72	16.36	1.86	0.92	0.58	0.37	1.08	11.8	7.86	1.19	33.66
1988	8.57	27.03	14.03	5.87	4.25	2.64	1.93	1.51	1.5	2.38	1.71	9.33
1989	1.02	55.32	15.11	6.18	4.53	4.43	2.18	1.52	1.06	4.7	4.32	11.87
1990	11.17	6.41	5.39	1.88	1.08	0.69	0.84	0.65	0.2	3.01	1.08	29.62
1991	15.66	12.74	8.42	2.5	1.76	3.86	0.85	0.58	0.39	0.3	4.38	1.72
1992	0.59	0.66	1.51	0.85	0.09	0.07	0.05	0.15	0.03	0.46	15.56	43.92
1993	19.05	11.52	36.05	3.93	2.47	1.28	0.92	0.72	0.45	0.38	0.51	16.79
1994	15.97	3.82	1.54	0.8	0.59	0.43	0.36	0.29	0.26	4.42	1.72	5.57
1995	58.23	13.81	7.9	9.68	7.45	2.94	2.2	1.64	1.06	3.52	23.78	54.04
1996	39.81	125.93	41.41	21.26	17.84	9.51	6.95	5.44	3.32	3.8	3.29	4.32
1997	14.54	8.03	44.51	9.32	3.91	2.49	1.83	1.32	3.46	1.31	5.04	25.84
	21.38	28.43	16.8	9.34	4.58	3.11	3.01	1.71	3.3	3.01	6.53	14.84

Appendix 15. Annual Values of Monthly Average Streamflow Values for 10% Wetland Areas

	January	February	March	April	May	June	July	August	September	October	November	December
1930	7.66	4	40.5	17.97	6.98	4.48	3.38	2.44	1.68	1.23	1.21	35.95
1931	21.25	12.45	11.94	16.55	4.32	2.98	6.8	1.95	1.38	1.22	2.89	11.76
1932	1.55	2.75	21.28	1.26	0.81	0.45	0.33	0.26	0.28	0.32	0.88	2.46
1933	25.81	10.44	24.46	5.34	3.79	2.52	1.85	1.23	0.86	0.74	6.76	14.55
1934	40.86	6.68	11.1	6.51	1.94	1.46	0.96	0.7	2.5	0.58	22.61	14.19
1935	11.9	21.68	4.19	2.58	2.24	1.26	0.89	0.63	0.55	0.39	0.98	1.08
1936	10.22	16.57	9.18	6.64	2.87	1.78	1.32	0.81	32.31	4.04	10.89	29.58
1937	43.85	185.51	30.56	19.1	12.05	8.48	6.46	4.69	3.27	2.17	3.28	3.64
1938	2.84	6.66	4.17	21.85	2.66	2.52	2.84	0.99	16.26	3.82	3.56	64.64
1939	82.31	150.36	43.41	30.09	16.88	10.76	8.62	5.98	5.05	2.98	16.55	27.77
1940	9.43	8.58	14.97	7.51	5.81	10.98	3.01	2.01	2.04	1.63	27.43	10.67
1941	6.85	4.53	14.45	35.11	4.14	2.82	2.29	1.52	1.01	1.51	0.7	12.99
1942	23.81	6.1	47	5.67	5.12	11.87	2.82	2.05	2.09	1.6	7.88	4.32
1943	4.94	1.3	7.32	14.66	5.65	3.17	4.64	2.7	2.08	1.76	30.05	3.77
1944	5.02	11.77	4.42	1.78	1.3	1.17	0.71	0.49	0.59	6.87	2.71	3.4
1945	44.04	32.57	12.75	6.22	3.68	2.56	1.78	1.29	0.95	2.35	0.79	1.64
1946	45.72	68.15	23.35	11.36	8.19	5.71	4.15	2.88	1.93	1.5	12.14	8.86
1947	6.05	10.84	8.68	13	2.15	1.63	1.06	0.71	0.57	0.91	7.86	16.17
1948	12.91	6	64.56	9.47	5.34	3.54	2.72	1.93	2.06	2.23	1.83	1.4
1949	16.21	11.09	4.4	3.39	5.68	1.43	1.1	0.76	0.64	0.46	13.2	21.49
1950	7.92	3.3	8.14	5.99	1.77	0.59	1.17	0.56	0.39	0.37	2.38	15.96
1951	7.37	2.77	4.5	15.31	2.17	0.68	2.83	3.63	3.63	1.79	1.07	3.76
1952	2.57	2.92	4.08	2.13	0.24	0.24	0.26	0.1	0.06	0.77	10.46	3.73
1953	16.37	26.35	10.99	18.66	3.37	2.24	1.63	1.17	0.92	0.69	6.64	14.2
1954	15.36	10.88	2.92	5.58	0.98	0.58	0.41	0.32	0.42	0.25	4.06	2.24
1955	21.12	42.32	44.39	14.39	8.08	4.23	3.03	2.15	1.37	7.28	30.73	25.81
1956	22.82	96.98	40	17.58	12.62	8.4	6.04	4.11	4.47	2.35	1.89	5.04
1957	1.66	13.14	16.51	4.8	5.06	1.01	1.19	0.85	0.58	4.95	0.75	9.04
1958	135.71	21.57	13.8	12.66	6.83	4.87	3.48	2.36	4.33	1.37	5.54	14.78
1959	14.74	36.48	3.97	2.25	2.27	1.19	1.74	0.68	5.17	0.93	3.87	8.91
1960	3.31	108.05	20.9	13.8	6.83	4.08	3.01	2.12	2.11	1.19	10.98	30.08
1961	20.55	40	28.19	8.38	5.22	8.58	3.94	2.49	4.22	2.31	2.97	7.28
1962	8.21	14.5	1.64	1.12	0.51	0.31	0.25	0.29	0.13	0.2	30.16	12.65
1963	7.45	5.39	4.12	13.75	1.73	3.39	3.16	0.9	0.59	0.61	1.83	3.13
1964	17.47	13.62	2.64	4.59	1.41	0.89	0.57	0.45	0.23	5.2	2.1	7.28
1965	7.75	3.15	2.37	1.27	0.63	0.42	0.29	0.19	0.64	0.73	1.89	1.14
1966	33.34	39.2	3.75	2.16	1.75	1.14	0.84	0.65	0.47	6.39	0.94	7.39
1967	16.56	29.76	12.71	16.11	5.27	2.73	2.14	1.32	0.89	1	1.76	4.26
1968	2.15	15.66	14.25	4.11	0.85	0.84	0.52	0.46	0.31	0.42	3.57	2.19
1969	9.8	16.03	9.75	4.99	1.99	1.17	0.9	0.55	1.22	18.14	4.82	14.87
1970	3.38	10.76	3.54	1.05	0.71	0.89	0.5	0.44	0.32	0.34	1.08	8.78
1971	56.19	8.41	14.69	11.28	2.28	1.42	1.03	0.69	2.54	0.98	4.51	11.72
1972	36.29	27.35	53.34	15.59	12.43	7.04	5.08	3.52	2.4	5.73	3.76	2.49
1973	2.99	4.4	1.36	7.39	0.59	0.39	0.32	0.27	41.7	35.46	8.15	61.96

1974	79.05	25.32	14.11	15.74	6.57	3.88	18.68	2.98	2.11	2.26	3.57	30.22
1975	13.52	14.75	12.2	4.74	9.49	1.82	1.14	0.72	0.53	0.37	0.44	36.59
1976	60.98	93.89	34.39	18.42	12.87	8.24	5.92	4.33	2.75	2.15	5.8	14.48
1977	18.82	50.15	32.87	13.64	11.14	6.75	4.96	3.53	14.89	7.17	4.05	10.22
1978	53.62	57.37	33.42	22.72	9.85	6.95	5.32	3.71	2.43	2.52	8.99	15.77
1979	22.96	13.94	15.69	3.03	4.83	1.4	1.06	1.55	1.27	6.24	2.36	9.87
1980	5.82	29.59	10	3.86	2.09	1.42	1.06	1.04	1.15	0.8	5.86	43.6
1981	28.98	42.1	22.08	8.28	5.98	3.92	2.85	2.14	4.67	2.03	3.62	5.3
1982	27.5	3.7	3.24	5.96	1.77	0.99	1.78	1.09	0.49	0.7	0.64	4.54
1983	3.8	2.86	5.4	2.95	1.6	0.22	0.05	0.14	0.02	0.39	6.04	12.75
1984	19.5	29.85	22.6	9.22	4.27	3.08	37.25	11.06	11.12	6.03	10.9	11.81
1985	25.02	121.1	13.77	8.28	7.44	4.35	3.11	2.16	1.56	3.89	8.75	6.83
1986	9.53	8.2	5.69	13.84	2.04	1.24	0.82	0.74	0.5	0.59	0.39	2.31
1987	6.57	4.72	16.37	1.86	0.92	0.58	0.37	1.08	11.8	7.86	1.19	33.68
1988	8.59	27.06	14.05	5.89	4.26	2.65	1.94	1.51	1.51	2.39	1.72	9.34
1989	1.02	55.34	15.12	6.19	4.54	4.43	2.18	1.52	1.06	4.71	4.32	11.87
1990	11.18	6.42	5.4	1.89	1.08	0.69	0.84	0.65	0.2	3.01	1.08	29.63
1991	15.68	12.75	8.44	2.51	1.77	3.86	0.85	0.58	0.39	0.3	4.38	1.72
1992	0.59	0.66	1.52	0.85	0.09	0.07	0.05	0.15	0.03	0.46	15.56	43.93
1993	19.06	11.53	36.07	3.93	2.48	1.28	0.92	0.72	0.45	0.38	0.51	16.79
1994	15.97	3.83	1.54	0.8	0.59	0.43	0.36	0.29	0.26	4.42	1.73	5.57
1995	58.23	13.82	7.91	9.68	7.45	2.94	2.2	1.64	1.06	3.52	23.78	54.11
1996	39.84	125.99	41.45	21.29	17.86	9.52	6.96	5.45	3.32	3.81	3.29	4.33
1997	14.54	8.04	44.53	9.33	3.92	2.49	1.83	1.33	3.47	1.31	5.04	25.84
	21.39	28.44	16.81	9.35	4.59	3.12	3.01	1.71	3.3	3.02	6.53	14.85

Appendix 16. Annual Values of Monthly Average Streamflow Values for 5% Wetland Areas

	January	February	March	April	May	June	July	August	September	October	November	December
1930	7.66	4.01	40.51	17.98	6.98	4.48	3.38	2.44	1.68	1.23	1.21	35.96
1931	21.26	12.46	11.95	16.56	4.32	2.98	6.8	1.96	1.38	1.22	2.9	11.77
1932	1.56	2.75	21.28	1.26	0.81	0.45	0.33	0.26	0.28	0.32	0.88	2.46
1933	25.82	10.45	24.47	5.34	3.8	2.52	1.85	1.23	0.86	0.74	6.77	14.56
1934	40.88	6.69	11.11	6.51	1.95	1.47	0.97	0.7	2.5	0.58	22.61	14.2
1935	11.91	21.7	4.2	2.58	2.24	1.26	0.89	0.63	0.55	0.4	0.98	1.08
1936	10.23	16.58	9.19	6.65	2.87	1.78	1.32	0.81	32.32	4.05	10.89	29.59
1937	43.85	185.54	30.58	19.11	12.06	8.48	6.46	4.7	3.27	2.17	3.28	3.64
1938	2.84	6.66	4.17	21.85	2.66	2.53	2.84	0.99	16.27	3.82	3.56	64.65
1939	82.32	150.37	43.42	30.1	16.88	10.76	8.63	5.99	5.06	2.98	16.55	27.79
1940	9.44	8.59	14.98	7.52	5.81	10.99	3.02	2.01	2.04	1.63	27.44	10.68
1941	6.86	4.53	14.46	35.12	4.15	2.82	2.29	1.52	1.01	1.51	0.7	12.99
1942	23.82	6.1	47.02	5.68	5.12	11.87	2.82	2.05	2.09	1.6	7.89	4.33
1943	4.95	1.31	7.33	14.67	5.65	3.17	4.65	2.71	2.09	1.77	30.06	3.78
1944	5.03	11.79	4.42	1.78	1.31	1.17	0.71	0.49	0.59	6.87	2.71	3.4
1945	44.05	32.58	12.76	6.22	3.68	2.56	1.79	1.29	0.95	2.35	0.79	1.64
1946	45.73	68.17	23.36	11.37	8.19	5.71	4.15	2.88	1.93	1.5	12.14	8.87
1947	6.06	10.85	8.69	13.01	2.15	1.63	1.06	0.71	0.57	0.91	7.86	16.18
1948	12.91	6.01	64.58	9.48	5.34	3.55	2.73	1.93	2.06	2.23	1.83	1.4
1949	16.22	11.09	4.4	3.39	5.68	1.43	1.1	0.76	0.64	0.46	13.21	21.5
1950	7.92	3.3	8.15	5.99	1.77	0.59	1.17	0.56	0.39	0.37	2.38	15.97
1951	7.38	2.77	4.5	15.32	2.17	0.69	2.83	3.63	3.64	1.79	1.07	3.77
1952	2.57	2.92	4.08	2.13	0.24	0.24	0.26	0.1	0.06	0.77	10.47	3.73
1953	16.38	26.36	11	18.68	3.37	2.24	1.63	1.17	0.92	0.69	6.64	14.21
1954	15.37	10.89	2.92	5.59	0.99	0.58	0.41	0.32	0.42	0.25	4.06	2.24
1955	21.12	42.33	44.4	14.4	8.08	4.23	3.04	2.15	1.37	7.28	30.74	25.82
1956	22.84	97.01	40.02	17.59	12.63	8.41	6.04	4.12	4.47	2.35	1.89	5.04
1957	1.66	13.14	16.52	4.81	5.07	1.01	1.2	0.85	0.58	4.96	0.75	9.05
1958	135.74	21.58	13.8	12.67	6.84	4.87	3.48	2.36	4.33	1.37	5.55	14.78
1959	14.75	36.49	3.98	2.26	2.27	1.2	1.74	0.68	5.18	0.93	3.87	8.91
1960	3.32	108.07	20.91	13.81	6.84	4.08	3.01	2.12	2.11	1.19	10.99	30.09
1961	20.56	40.02	28.21	8.38	5.23	8.59	3.94	2.5	4.22	2.32	2.97	7.28
1962	8.21	14.51	1.65	1.12	0.51	0.31	0.25	0.29	0.13	0.2	30.16	12.66
1963	7.45	5.39	4.12	13.76	1.73	3.39	3.17	0.9	0.59	0.61	1.84	3.13
1964	17.48	13.63	2.64	4.6	1.41	0.89	0.57	0.45	0.23	5.21	2.1	7.29
1965	7.76	3.16	2.37	1.28	0.63	0.42	0.29	0.2	0.64	0.73	1.89	1.15
1966	33.35	39.21	3.75	2.16	1.75	1.14	0.84	0.65	0.47	6.39	0.94	7.39
1967	16.56	29.77	12.72	16.12	5.28	2.74	2.14	1.32	0.89	1	1.76	4.27
1968	2.16	15.66	14.26	4.11	0.85	0.84	0.52	0.46	0.31	0.42	3.57	2.19
1969	9.8	16.03	9.76	5	2	1.17	0.9	0.55	1.22	18.15	4.83	14.88
1970	3.39	10.76	3.55	1.05	0.71	0.89	0.5	0.44	0.32	0.34	1.08	8.79
1971	56.2	8.42	14.7	11.29	2.28	1.42	1.03	0.69	2.55	0.98	4.51	11.73
1972	36.31	27.36	53.37	15.6	12.44	7.05	5.09	3.52	2.4	5.74	3.76	2.49
1973	3	4.41	1.36	7.39	0.59	0.39	0.32	0.27	41.7	35.47	8.16	61.98

1974	79.07	25.34	14.13	15.76	6.57	3.89	18.69	2.98	2.11	2.26	3.57	30.23
1975	13.53	14.76	12.21	4.74	9.5	1.82	1.14	0.72	0.53	0.37	0.44	36.6
1976	60.99	93.92	34.4	18.43	12.88	8.24	5.92	4.33	2.75	2.15	5.8	14.48
1977	18.83	50.16	32.88	13.65	11.14	6.75	4.96	3.53	14.89	7.18	4.06	10.22
1978	53.63	57.39	33.44	22.73	9.86	6.96	5.32	3.71	2.43	2.52	9	15.79
1979	22.97	13.95	15.7	3.03	4.83	1.4	1.06	1.55	1.27	6.24	2.37	9.88
1980	5.83	29.6	10.01	3.86	2.1	1.43	1.06	1.04	1.15	0.8	5.87	43.62
1981	28.99	42.12	22.09	8.29	5.98	3.92	2.85	2.15	4.68	2.03	3.62	5.31
1982	27.51	3.7	3.25	5.96	1.77	0.99	1.78	1.09	0.49	0.7	0.64	4.54
1983	3.81	2.87	5.4	2.95	1.6	0.22	0.05	0.14	0.02	0.39	6.05	12.76
1984	19.51	29.86	22.61	9.22	4.28	3.08	37.26	11.07	11.13	6.04	10.91	11.82
1985	25.04	121.12	13.78	8.29	7.45	4.35	3.11	2.16	1.56	3.89	8.75	6.83
1986	9.54	8.2	5.69	13.84	2.04	1.25	0.83	0.74	0.5	0.59	0.39	2.31
1987	6.58	4.72	16.38	1.87	0.93	0.58	0.37	1.09	11.81	7.87	1.2	33.7
1988	8.6	27.08	14.07	5.89	4.26	2.65	1.94	1.51	1.51	2.39	1.72	9.34
1989	1.02	55.35	15.13	6.19	4.54	4.43	2.18	1.52	1.06	4.71	4.33	11.88
1990	11.19	6.42	5.41	1.89	1.08	0.7	0.84	0.65	0.2	3.01	1.08	29.63
1991	15.68	12.76	8.45	2.52	1.77	3.87	0.86	0.58	0.4	0.3	4.38	1.72
1992	0.59	0.66	1.52	0.85	0.09	0.07	0.05	0.15	0.03	0.46	15.56	43.94
1993	19.07	11.54	36.08	3.94	2.48	1.28	0.92	0.72	0.45	0.38	0.51	16.79
1994	15.98	3.83	1.54	0.8	0.59	0.43	0.36	0.29	0.26	4.42	1.73	5.58
1995	58.24	13.83	7.91	9.69	7.45	2.94	2.2	1.64	1.07	3.52	23.79	54.1
1996	39.85	126.02	41.47	21.3	17.87	9.53	6.97	5.45	3.33	3.81	3.3	4.33
1997	14.55	8.04	44.54	9.33	3.92	2.49	1.83	1.33	3.47	1.31	5.04	25.85
	21.4	28.45	16.82	9.36	4.59	3.12	3.01	1.71	3.3	3.02	6.53	14.86

Appendix 17. Annual Values of Monthly Average Streamflow Values for 0% Wetland Areas

	January	February	March	April	May	June	July	August	September	October	November	December
1930	7.67	4.01	40.55	18.01	7	4.49	3.38	2.44	1.68	1.23	1.21	35.99
1931	21.29	12.48	11.96	16.58	4.33	2.99	6.82	1.96	1.38	1.22	2.9	11.78
1932	1.57	2.76	21.29	1.27	0.81	0.45	0.33	0.26	0.28	0.32	0.89	2.46
1933	25.85	10.47	24.49	5.35	3.8	2.53	1.85	1.23	0.86	0.74	6.78	14.58
1934	40.92	6.71	11.13	6.53	1.95	1.47	0.97	0.7	2.5	0.58	22.63	14.23
1935	11.94	21.74	4.22	2.59	2.25	1.26	0.89	0.63	0.55	0.4	0.98	1.08
1936	10.24	16.59	9.21	6.66	2.88	1.79	1.33	0.81	32.33	4.06	10.91	29.61
1937	43.88	185.6	30.62	19.14	12.07	8.49	6.47	4.7	3.27	2.17	3.28	3.65
1938	2.84	6.67	4.18	21.87	2.67	2.53	2.84	0.99	16.28	3.82	3.57	64.69
1939	82.37	150.43	43.45	30.12	16.89	10.77	8.63	5.99	5.06	2.98	16.58	27.84
1940	9.47	8.61	15.01	7.54	5.82	11	3.02	2.01	2.04	1.63	27.48	10.7
1941	6.88	4.54	14.48	35.16	4.16	2.83	2.3	1.52	1.01	1.51	0.7	13.01
1942	23.84	6.12	47.07	5.7	5.13	11.9	2.83	2.06	2.1	1.61	7.9	4.33
1943	4.96	1.31	7.36	14.69	5.67	3.18	4.67	2.72	2.1	1.79	30.08	3.79
1944	5.04	11.82	4.44	1.79	1.31	1.17	0.71	0.5	0.59	6.89	2.71	3.4
1945	44.08	32.61	12.79	6.24	3.69	2.57	1.79	1.29	0.96	2.36	0.8	1.65
1946	45.77	68.22	23.39	11.38	8.2	5.71	4.15	2.88	1.93	1.5	12.15	8.88
1947	6.07	10.87	8.7	13.03	2.16	1.64	1.06	0.72	0.57	0.92	7.87	16.22
1948	12.94	6.03	64.62	9.49	5.35	3.55	2.73	1.94	2.06	2.24	1.84	1.41
1949	16.25	11.12	4.41	3.4	5.69	1.43	1.11	0.76	0.64	0.46	13.23	21.51
1950	7.94	3.31	8.18	6	1.78	0.6	1.17	0.56	0.39	0.37	2.38	16
1951	7.4	2.78	4.52	15.33	2.19	0.69	2.84	3.64	3.66	1.81	1.08	3.79
1952	2.58	2.93	4.09	2.14	0.24	0.24	0.26	0.1	0.06	0.77	10.48	3.75
1953	16.41	26.4	11.02	18.69	3.38	2.25	1.63	1.17	0.93	0.69	6.66	14.22
1954	15.4	10.93	2.94	5.6	0.99	0.58	0.41	0.32	0.42	0.25	4.06	2.25
1955	21.16	42.37	44.42	14.41	8.09	4.23	3.04	2.15	1.37	7.29	30.76	25.85
1956	22.87	97.09	40.07	17.61	12.65	8.41	6.05	4.12	4.48	2.36	1.9	5.04
1957	1.66	13.16	16.55	4.83	5.08	1.02	1.2	0.86	0.58	4.97	0.76	9.07
1958	135.8	21.61	13.82	12.69	6.84	4.88	3.49	2.36	4.34	1.37	5.56	14.79
1959	14.77	36.52	3.99	2.26	2.28	1.2	1.74	0.68	5.18	0.93	3.88	8.93
1960	3.33	108.12	20.94	13.83	6.85	4.08	3.01	2.12	2.11	1.19	11	30.13
1961	20.61	40.05	28.26	8.41	5.24	8.61	3.95	2.5	4.23	2.33	2.98	7.29
1962	8.23	14.54	1.65	1.13	0.51	0.31	0.25	0.29	0.13	0.2	30.19	12.68
1963	7.47	5.4	4.13	13.77	1.73	3.4	3.18	0.91	0.6	0.61	1.84	3.14
1964	17.5	13.66	2.65	4.61	1.41	0.9	0.57	0.46	0.23	5.22	2.11	7.3
1965	7.78	3.17	2.39	1.29	0.64	0.42	0.3	0.2	0.64	0.74	1.89	1.15
1966	33.38	39.26	3.77	2.16	1.76	1.14	0.84	0.65	0.48	6.4	0.95	7.4
1967	16.59	29.8	12.74	16.15	5.29	2.74	2.14	1.33	0.89	1	1.77	4.28
1968	2.16	15.67	14.28	4.13	0.85	0.84	0.52	0.46	0.31	0.42	3.57	2.2
1969	9.83	16.06	9.79	5.02	2.01	1.17	0.9	0.55	1.23	18.18	4.84	14.9
1970	3.4	10.78	3.55	1.06	0.72	0.89	0.5	0.44	0.32	0.34	1.08	8.8
1971	56.24	8.44	14.72	11.31	2.28	1.42	1.03	0.69	2.56	0.98	4.52	11.76
1972	36.34	27.39	53.43	15.62	12.46	7.06	5.09	3.52	2.4	5.75	3.77	2.5
1973	3.01	4.42	1.37	7.4	0.59	0.39	0.32	0.27	41.72	35.5	8.18	62.02

1974	79.13	25.38	14.16	15.79	6.59	3.89	18.71	2.99	2.12	2.26	3.57	30.26
1975	13.55	14.78	12.22	4.75	9.52	1.83	1.14	0.72	0.53	0.37	0.45	36.64
1976	61.02	93.98	34.44	18.46	12.9	8.25	5.92	4.33	2.75	2.16	5.81	14.51
1977	18.85	50.19	32.91	13.66	11.15	6.75	4.97	3.54	14.91	7.18	4.06	10.24
1978	53.67	57.44	33.48	22.75	9.87	6.96	5.33	3.71	2.44	2.53	9.01	15.82
1979	22.99	13.95	15.74	3.03	4.84	1.4	1.06	1.55	1.27	6.24	2.37	9.89
1980	5.84	29.64	10.04	3.87	2.1	1.43	1.06	1.04	1.15	0.8	5.88	43.64
1981	29.04	42.15	22.12	8.3	5.99	3.93	2.86	2.15	4.68	2.03	3.63	5.32
1982	27.52	3.71	3.25	5.97	1.78	0.99	1.78	1.09	0.5	0.7	0.64	4.55
1983	3.81	2.87	5.4	2.96	1.61	0.22	0.05	0.14	0.02	0.39	6.05	12.78
1984	19.52	29.87	22.66	9.24	4.28	3.08	37.31	11.09	11.15	6.05	10.94	11.83
1985	25.07	121.18	13.81	8.3	7.46	4.36	3.11	2.17	1.56	3.89	8.76	6.84
1986	9.54	8.21	5.7	13.87	2.05	1.25	0.83	0.74	0.5	0.59	0.39	2.32
1987	6.59	4.73	16.4	1.88	0.93	0.59	0.38	1.09	11.83	7.89	1.2	33.74
1988	8.62	27.13	14.1	5.91	4.27	2.66	1.94	1.52	1.51	2.4	1.73	9.35
1989	1.03	55.39	15.15	6.2	4.55	4.44	2.18	1.53	1.06	4.72	4.33	11.91
1990	11.21	6.45	5.44	1.9	1.09	0.7	0.84	0.65	0.2	3.01	1.08	29.66
1991	15.71	12.79	8.47	2.53	1.78	3.88	0.86	0.58	0.4	0.3	4.38	1.73
1992	0.59	0.66	1.52	0.85	0.09	0.07	0.05	0.15	0.03	0.46	15.57	43.97
1993	19.1	11.56	36.11	3.95	2.49	1.29	0.92	0.72	0.46	0.39	0.51	16.81
1994	15.99	3.85	1.55	0.8	0.59	0.43	0.37	0.29	0.26	4.43	1.73	5.59
1995	58.25	13.85	7.91	9.69	7.46	2.95	2.21	1.64	1.07	3.53	23.82	54.12
1996	39.89	126.1	41.51	21.32	17.89	9.54	6.98	5.46	3.33	3.82	3.3	4.34
1997	14.57	8.06	44.58	9.34	3.93	2.5	1.84	1.33	3.48	1.32	5.05	25.87
	21.42	28.48	16.84	9.37	4.6	3.13	3.01	1.72	3.3	3.02	6.54	14.88