A SYSTEM FOR SUPPORTING WETLAND MANAGEMENT DECISIONS

VOLUME 1

Donovan Charles Kotze

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DECLARATION

This thesis and associated research comprise my own original work except for assistance which is acknowledged, or where due reference is made in the text. This work has not been submitted for degree purposes to any other university.

Donovan C. Kotze

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ABSTRACT

In South Africa, the loss of wetlands and their associated benefits has been considerable. A need was identified for a system that, using available information, would assist in achieving a balance between local, mainly short-term benefits to individuals and spatially wider and longer term benefits to society. Such a system, termed WETLAND-USE, was developed with the philosophy that:(1) wetlands have been well demonstrated to supply several indirect benefits to society (e.g. water quality enhancement); (2) the impact on these benefits can be described on a qualitative basis using field indicators that characterize the wetland and the disturbance associated with a particular land-use; (3) this information can be communicated to wetland users, which will contribute to achieving a desired balance, provided there is an enabling organizational environment and due consideration is taken of the socio-economic and organizational factors affecting wetland management.

The primary conceptual framework underlying WETLAND-USE was the pressure-state-perceptions-policy framework, which depicts: the mode of use (i.e. the pressure); how this affects the state of the system (including its underlying processes and the goods and services it delivers); which in turn shape the perceptions that ultimately determine the policy pertaining to further use. This cycle is repeated at a range of organizational levels from local to national and takes place within a particular socio-economic context.

WETLAND-USE, which was designed for use by fieldworkers, and built using a rule-based, expert system approach, has two main parts, dealing largely with biophysical and social aspects respectively. Part 1, which guides the collection of data relating to the state of the wetland, assists in: (1) predicting the likely impacts of disturbances associated with a proposed land-use (the pressure) on the wetland state, and (2) providing ongoing management guidelines for particular land-uses. Part 2 assists in: (1) describing the social, land tenure and policy contexts of the wetland; and (2) establishing and maintaining organizational arrangements, local policy and management objectives and goals.

Several discrete investigations were required for the development and refinement of WETLAND-USE, which was done in an iterative fashion. Initial discrete investigations fed into the development of a prototype system which was refined through evaluation using a questionnaire survey and further discrete investigations. The revised system was re-evaluated using a fieldworkshop approach and, based on the performance of the system in the field, it was revised further to produce the final system.

In the two initial discrete studies, protocols were developed for characterizing key physical determinants of wetland functioning, notably: (1) degree of wetness, one of the primary functional determinants, described in the field using readily identifiable soil morphological indicators (e.g. matrix chroma and mottles) and (2) landform setting, which strongly influences local flow patterns and lateral exchange of water and water-borne materials. Graminoid plant species composition and functional groups (defined in terms of photosynthetic pathway) were then described in relation to the above physical determinants, together with rainfall, temperature and soil texture, within wetlands spanning a wide altitudinal range. This revealed that degree of wetness and altitude had the strongest influence over the vegetation parameters examined.

An investigation into incorporating cumulative impacts into wetland decision making revealed that consideration should be given to: wetland loss in relation to ecoregions and catchments, and the relation of change in wetland extent, spatial configuration and context respectively to wetland function. Current conservation initiatives in KwaZulu-Natal were shown to account poorly for cumulative impacts on wetlands. Rules of thumb for making such considerations, given severe data limitations, were developed with reference to the high turn-over of species along the altitudinal gradient observed in the vegetation study. The "rules" were than applied to a case-study, the upper Mgeni catchment, as part of an initiative to engage a diversity of stakeholders in wetland information gathering and use. This resulted in the selection of priority wetlands in the catchment and an examination of the extent to which integration had been achieved vertically (across hierarchical levels) and horizontally (across organizations within particular hierarchical levels).

In order to broaden the range of land-uses accounted for by the WETLAND-USE prototype, it was applied to a communally used wetland, Mbongolwane, and found to account poorly for the traditional cultivation and vegetation harvesting practices encountered. WETLAND-USE was modified to include a greater diversity of land-use types as well as enhancing its capacity to allow assessments to be conducted using the system's general criteria, thereby making WETLAND-USE more robust.

In enhancing the capacity of WETLAND-USE to account for the social and organizational dimension of wetland management, the involvement of local and outside organizations in influencing wetland resource use in five sites was examined in relation to predefined frameworks. The sites, Mandlazini wetland, Mbongolwane wetland, Blood River vlei, Ntabamhlope vlei and Wakkerstroom vlei were chosen to represent a diversity of social contexts and management authorities. This revealed that in communally used areas in particular, a wide range of organizations are involved to varying degrees in influencing the use of different wetland resources. The level to which the local organizational environment contributed to sustainable use varied greatly among wetlands, but in all cases had important deficiencies: (1) self-governing resource-management organizations were largely lacking and in communal areas were weakening under contemporary conditions; and (2) although a formal management system was in place in two of the five wetlands, it was largely absent in the remaining three. There has been little involvement from extension services in facilitating local policy development and in promoting alternative land-uses which have less pressure on the state of the wetland. Local wetland management policy and collaboration among land-owners in wetlands under multiple separate ownership such as Blood River vlei was identified as being particularly poor.

The evaluations of WETLAND-USE revealed that, in relation to the underlying philosophy of the thesis, WETLAND-USE had been improved through field application and incorporation of the findings of the discrete investigations. Nevertheless, important limitations of the study were highlighted, including: its high level of reliance on expert opinion in the face of a paucity of empirical data relating to the functioning of local wetlands and their attendant benefits (and how these are affected by anthropogenic disturbances), and a particularly shallow representation of socio-economic factors. The identification of these limitations was useful in highlighting key areas for further research

TABLE OF CONTENTS

VOLUME 1

PART 2
INVESTIGATIONS TO ENHANCE PARTICULAR BIOPHYSICAL AND SOCIAL CONSIDERATIONS OF WETLAND-USE

CHAPTER 4
IMPROVED CRITERIA FOR CLASSIFYING HYDRIC SOILS IN SOUTH AFRICA

CHAPTER 5
THE DEVELOPMENT OF A CLASSIFICATION SYSTEM FOR HYDRO-GEOMORPHOLOGICAL SETTINGS

CHAPTER 6
VEGETATION PATTERN WITHIN AND AMONG PALUSTRINE WETLANDS ALONG AN ALTITUDINAL GRADIENT IN KWAZULU-NATAL

CHAPTER 7
ACCOUNTING FOR CUMULATIVE IMPACTS ON WETLANDS

CHAPTER 10
APPLYING WETLAND-USE IN A COMMUNALLY USED WETLAND: ORGANIZATIONAL ISSUES EXAMINED

CHAPTER 11
INTERVENTION OF LOCAL AND EXTERNAL ORGANIZATIONS IN THE USE OF WETLANDS: FIVE STUDY SITES EXAMINED

PART 3
OVERALL EVALUATION AND CONCLUSION

CHAPTER 12
EVALUATION AND REFINEMENT OF WETLAND-USE

CHAPTER 13
SUMMARY, CONCLUSIONS AND FUTURE RESEARCH

VOLUME 2

APPENDIX A

EXTENSION SERVICES AND WETLAND MANAGEMENT:
A QUESTIONNAIRE AND WORKSHOP BASED STUDY

APPENDIX B

AGRICULTURAL LAND-USE IMPACTS ON WETLAND FUNCTIONAL VALUES

APPENDIX C

WETLAND-USE: PROTOTYPE

APPENDIX D

WETLAND-USE: FINAL DRAFT

APPENDIX E

WETLAND-USE BOOKLETS

PART 1

DEVELOPMENT AND OVERALL DESIGN OF THE DECISION SUPPORT SYSTEM

CHAPTER 1

INTRODUCTION

1.1 Motivation for developing a wetland management decision support system

Wetlands are considered to be one of the most globally endangered habitat types (Maltby, 1986). In a survey of the need for biodiversity preservation action conducted among 200 South African natural scientists the greatest number of respondents (38%) rated freshwater/wetland systems the highest. This was well ahead of the next highest rated system, estuaries and lagoons (14%) (Preston and Siegfried, 1995). In South Africa there has been considerable loss of wetlands and their associated benefits to humanity, primarily owing to agricultural development (e.g. drainage and pasture production) and poor land use practices leading to erosion (Kotze *et al.*, 1995). In the Mfolozi catchment, for example, 58% of the original wetland area is estimated to have been lost (Begg, 1988). This degradation of South African wetlands is a concern now recognized by Government as requiring urgent action (DEAT, 1997) and the protection of wetlands is considered fundamental to the sustainable management of South Africa's water resources (Wyte, 1995).

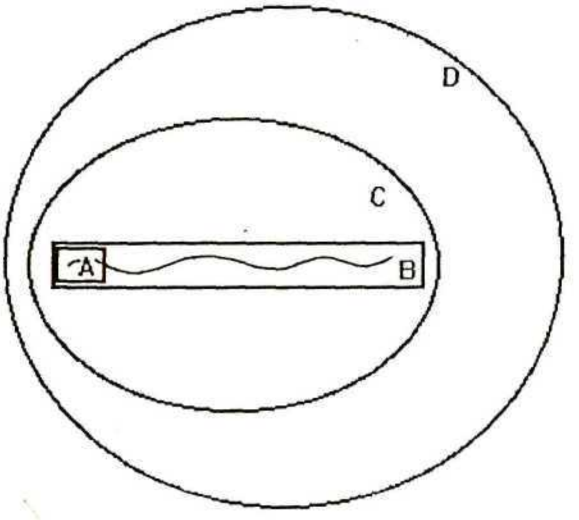
In South Africa, despite the high conservation priority these systems are perceived to have, there has been a deficiency of policy, broad management strategies, specific guidelines and research directed at inland freshwater wetland conservation in particular (Breen and Begg, 1989; Kotze *et al.*, 1995). Regarding research, for example, for the period up to 1993, the DEAT wetland bibliography (van der Walt *et al.*, 1995) cites only 33 publications relating to marshes and swamps compared with over 400 publications relating to estuaries. Furthermore, government acknowledges that insufficient attention has been given in the past to secure the effective management of the country's wetlands in general (DEAT, 1997).

The benefits that accrue from wetlands can be conveniently divided into direct benefits, (e.g. crops grown in a wetland) which accrue to individuals and indirect benefits (e.g. maintenance of biodiversity), which generally have a benefit to wider society. Several reviews of the indirect benefits of wetlands have been produced, including those of Reppert *et al.* (1979), Adamus (1983), Sather and Smith (1984) and Kotze and Breen (1994), and the indirect benefits commonly cited in the literature are:

1. enhancement of water quality (Kadlec and Kadlec, 1979; Mitsch and Gosselink, 1986; Hemond and Benoit, 1988; Hammer, 1992);
2. flood attenuation (Dugan, 1990);
3. streamflow regulation (Scaggs *et al., 1991*);
4. erosion control (Carter *et al.*, 1978);
5. ecological (support of biotic diversity through the provision of habitat for wetland-dependent fauna and flora) (Goodman, 1987; Preston and Bedford, 1988); and
6. global climate stabilization (de la Cruz, 1982; Gorham, 1992).

Water, because of its mobility, has the characteristics of a "common property" resource and, because of its value to society, it is often "claimed" by individuals. Land, on the other hand, is easily bounded in space in time and is more amenable to allocation. Being the interface of land and water, wetlands have complex characteristics of ownership. Furthermore, wetlands, at least those in riparian areas, are strongly connected to other components in the landscape, and wetland functioning is to a large extent determined by the properties and behaviour of the catchment. The wetland may, in turn, have an important influence on downstream aquatic and riparian systems. This connectedness of wetlands in the landscape and the complexities of ownership, together with the dynamic nature of wetlands, complicate analyses of flows of goods and services and of costs and benefits.

Further complicating analyses is the fact that indirect benefits vary according to the primary spatial area in which they accrue, referred to by Goulder and Kennedy (1997) as the "social endpoint" (Fig. 1.1). Although the spatial areas are obviously not restricted entirely to those given in Fig. 1.1, wetlands control erosion primarily in the area that they occupy, and they enhance water quality, attenuate floods and regulate streamflow in the downstream area, with their influence decreasing with downstream distance. The contribution of wetlands to biodiversity support and climate stabilization extend much further (i.e. from ecoregions to the entire biosphere).



A. Wetland area: Erosion control

B. Downstream area: Water quality enhancement, Flood attenuation & Streamflow regulation

C. Ecoregion/biome/continent: Biodiversity support

D. The planet's biosphere: Climate stabilization

Fig. 1.1 A conceptual diagram showing the primary spatial areas in which particular benefits of wetlands accrue

When a wetland is transformed (e.g. drained for crop production) the goods and services it provides are altered accordingly, with direct benefits often being gained at the expense of indirect benefits. Although indirect benefits have tended to be undervalued owing to the indirect manner in which they benefit society, as the amount of wetland remaining has steadily declined, increased recognition is being given to these values and the costs incurred by society when they are lost (see DEAT, 1997). Nevertheless, wetland use still tends to be planned from the restricted perspectives of individual wetland users or landowners with specific interests (e.g. livestock grazing). Little attention is usually given to the effects on those wetland functions which benefit society at large. It is suggested that an important factor contributing to this "restricted view" is the lack of relevant information that is in a form readily accessible to management practice.

Extending the original definition of the World Commission on Environment and Development (WCED, 1987) and including the ideas of Goodland (1995) and Lawrence (1997), sustainable use (of natural resources) is defined as "use which is within biological limits and meets the ecological, social and economic needs of humans such that the future is not compromised for the present (a temporal dimension) and geographic area(s) are not compromised for other geographic area(s) (a spatial dimension)". One of the pillars of the Ramsar convention is that of wise use of wetlands, which according to the Ramsar Strategic Plan 1997-2002 (Convention on Wetlands, 1998), is taken to be synonymous with "sustainable use". The term sustainability, however defined, is sufficiently broad that there will inevitably be conflicting interpretations, and more specific guidance for action is required (Sunderlin 1995; Lawrence, 1997).

In the case of wetlands in South Africa, there is clearly a need for a system that, using the best currently available information, would assist in making trade-offs between benefits derived by the individual user and benefits derived by society at large (i.e. a system to promote the sustainable use of wetlands). Rogers (1997a) contends that if science is to better serve management it must discard the "strategy of hope" that good science will inevitably lead to informed management and develop an explicit interface for technology development and transfer. Few managers (and extension workers operating at the management interface) write in scientific journals, and scientists generally perceive the non-scientific literature to be "grey" and of limited value. Scientists and natural resource managers, therefore operate from different world views, and specific attention needs to be given to the translation of science into management practice (Berliner, 1990; Smith, 1993; Pullian, 1997; Rogers, 1997a). "To manage" is "to be in charge of or to exercise control over" (McLeod, 1987) and in this study it is clearly recognized that managers are more often than not local individuals with rights of use over a particular area rather than being high-level planners.

The need for a system to support local management decisions for wetlands is further emphasised by the results of a survey of extension workers in the study area (see Appendix A). This showed that within KwaZulu-Natal, Free State and Mpumalanga there were very few wetlands reported which were co-operatively managed by different land-owners or that had some form of management system with measurable objectives that explicitly accounted for indirect benefits to society. Appendix A also indicates that there has been a low level of involvement by extension workers in the development of local policy and in promoting the sustainable use of wetlands.

1.2 The underlying philosophy and objectives of the thesis

Recognizing the need to address the conflict between the direct and indirect beneficiaries of wetlands, the philosophy underlying the thesis is the following.

1. It is desirable to have a balance between the direct benefits derived by local users and the indirect benefits to society.

2. Wetland systems can be assumed to have several indirect benefits through the various services that they provide (e.g. water quality enhancement).

3. Qualitative and semi-quantitative descriptors relating to wetland functioning can be used to assess, on a qualitative basis at least, the impact of particular land-uses on these benefits, and these assessments can be made using a generic system, which includes generic land-use categories with assumed associated features. (For example, annual ryegrass pastures require the annual disturbance of soil, the addition of nutrients through fertilization and drainage channels to prevent prolonged soil saturation.)

4. The concepts and details of the above assessments can be readily understood by extension workers who will be able to communicate this to wetland users.

5. The above will contribute to achieving a balance between direct and indirect benefits, provided that consideration is also given to the economic, social, organizational and institutional factors affecting wetland management.

The overall goal of the thesis is to examine the above philosophy through the development and testing of a system to support wetland management decisions. The specific objectives are the following.

1. Develop, through the incorporation of current knowledge and expertise, a system for use by extension workers in supporting wetland management decisions.

2. Undertake investigations necessary to enhance the biophysical and social considerations of the system.

3. Evaluate the system and re-examine the underlying philosophy of the thesis in the light of the evaluation.

The type of wetland examined is freshwater palustrine wetland, with palustrine referring to non-tidal wetland dominated by persistent emergent plants (e.g. reeds) emergent mosses or lichens, shrubs or trees (Cowardin *et al.*, 1979). The study area, which encompasses much of the higher rainfall inland areas in South Africa with a summer rainfall pattern, is shown in Fig. 1.2.

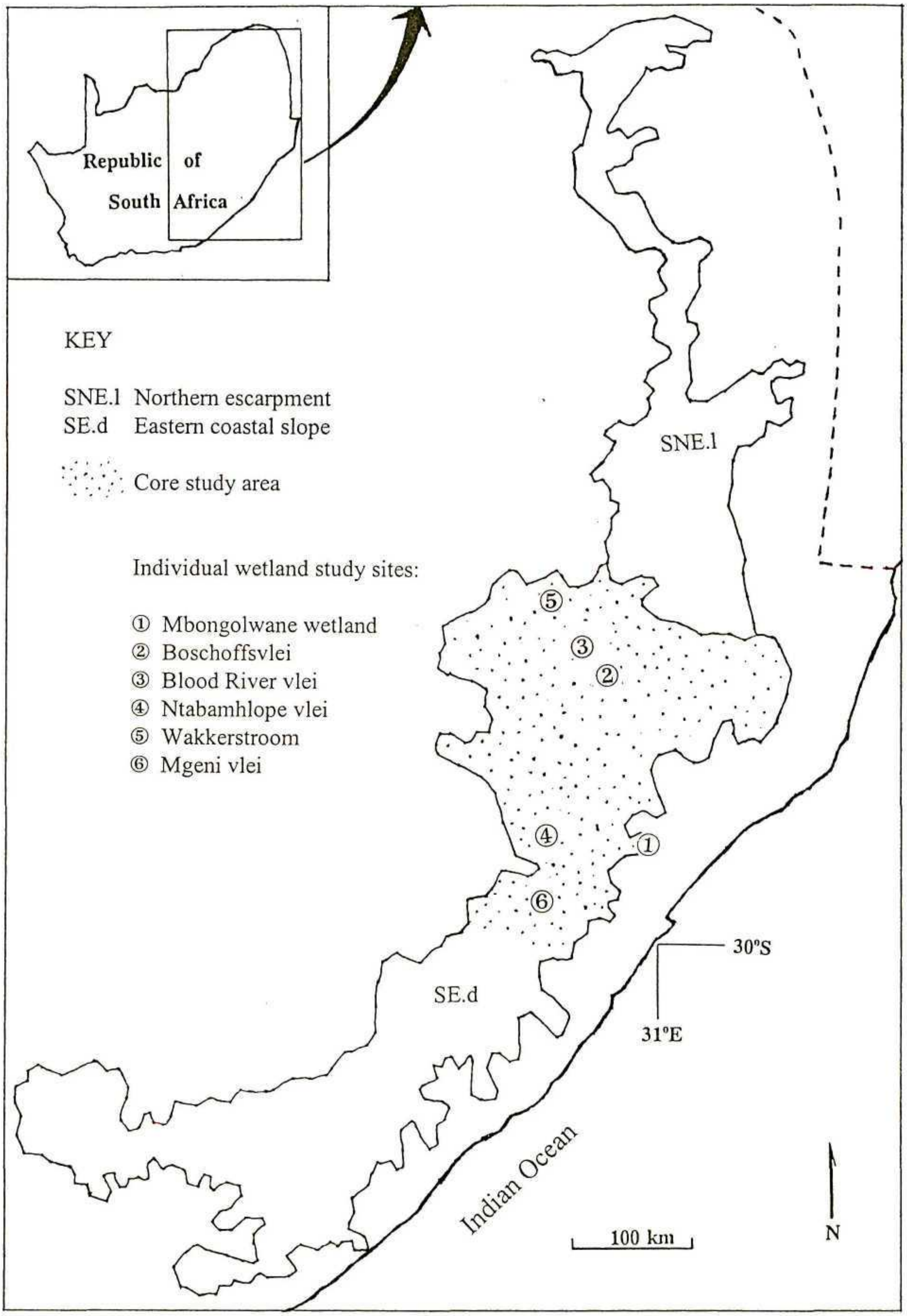


Fig. 1.2 Location of the study area, comprising the eastern coastal slope (SE.d) and Northern escarpment (SNE.l) wetland regions of South Africa as defined by Cowan (1995a)

1.3 Structure of the thesis

The thesis chapters are grouped into three main parts. Part 1 begins by dealing with the motivation for the thesis, its underlying philosophy and its objectives. It then describes the development and the conceptual bases of a decision support system, termed WETLAND-USE, which is the central focus of the thesis.

An important component of the thesis is the synthesising and organizing of current scientific literature and expertise in a manner useful to management rather than the scientific activity of gathering and interpreting primary data. However, certain key biophysical and social considerations of the system, given in Part 2, were identified as requiring specific investigation. Biophysical considerations include: hydrology and soils; landforms; vegetation; the landscape context of wetlands; and the effect of small-scale, traditional use of wetlands.

* Hydrology is the primary driving variable determining the structure and functioning of wetlands (Mitsch and Gosselink, 1986). Thus, in order to manage a wetland so as to account for its functioning and associated values it is necessary to characterize a wetland's hydrology. As long term data are generally lacking this is usually impossible to do directly and it is therefore necessary to use the best surrogate available, namely soil morphology.

* The landform, through its influence on both surface and subsurface water movement, has a strong influence over hydrology and it is therefore also considered necessary that landforms be characterized (Semenuik, 1987; Brinson, 1988).

* Hydrology, together with other important driving variables (notably climate) has an important influence on system structure and functioning through its influence on vegetation (e.g. by affecting photosynthesis and nutrient cycling) (Mitsch and Gosselink, 1986). It is therefore considered necessary to examine how the hydrology/soil characterization relates to vegetation pattern and how this varies among wetlands under different climatic conditions.

* In order to assess the impacts on a wetland and its associated benefits, wetlands should be considered in a broad landscape and catchment context rather than being restricted solely to features of the particular site (Brinson, 1988) and it is therefore necessary to examine how these broad-scale considerations can be made.

A paucity of local data, understanding and protocols for all of the above aspects require specific investigations for each. A further investigation is undertaken of land-use practices at a case-study wetland under communal use. This is motivated by the fact that such land-uses were poorly accounted for in comparison with land-uses typically associated with commercial farming enterprises.

It is recognized that a key element of achieving sustainable use of natural resources is taking due consideration of social factors (WWF, 1993a). Social, and specifically organizational, influences on the use of wetlands are investigated in the remainder of Part 2 using a hierarchical approach. At the lower level, the organizational context of a single case-study wetland is examined in detail. At a higher level, five study sites, including the initial site, are described and compared at a lower resolution and recommendations made based on the two studies.

In Part 3, various performance-related aspects of the WETLAND-USE, such as its internal consistency clarity, and repeatability are evaluated and refinements made based on these evaluations. Finally, the objectives of the thesis and its underlying philosophy are re-examined, the scientific contribution of the thesis discussed and recommendations given for further research.

The logical sequence in which the different investigations and system developments were conducted, together with the inter-relationships among the different elements of the thesis are shown in Fig.1.3. The investigations reported in Chapter 1 to 5 (which focus on biophysical aspects), together with the knowledge gained from a review of the literature (Appendix B) were used in the development of the prototype WETLAND-USE system (Kotze *et al.*, 1994a and b; Appendix B). Its evaluation, reported in Chapter 12, revealed that in order to refine the system, further investigations were required, namely those reported in Chapters 6 to 9 (further biophysical aspects) and in Chapters 10 and 11 (social/organizational aspects). The system was then revised and re-evaluated (Chapter 12) and conclusions drawn (Chapter 13). In the following Chapter details of the approach used in developing the system are described. A comprehensive glossary of terms used in the thesis appears in Appendix D, Part 1, page 60.

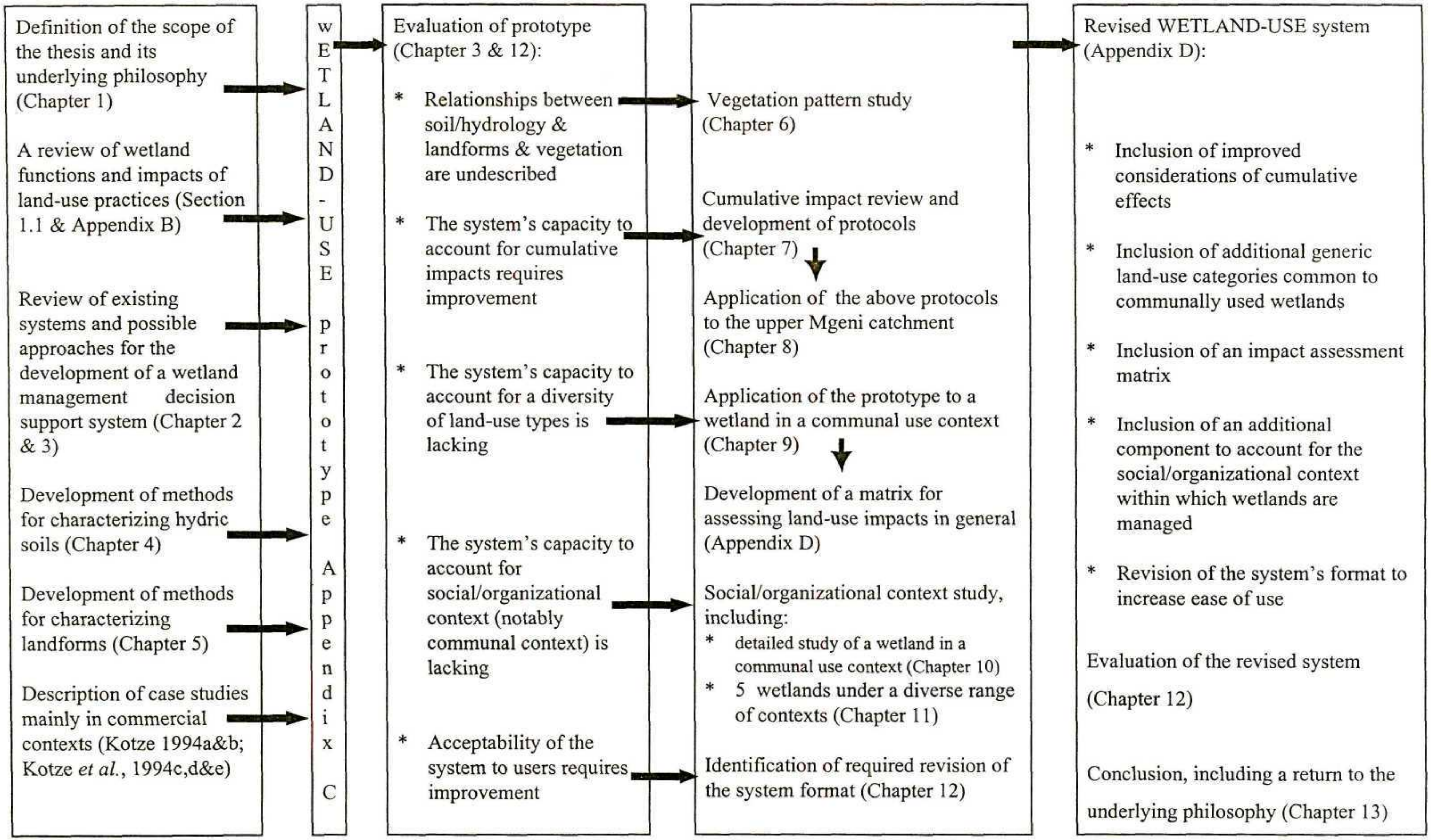


Fig 1.3 The logical sequence and inter-relationships of the different research components conducted for the thesis.

CHAPTER 2
CONSTRUCTION OF WETLAND-USE

2.1 Background to the chosen approach

Justification for the choice of a rule-based, expert system approach for developing a decision support system for wetland management

Knowledge in the environmental disciplines is scattered throughout various organizations and literature sources and a large proportion is not in a form suitable to be used directly for management or planning purposes. Consequently, the publication of scientific papers can no longer be regarded as a satisfactory end-product of research (Berliner, 1990). This is certainly true concerning knowledge about the response of wetlands to different land-use practices in South Africa. Furthermore, Smith (1993) emphasises that much of the information and knowledge of how wetlands function is of a qualitative nature.

Thus, there is a need to present this knowledge and expertise in a form which is easily accessible to managers. Modelling and, in particular, user-friendly expert system models are seen as an effective means of reaching this end (Starfield and Belloch, 1986). Expert systems have been developed for a wide range of natural resource management problems. In South Africa, these include those of: O'Keeffe *et al.* (1987) for classifying rivers according to their conservation status; Starfield *et al.* (1987) for predicting, on a qualitative basis, the effects of salinity fluctuations on the biota of Lake St. Lucia; Murphy (1988) for providing advice for decision makers undertaking preliminary environmental assessments of water-related resort developments in the South-Western Cape coastal zone; Berliner (1990) for determining suitable stocking rates for grazing herbivores and providing advice on bush clearing; and Bailey *et al.* (1993) for assisting with fire management decisions for Pilanesberg National Park.

An examination of systems designed specifically to provide wetland managers and planners with decision support was undertaken. This showed there to be numerous systems developed for evaluating wetland functional values (e.g. Wetland Evaluation Technique [WET]: Adamus *et al.*, 1987; Minnesota Wetland Evaluation Methodology [WEM]: US Army Corps of Engineers, 1988; and Method for the Comparative Evaluation of Nontidal Wetlands in New Hampshire: Ammann and Stone, 1991). Since it is necessary to account for wetland functions in order to meet the objectives of: (1) assisting decision makers in making land-use choices for wetland landscape units; and (2) for recommending how the given units should be managed, these techniques were of relevance to this study.

However, Maltby (1991) notes that "Wetland evaluation techniques are heavily biassed towards the developed world and especially to the United States. In particular, there is no account taken of human populations that rely on wetlands for immediate resource needs". This statement is confirmed by the fact that in a comprehensive review of wetland evaluation techniques, Adamus (1991) found that none of the methods were capable of assessing suitability of wetlands for particular uses, generating performance standards (e.g best management practices) or predicting the impact of particular uses. In the United States, such assessments (e.g. land-use suitability) are made using intensive site specific investigations and/or the best professional judgement. This is feasible as there are many wetland experts available to conduct assessments, and resources are less limiting for conducting such assessments. In South Africa, however, there is a lack of both wetland specialists and funding. In addition, as is the case in many developing countries, there is more use made of the natural resources provided by wetlands. Thus, the need for a wetland management decision support system is likely to be greater in South Africa than in the United States.

It should be emphasised, though, that the intention of WETLAND-USE is not to replace professional judgement and intensive site-specific investigations where they are required. Instead, it is designed to assist nature conservation and agricultural extension workers and other fieldworkers with general biological or agricultural training who are required to conduct assessments and give wetland management recommendations in their day-to-day tasks.

Agricultural and nature conservation extension services (who are the primary users for which the system is designed) were involved throughout the development of WETLAND-USE to ensure that the system addressed their most important management recommendation requirements. There was a strong consensus that these extension services lacked readily available information for making recommendations relating to wetland management decisions. Given this situation and the fragmented and generally shallow nature of the information about wetland management and land-use in South Africa, it was decided that a rule-based expert system approach would be the most feasible methodology.

What is an expert system?

An expert system may be defined as a system (usually a computer program) that exhibits, within a specific knowledge domain, a degree of expertise in problem solving that is comparable to that of a human expert, by exploiting a knowledge base and a reasoning mechanism (Guida and Tasso, 1989; Indignizio, 1991). Indignizio (1991) points out that while the computer and computer programming support the implementation and solution of any expert system, they are not the essence of expert systems. In fact, as illustrated by Indignizio (1991), one can develop expert systems and derive conclusions from them through a strictly manual approach. Expert systems of a kind, used by Chinese engineers for disseminating expertise concerning the construction of dams and waterways, were in existence several thousands of years ago. Indignizio (1991) contends that the single major factor in the construction of an expert system is the formation of the knowledge base or, more accurately, the formation of a model of the knowledge base. The primary task in expert system development, then, is to acquire and represent, in the knowledge base, the rules employed by a human expert in solving a particular problem (see following Section).

The basic process involved in using an operational expert system is that the user provides the expert system with information and receives expert advice. Internally, the expert system consists of two main components: the knowledge base containing the knowledge and the inference engine (reasoning mechanism) which draws conclusions (Fig. 2.1).

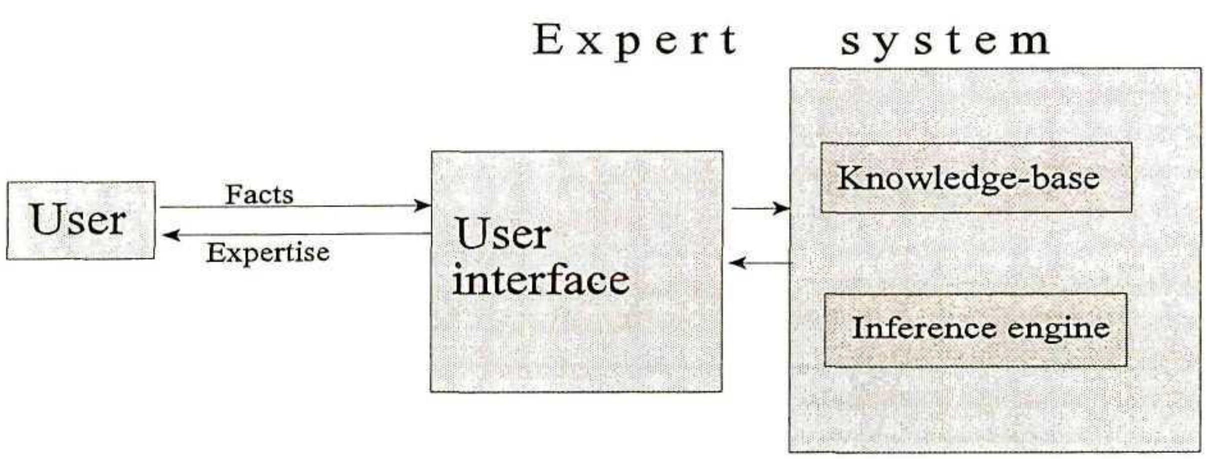


Fig. 2.1 The basic concept of an expert system (adapted from Kulikowski, 1989)

The user-interface facilitates the exchange of information and expertise. As the problems typically addressed have no mathematical solutions, expert systems usually rely on inference to achieve a solution. Thus, an essential requirement of the user-interface should be the ability to explain the system's reasoning so that it can be checked (Giarratano and Riley, 1989). An additional desirable feature of this component is the ability of the user interface to tailor the level of help support or guidance according to the level of experience or expertise of the user.

Important characteristics of expert systems (given by Forsyth, 1984; and Hayes-Roth, 1985) include:

1. restriction to a specific domain of expertise (e.g. the diagnosis of a particular disease);

2. the separation of facts and the inference mechanism (i.e. the knowledge is not hard coded into the deductive procedure);

3. the ability to explain their train of reasoning to the user in a comprehensible way;

4. the utilization of uncertain knowledge; and

5. the ability to solve problems quickly.

WETLAND-USE cannot, strictly speaking, be considered an expert system because:

1. the knowledge base, although represented using a consistent format, is not separated from the inference engine, and both are part of a single unit; and

2. there is certainly no single expert for the problems that are being addressed in this study. Although this is not an obligatory requirement of an expert system, it is characteristic of most expert systems. Even when the chosen knowledge domain was broken down into sub-problems, identifiable experts were often not found. Thus, a lot of the knowledge base was derived through synthesising literature information and modifying components from existing wetland evaluation models, primarily WET (Adamus, *et al.*, 1987).

However, a general expert system approach was adopted for the development of WETLAND-USE, the knowledge being represented in the form of "if-then" rules, with the reasoning clearly displayed. The knowledge is represented in such a way that it can be readily incorporated into an expert system shell. The primary sources of knowledge for deriving the knowledge-base for WETLAND-USE were the scientific literature (see Appendix B) and consultation with experts.

Constructing an expert system

Expert systems are constructed through a process termed knowledge engineering which is executed by a knowledge engineer. The term knowledge engineering was coined by Feigenbaum (1980) and refers to the task of accumulating information from a human expert or other source (knowledge acquisition) and coding it into a knowledge base as a precise set of facts and rules (knowledge representation) (Giarratano and Riley, 1989). An iterative process is characteristically involved in the development of an expert system (Fig. 2.2).

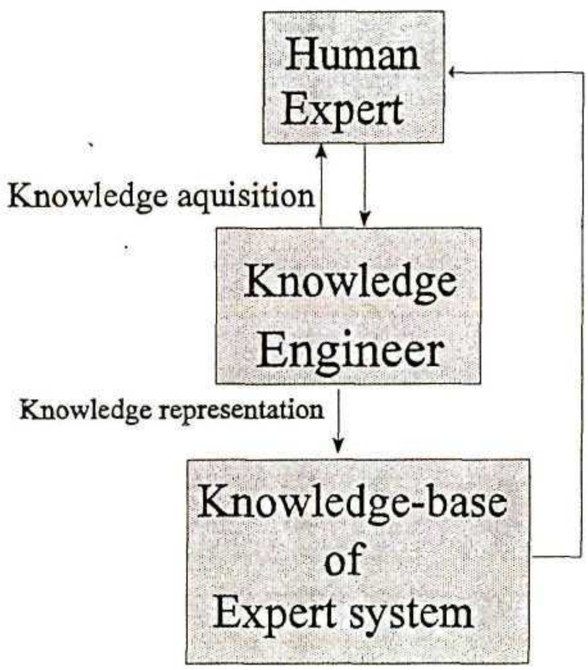


Fig. 2.2 Development of an expert system (adapted from Giarratano and Riley, 1989)

The knowledge engineer begins by establishing a dialogue with the human expert in order to elicit the expert's knowledge. This step, which often proves considerably more problematic than it appears, may be achieved using several means (e.g. simply asking the experts to explain how they reach the given conclusions or asking them to proceed through the decision making process of a series of examples) (Forsyth, 1984; D'Agapeyeff, 1989).

Next, the knowledge engineer codes the knowledge explicitly into the knowledge base. The expert then evaluates the expert system and gives a critique to the knowledge engineer who revises the system. This process iterates until the system's performance is judged to be satisfactory by the expert (Giarratano and Riley, 1989). Where literature is the primary knowledge source, this iterative process is not possible. However, comment concerning specific sections of the model was sought from specialists in the following fields:

1. land-use assessment,
2. grazing management,
3. water quality management,
4. wetland-dependent species,
5. soil conservation,
6. impact assessment,
7. goal-maintenance systems, and
8. social assessment.

The feed-back generated by their appraisals of the relevant sections of the model was used in subsequent revisions.

An expert system often starts as simple and incomplete, and through this iterative process evolves into the more organized and complete final system (Waterman, 1986). Thus, even a very "naive" system, used to generate feedback for directing further construction of the knowledge base, may be extremely valuable. This approach was used in the study, with the initial system being represented by the demonstration prototype and the more complete, but not yet finalized, system by the full prototype (see Section 2.2).

Depth of knowledge representation

Knowledge can be represented at different levels or depths, depending on the degree to which causal relationships are accounted for (Berliner, 1990). Deep knowledge, which is mechanistic in nature, is concerned with insight into mechanisms and processes. In contrast, shallow knowledge is built from empirical data and is not concerned with explaining why something occurs (Giarratano and Riley, 1989). For example, it is possible to build a medical expert system with shallow knowledge as follows: IF you have a fever THEN take an aspirin.

The system does not describe the fundamental biochemistry of the body and why aspirin decreases fever but, nevertheless, is able to give useful advice. Shallow knowledge bases typically consist of a set of heuristic rules. An heuristic rule is a "rule of thumb" which may help in finding a solution but is not guaranteed to do so as a mathematical formula is guaranteed to find a solution. Heuristics are very important in expert system building because the problems that expert systems are best suited to solving are typically ill-defined such that an mechanistic solution does not exist or is too inefficient to be practicable. By contrast, heuristic rules are not well suited to representing deep causative knowledge (Coulsdon *et al.*, 1987; Giarratano and Riley, 1989).

Ways of representing knowledge

There are various ways of representing knowledge, including: production rules, frames and semantic networks. A production rule is of the type: IF A THEN B, where if precondition A is fulfilled then conclusion B is assumed to hold true (Ally and Combs, 1984). Each rule is identified by a name. Following the name is the IF part of the rule. The section of the rule between the IF and THEN part of the rule is called by various names such as antecedent or conditional part. Although frame-based systems are good at representing descriptive knowledge, production systems are often better for representing problem-solving expertise because experts tend to find that this formulation comes naturally to them (Rich, 1983). In addition, production systems are relatively simple to construct and new rules may be added to account for new situations without unduly disrupting the rest of the system (Murphy, 1988).

Knowledge representation based entirely on rules tends to become clumsy and difficult to manage in systems with very many rules (Berliner, 1990). Frames provide a means of organizing knowledge into separate structures. Each frame is centred about an object with properties of the object (or class of objects) occupying positions in the frame called slots (Rich, 1983).

Semantic nets comprise nodes which represent objects, concepts or situations and arcs which connect the nodes and express the relationship between the nodes (e.g. is-a, has-a) (Giarratano and Riley, 1989). Semantic nets lack a means of embedding heuristic information and, like any tool, they should not be distorted into a universal tool but should be used for things they do best, i.e. showing binary relationships (Giarratano and Riley, 1989).

2.2 The construction of WETLAND-USE based on the expert system development process

Four primary phases based on those of Guida and Tasso (1989) and Kulikowski (1989) were involved in the development of WETLAND-USE:

1. problem identification and conceptualization, and choice of the knowledge domain;
2. choice of modelling approach and technique;
3. demonstration prototype construction;
4. full prototype construction; and
5. revised prototype ("final system").

Phase 1: problem identification and conceptualization

The first phase involved identifying precisely the problem to be addressed (given in Chapter 1) and finalizing the main functional and technical specifications of the system. The problem to be addressed was chosen in close co-operation with the potential users of the system and its design was set to try and meet the requirements of the chosen problem (see Chapter 1).

Choice of the knowledge domain, which leads on directly from identifying the problem to be addressed, is a critical task in the development of an expert system (Prerau, 1989). One of the biggest pitfalls in expert system building is to choose a problem that is too broad to handle adequately (Waterman, 1986). The problem of wetland management is extremely broad. Consequently, it calls for a narrowing of the model's focus. In the case of the prototype system, this was been done by:

1. restricting the geographical area over which the model is assumed to be valid to the KwaZulu-Natal Midlands, which falls within the core study area (see Fig.1.2);
2. limiting the land-uses considered to some of those which are most common in the study area;
3. limiting the hydrological and ecological benefits considered; and
4. limiting the organizational/management context.

Although benefits considered remained the same, the scope was broadened to some extent when revising the prototype by:

1. including a wider geographical area (see Fig. 1.2), which encompasses portions of the Free State, Mpumalanga and KwaZulu-Natal provinces;
2. increasing the land-uses considered, notably by including land-uses associated with non-mechanized agriculture in communally used wetlands; and
3. adding social and organizational considerations, which were largely absent in the prototype.

Phase 2: choice of modelling approach

A fundamental question addressed in this second phase is whether or not an expert system approach is an appropriate means of solving the problem that has been identified. Some general guidelines may be followed in deciding this. First, there obviously needs to be an expert or expertise available for the identified problem. Second, if the expertise is not or will not be available on a reliable and continuing basis then there is a need to capture the expertise. If the domain of expertise is readily accessible and inexpensive there may be no need for an expert system (Prerau, 1989).

Third, if the information required for solving the problem is scattered across a wide range of fragmented sources, there is a need for consolidating it, as well as possibly providing advice on how best to access this information. An expert system approach is well suited to achieving this.

Fourth, the problem should preferably be solved with heuristics rather than algorithms. Problems solved with algorithms would be better handled by a system that uses conventional programming.

Fifth, the problem domain should be reasonably well understood, unless one of the primary reasons for constructing the model is to reveal knowledge gaps and prioritize future research. There are many poorly understood resource management problems where basic research would assist greatly in improving the decision making process. Nevertheless, decisions concerning these poorly understood management problems need to be, and are currently being, made. Decisions do not wait for the outcome of research but rather are based on "current wisdom" (Breen, 1992). The building of expert systems for these problems may appear futile, given the poor knowledge bases they will be using. However, even if they do not directly improve current management decisions, they will nevertheless still be of value in that the process of explicitly stating the assumptions on which the current management decisions are based, and which of these assumptions have adequately been demonstrated to be true, facilitates identification of the most important research priorities (Starfield and Bleloch, 1986; Berliner, 1990; Breen, 1992). This may assist greatly in directing future research efforts to those areas that are likely to yield the greatest returns.

Considering that: (1) in South Africa, wetland management information is scattered and not readily available; and (2) wetland management problems are poorly understood and better solved with heuristics than with algorithms, the decision was taken to build the prototype version of WETLAND-USE as a manual rule-based model that could easily be incorporated into an expert system shell. Smith (1993) recommends a rule-based approach for assessing the functions of wetlands because it makes use of qualitative information that is often the only type of information available and is compatible with the limited time and resources available for conducting assessments.

Phase 3: construction of the demonstration prototype

The main goal of this phase was to obtain an insight into the complexity of the system by focussing on a selected sub-problem, namely the land-use: planted pastures. This prototype also assisted in:

1. modifying and expanding the design identified in the first phase;
2. choosing descriptors; and
3. designing the output format of the model and its explanation and reasoning facility.

Phase 4: full prototype construction

According to Guida and Tasso (1989) the full prototype, although satisfying the functional acceptance criteria specified in phase 1, is not the final output since:

1. it has yet to be installed in the real operational environment but is operating in a laboratory environment;

2. it has only been tested with realistic data samples prepared by the system designers with the support of the domain experts and users (i.e. it has been verified but not yet validated in a "field situation"); and

3. it is still embedded in the development environment and is generally not as efficient and reliable as requested.

This was true for the WETLAND-USE prototype (given in Appendix C) and in Chapter 12 it is reported that application of the prototype in the field by users revealed important shortcomings in its layout and ease of use.

Phase 5: construction of the revised system

The evaluation and revision of WETLAND-USE were closely interlinked and were conducted in an iterative fashion (see Fig 2.3, which expands on Fig 1.3 with particular reference to evaluation of WETLAND-USE). The results of the various evaluations and how they were incorporated into successive revisions of the system are discussed in Chapter 12.

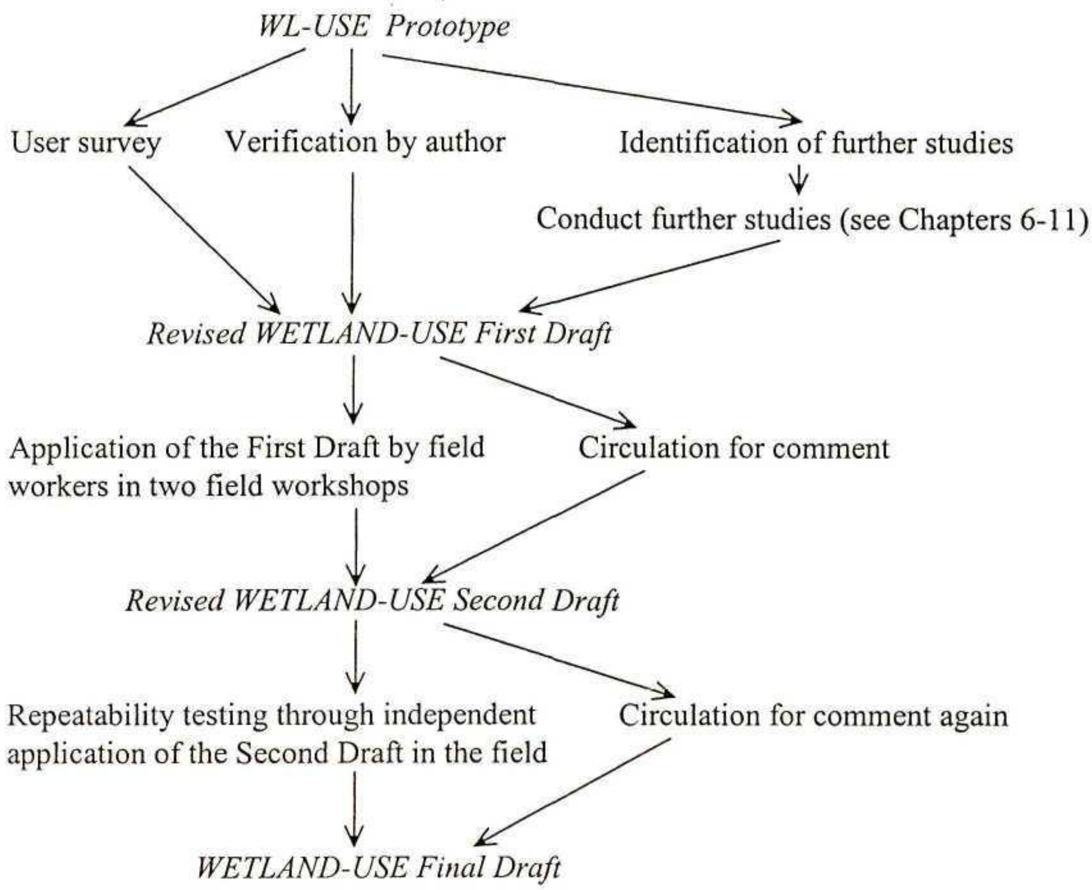


Fig. 2.3 Flow diagram showing the successive evaluations and refinements undertaken in revising WETLAND-USE

The revision of the prototype was undertaken by modifying existing components as well as by adding new components to the system, namely social/organizational assessment and goal maintenance components (see Appendix D, Part 2). It is important to note that the components in Part 1 are in a more advanced state of development as they have been used in an operational environment whereas the components in Part 2, which were added to the prototype, have been used only to a very limited extent in the field.

Once the prototype had been produced, the researcher was in a position to have a better understanding of the issues being addressed. This provided the basis on which to examine critically the system in relation to its underlying conceptual frameworks, an exercise which assisted in clarifying the system's various components and how they related to each other. This and the overall structure of WETLAND-USE are discussed in the following Chapter.

CHAPTER 3
THE CONCEPTUAL BASES AND DESIGN OF WETLAND-USE

3.1 Introduction

As elaborated on in Chapter 1, when a wetland is disturbed by humans (e.g. through drainage and crop production) the goods and services it provides are altered accordingly, with goods commonly being gained at the expense of services. The inter-relationships and feedback mechanisms between wetland users and the wetland and the stream of goods and services that it delivers are complex and multidimensional. In order to deal, on a conceptual basis, with these relationships and mechanisms it has been necessary to disaggregate them through the use of specific frameworks dealing with particular biophysical and social aspects. The following frameworks contribute to varying degrees to the conceptual bases for WETLAND-USE:

1. the pressure-state-perceptions-policy framework;
2. a patch dynamics/disturbance framework (the primary framework for representing the internal biophysical dynamics of the wetland);
3. economic valuation frameworks; and
4. a property rights framework.

These frameworks were aggregated to provide the overall conceptual basis for WETLAND-USE, a system for managing patch dynamics and disturbance of a wetland in order to accommodate, on a sustainable and equitable basis, the goods and services supplied by a wetland. The objectives of this chapter are the following.

1. Briefly outline the above frameworks.

2. Describe the overall design and individual components of WETLAND-USE.

3. Examine how the four primary frameworks underlying WETLAND-USE were incorporated into WETLAND-USE and, in the process, how they were integrated with the other frameworks.

3.2 An outline of the primary frameworks underlying WETLAND-USE

3.2.1 The pressure-state-perceptions-policy framework

The intervention of external organizations in the use of natural systems by local people was represented by a modification of the pressure-state-response framework, which follows a cause-effect-social response logic and was developed by the Organization for Economic Cooperation and Development (Hammond *et al.*, 1995). According to the pressure-state-perceptions-policy framework, management and use of a natural system generates pressures which result in modifications to the state of the system, and this in turn modifies perceptions. It is these perceptions which direct the formulation of policy, which in turn provides the principles guiding the regulation of management and use of the system (Fig. 3.1) (Rogers and Naiman, 1997). Policy is defined as a purposive course of action based on currently acceptable social values, followed in dealing with a problem or matter of concern, and predicting the state of affairs which would prevail when that purpose has been achieved (Hart, 1995).

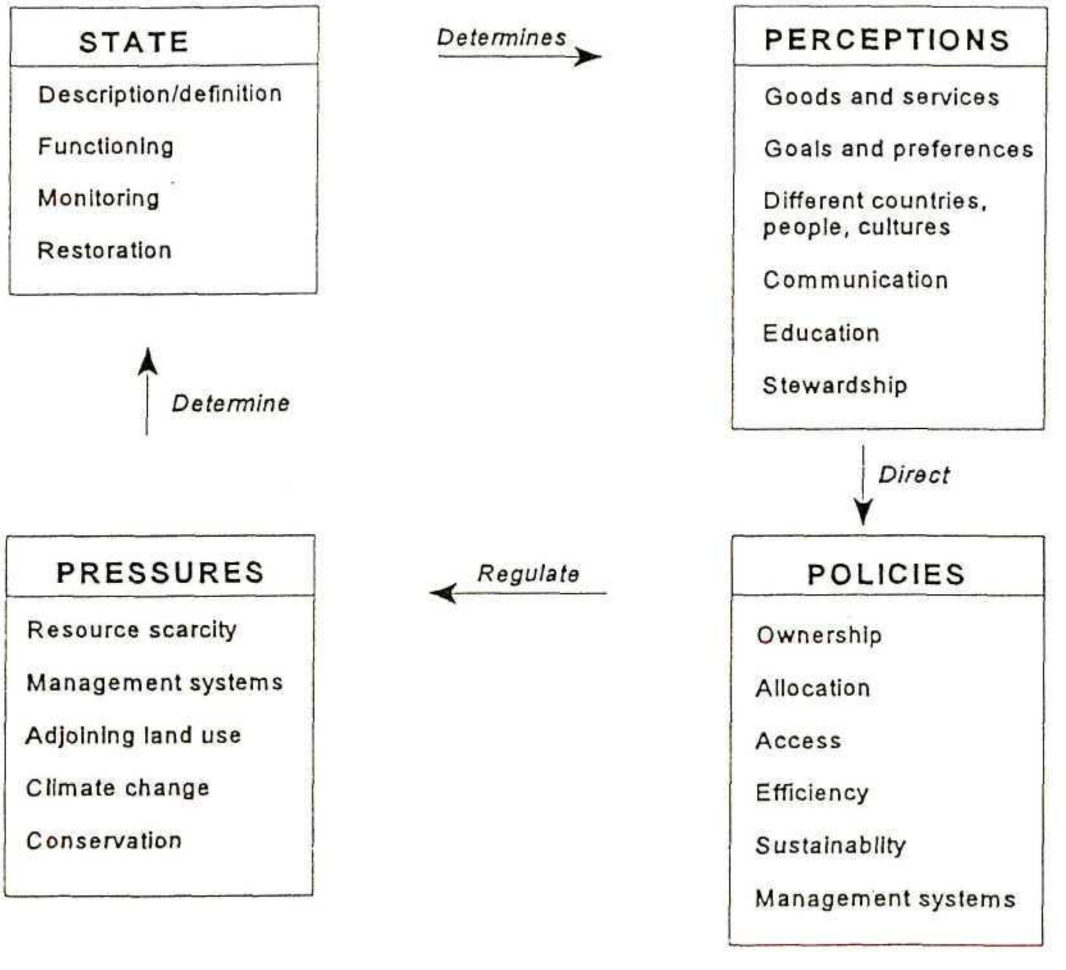


Fig. 3.1 Pressure-state-perceptions-policy framework (after Breen *et al.*, 1997a).

It is contended that it is not an overall one dimensional measure of "state" (e.g. ranging from totally degraded to pristine) that influences the perceptions of stakeholders but rather the flow of goods and services (and associated costs and benefits) that they observe to be delivered by a wetland. Thus, two further items are required that make goods and services explicit in the framework (Fig. 3.2). It should also be noted that the linkages (represented by the arrows) are considered to be just as important as the elements (represented by the boxes) as they describe how a particular element is influenced by a preceding one.

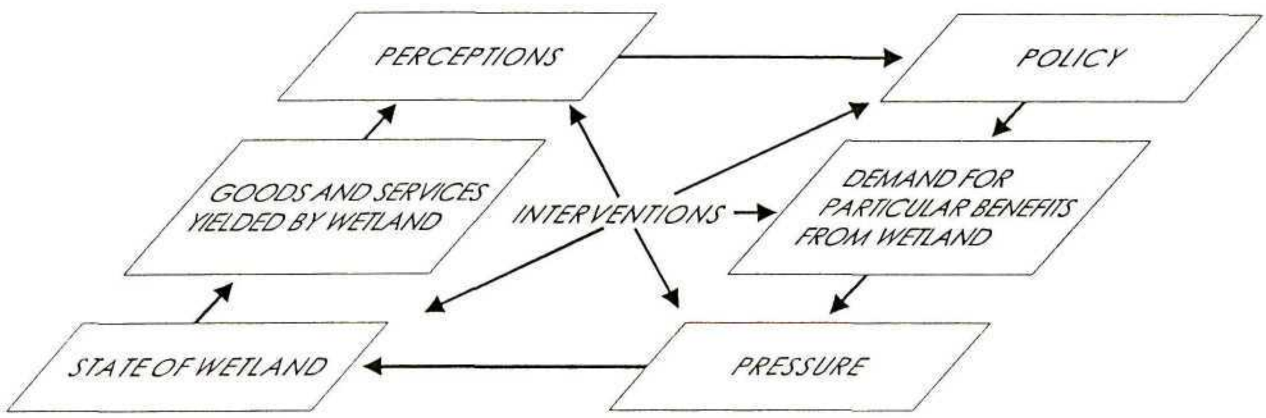


Fig. 3.2 Modified pressure-state-perceptions-policy framework.

The outside organizational influence on the pressure-state-perceptions-policy cycle may be described in terms of intervention in these different components. To intervene is to take a decisive role (which may or may not be considered intrusive) in order to determine events. As elaborated further in Section 10.2, in the above cycle there are five different forms of intervention based on the particular points at which intervention takes place (Fig 3.2). Interventions at point 1 influence the perceptions of users, primarily by alerting them to the impacts of particular land-uses on the stream of goods and services from a system, especially those which are less tangible, accrue remotely and/or after a long time. Interventions at point 2 and point 3 assist in the development of policy and influence the demand for particular wetland benefits respectively. Interventions at point 4 encompass regulations to influence how the demand for a particular wetland benefits is translated into type and level of use. Interventions at point 5 include physical measures (e.g. erosion control structures) to reduce the impact of a particular type and level of use that has been carried out. Interventions directly in the goods and services supplied by a wetland are not included in Fig. 3.2 as these are determined indirectly by influences on the wetland's state.

Pressure cannot be defined in isolation of the system under scrutiny. Depending on the internal structure of the system and its context, what is a high pressure for one system may be a low pressure for another system. For example, a disturbance of the soil in a wetland with soils having high erodibility may have a considerably greater pressure than an equivalent disturbance of a wetland with soils of low erodibility. Similarly, a given disturbance of a wetland may result in a higher pressure on the wetland if all of the wetland area in the surrounding landscape was disturbed than if it was not, owing to the interconnectedness of wetlands in the landscape (see Chapter 7).

Certain forms of pressure are commonly associated with particular socio-economic contexts. In the large-scale commercial context, wetlands are characteristically disturbed through dams and associated deep flooding and through mechanized cultivation involving drainage channels and the addition of fertilizers. In the small-scale, communal context dams are generally lacking and wetlands are characteristically disturbed through cultivation by hand without major artificial drainage channels and the addition of chemical fertilizers (see Chapter 9).

Wetland patches and associated processes have a perceived value as a result of the goods and services that they deliver, which varies according to the nature of the wetland. This also varies according to the context of those viewing the wetland, which may be grouped broadly into:

1. local people with rights of use, including private tenure (large-scale commercial farmers) and communal tenure (subsistence/small scale farmers) situations;
2. downstream beneficiaries; and
3. society in general, considered at provincial, national and global levels.

The same patches may be perceived and valued very differently depending on from which of these contexts it is being observed, and on additional factors such as the economic and educational status of users. It is therefore necessary to accommodate different users' perceptions. A permanently saturated patch of *Phragmites australis* reeds, for example, is generally of little value to a commercial farmer but in a communal subsistence context is often an important source of roofing material. Direct users of the wetland are likely to vary according to the degree to which they are informed of the impact of use on the services and future goods provided by the wetland rather than being motivated primarily by goods to be derived in the short term. Again, this may depend on a host of factors.

Policy is a purposive course of action based on currently acceptable social values, followed in dealing with a problem or matter of concern, and predicting the state of affairs which would prevail when that purpose has been achieved (Hart, 1995). Smith (1996) indicates that the fundamental issues of policy are essentially those posed by Lasswell (1950) for the study of politics, namely: who gets what, when and how? At the level of an individual one has one's own personal values that influence actions relating to a particular concern (e.g. wetland use). On a collective basis, a group of people may have shared values. There is plenty of empirical evidence to show of individuals, sharing agreed-upon guiding principles, and developing policy for their group. The larger and more heterogenous the group, however, the less personal involvement individuals are likely to have in the development of policy for the group (i.e. policy becomes more "remote") and the less likely there is to be full agreement on the policy. Group members may nonetheless be guided by the policy by virtue of having broad support for its principles and out of a sense of loyalty to the group, but not necessarily because they agree exactly with all the details of the policy. Local "policy makers" have personal involvement with the specific wetland. In contrast, at higher organizational levels "policy makers" are spatially separated and more divorced from the wetlands for which they are developing policy. A wetland and its local users is not a closed system, and local policy development is also likely to vary greatly in the extent to which it is influenced by higher level policies.

The pressure-state-perceptions-policy framework is commonly used for characterizing situations at broad organizational scales. In this thesis, however, it is proposed that it may be applied at several different levels in the form of a nested hierarchy of interconnected pressure-state-perceptions-policy sub-systems (Fig. 3.3). As indicated in the previous paragraph, the extent to which the various levels are linked may vary considerably. The focus of this thesis is on the application of the framework at the local level. Nevertheless, it was necessary to give attention to how this lower level relates to higher levels in order to place the local situation in a broader context. As one moves from local to national, a wider range of contexts is likely to be encompassed and the emphasis of the particular elements will change. In many cases, wetland resource users and advisors operating at a local level are not aware of policies developed at a higher organizational level, even if their own guiding principles are similar or the same as those contained in the higher level policy. The temporal dimension may also be encompassed in the pressure-state-perceptions-policy framework through representation of repeating cycles. For example, a high pressure may result in a changed state, which is observed and alters the perceptions of users, and this in turn leads to a changed policy that ultimately results in a reduced pressure.

The local organizational context obviously has an important influence over the development of policy. By way of example, the situation at Blood River is contrasted with that at Mbongolwane in Chapter 11. Blood River includes over 50 different land-owners managing their own privately-owned wetland portions largely independently, with very little co-operation in most spheres of management. Mbongolwane, a communally used wetland, has a tradition of consensus and a history of operating rules and conflict resolution that is administered through a tribal organizational hierarchy, albeit with many inherent problems (see Chapter 10 and 11). Thus, even though the level of formal education of the users is much lower and the number of wetland users far greater than at Blood River, mutually agreed on explicit policy is likely to be more readily developed for Mbongolwane.

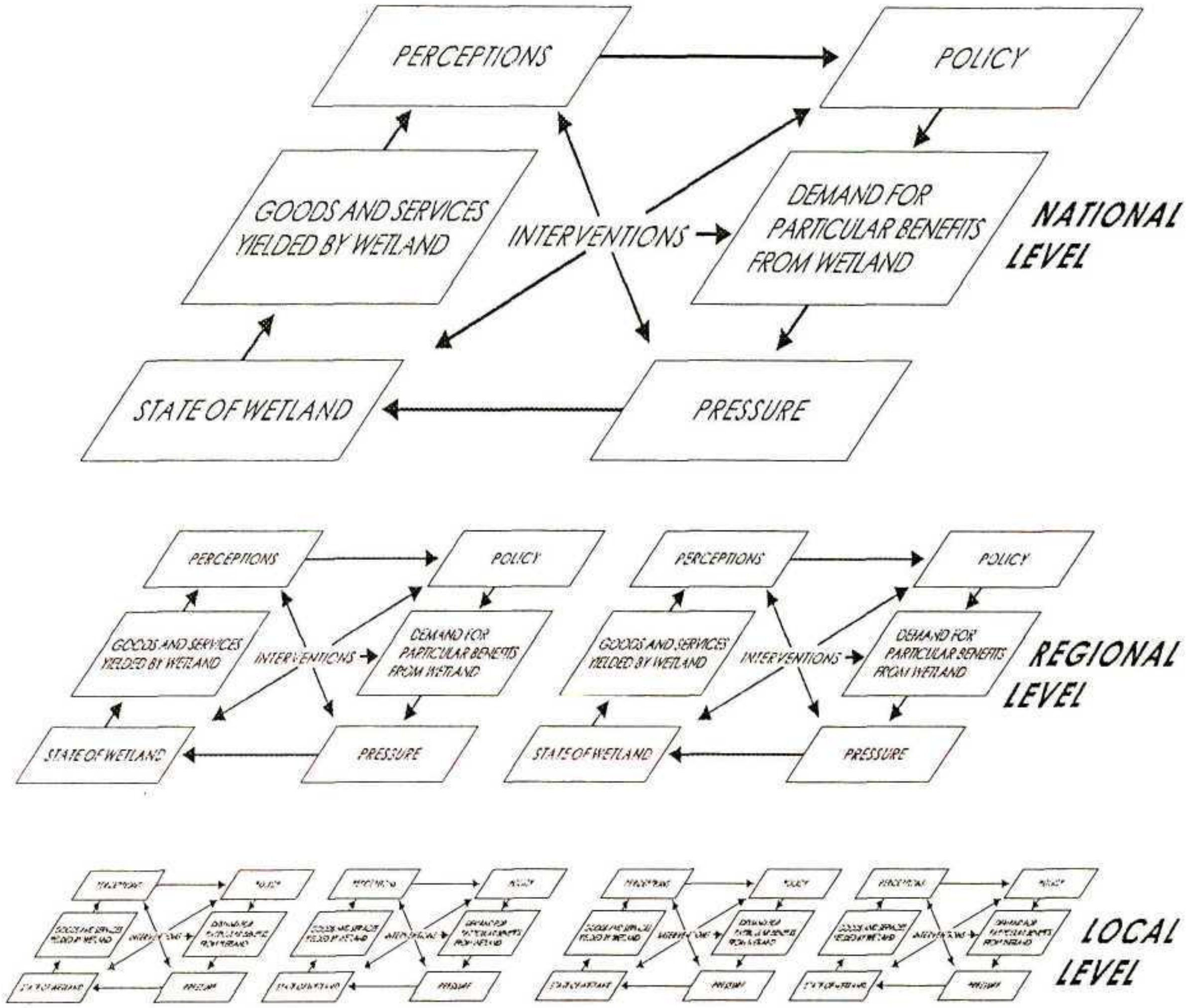


Fig. 3.3 A nested hierarchy of pressure-state-perceptions-policy frameworks.

The pressure-state-perceptions-policy framework includes both biophysical and social elements, and is more inclusive than the other frameworks to be discussed. Although this is at the expense of depth of those elements represented, it provides a "skeleton" on which to hang other frameworks, giving depth to the particular elements and linkages below which they are positioned.

3.2.2 Patch dynamics and disturbance theories

In the United States and elsewhere, there has recently been a shift in biological conservation and management from the conservation of single species and their habitats toward conservation and management of the interactive networks of species and large-scale ecosystems on which species depend (Ostfeld *et al.* 1997). The ecosystem approach offers an effective way to conserve poorly known species and habitats as there are too many species to deal with them individually (Meyer, 1997;

Franklin, 1993). Several authors (e.g. Pickett and White, 1985; Ostfeld *et al.*, 1997; Rogers,1997a) argue that the linked concepts of patch dynamics and disturbance theory provide useful conceptual frameworks for understanding ecosystem processes.

Patch dynamics theory

A patch is a spatial unit which differs from its surroundings in nature and appearance (Kotliar and Wiens, 1990). Patches vary in size, shape, internal homogeneity, boundary conditions and thus discreteness as well as in their spatial configuration relative to other patches. On different scales, a patch may be a continent, a wetland, or a pool in a wetland. An array of patches may be seen as a mosaic at a particular scale. Recognition that patchiness changes in time leads to the concept of "patch dynamics" and that patches may be nested within one another leads to the concept of "hierarchical patch dynamics" (Rogers, 1997a).

Ostfeld *et al.* (1997) suggest that the concept of patchiness may effectively link new views in ecology to new approaches in conservation. Although, as yet patchiness has no complete or unified theory it can serve as a conceptual tool to accommodate several important aspects of ecological systems. Patchiness makes the spatial matrix of ecological processes more explicit; it highlights the fluxes of organisms and materials; and encompasses the dynamics of entire mosaics, their composite parts and the edges/ecotones of these parts; and is applicable to various scales (Forman and Gordon, 1986; Ostfeld, *et al.* 1997). Because of the patchy distribution of wetlands (see Begg, 1988) and many wetland associated biota (Sjögren, 1991; Gibbs, 1993) as well as the characteristically dynamic nature of many wetlands (Rogers, 1997b) a patch dynamics framework has specific relevance to wetlands.

Although the terminology used is somewhat different, the general concept of patch dynamics is certainly not confined to the discipline of ecology and has been used for some time by soil scientists and geomorphologists. Strahler and Strahler (1973), for example, outline a framework for the analysis of soils and landscapes which is expressed in the following terms.

1. Systems (patches) possess boundaries, either real or arbitrary.
2. Inputs and outputs of energy and matter cross system boundaries.
3. Systems possess pathways of energy transport and transformation associated with matter within the system.
4. Within systems, matter may be transported from place to place or have its physical properties transformed by chemical reaction or change of state.

5. Open systems tend to attain a dynamic equilibrium where rate of input equals rate of output. However, where input or output rates change the system tends towards a new dynamic equilibrium state, with the transitional state depending on the sensitivity of the system.
6. The greater the storage capacity within the system for a given input, the lower the sensitivity of the system.

It is proposed that the concept of patch dynamics also assists in linking ecological and social elements for several reasons. Human activities in industrialized and developing countries are continuing to impose patchiness on landscapes by dividing and fragmenting contiguous natural areas. Social factors are patchily distributed. For example, in South Africa, as in many developing countries, one finds stark and sudden spatial changes in socioeconomic conditions. Property rights, even within a similar socio-economic context, are spatially patchy and often shifting in time. Furthermore, there is no fundamental general difference in terms of the contemporary template between wetlands in different social contexts (e.g. communal areas and private areas). Thus, there is no apparent reason why the schemes for defining patches should not be equally applicable to wetlands in a range of social contexts.

Our ability to detect environmental heterogeneity is partly a function of the scale of the investigation. Scale encompasses both "grain", the size of individual units of observation, and the "extent", the overall area included in the study. The same terminology can be used to describe organism response. The grain of organism response is the finest scale at which an organism responds to patch structure while the extent is the largest scale of heterogeneity to which an organism responds. The notion of scale has always been intuitive to ecologists but its formal treatment has been largely restricted to hierarchy theory (see O'Niel *et al.*, 1986; Rogers and Bestbier, 1997). Addressing scale in an explicit manner is also seen as one of the means of linking frameworks dealing with biophysical and social elements respectively. For example, conventional economics characteristically deals with short time horizons (years to decades) while patch dynamics would also encompass much longer time scales (e.g. decades to millennia).

To manage patch structure and dynamics it is necessary to recognize the determinants of patch structure in a given landscape. The geological template defines the physical and chemical resource base of ecosystems, which are reworked over time by the primary physical forces of wind, water, gravity and heat and by biological processes (e.g. biomass accumulation) and interactions of organisms (including life history, population and community processes) to generate a contemporary template (Rogers, 1997a). Human activities are commonly an additional factor having an important influence on patch structure and dynamics, and managers are increasingly required to manage for changes in heterogeneity introduced by human activities.

Two approaches that have patchiness as a central concept in their frameworks are: metapopulation theory and landscape ecology (Wiens, 1997a). Metapopulation theory views a population as a set of spatially separated sub-populations that are linked by dispersal. According to metapopulation theory local populations may suffer extinctions, but under the right conditions, colonization from other sub-populations will re-establish populations in those patches before all of the local sub-populations become extinct (Gilpin and Hanski, 1991; Hanski and Gilpin, 1997)[1].

Landscape ecology emphasises the spatial structure of entire landscape mosaics, and is frequently practised at broad spatial scales. Its distinguishing feature as a discipline, however, is the focus on explicit spatial patterns and interactions, which is applicable to any scale of investigation (Wiens, 1997a). Although landscape ecology has no well-defined theoretical framework, the structure of a landscape mosaic and the response of organisms to that structure are commonly described within four themes: patch quality, boundaries, patch context and connectivity. It is important to stress that landscape structure is organism specific (e.g. what is a highly fragmented landscape to one kind of organism may be relatively homogenous to another) (Wiens, 1997b).

Disturbance theory

A disturbance is any relatively discrete event in time that disrupts ecosystem, community or population structure and changes resources, substratum availability, or the physical environment (Pickett and White, 1985). This is a purposefully generalized definition, and matters of scale and process will have to be specified in each case as the level of disturbance described relates to the spatial and temporal scale of observation. Several variables (given in Pickett and White, 1985) can be used to measure a disturbance regime, including:

* area disturbed;

* spatial distribution (in relation to geographic, topographic and environmental gradients);

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[1] Although several variations on the metapopulation model have been described, general conditions for metapopulation persistence are that: local breeding populations occupy relatively discrete habitat patches; no local population is so large that its expected lifetime is long relative to the metapopulation as a whole; population dynamics are asynchronous among local patches; and habitat patches (i.e. sub-populations) are not so isolated that recolonization of empty, suitable patches is prevented by distance alone (Hanski and Gilpin, 1997).

* frequency (mean number of events per time period);

* intensity, referring to the physical force of the event per area per time (e.g. heat released per area per time period of fire);

* synergism (effects on the occurrence of other disturbances); and

* severity (of impact on the organism, community, or ecosystem).

A descriptor not included by Pickett and White (1985) is the timing of the disturbance (e.g. in relation to phenological or hydrological cycles), which may have important consequences for the outcome of the disturbance.

Disturbance theory also includes a description of the parameters that respond to disturbance. These include: system structure, which refers to the amount and deposition of biomass relative to the substratum and the degree of connectedness of the biomass to the substratum; the amount of resources available to the organisms at a particular site; life history strategy, which refers to the genetically determined rate of growth, allocation of assimilate, structure, and timing of life cycle events of organisms; competitive abilities of the involved organisms; and the landscape composition and configuration (Pickett and White, 1985).

Although no coherent disturbance theory exists, two major hypotheses are current in the literature on disturbance (Peet *et al.*, 1983; Pickett and White, 1985). The first is the intermediate disturbance hypothesis (see Connell, 1978; Grime, 1979) which states that species richness will be greatest in communities experiencing some intermediate level of disturbance. The second hypothesis states that where disturbance recurs more frequently than the time required for competitive exclusion, richness should be maintained (Huston, 1979). Both of these statements leave much unspecified (e.g. what is considered to be a "high" level of disturbance) (Pickett and White, 1985).

Disturbance theory, together with a patch dynamics framework, assists in characterizing (in biophysical terms) the nature of a particular use of a wetland (i.e. the pressure) and how this in turn affects the nature or state of the of the area disturbed. It is focused on biophysical factors and does not deal with the socio-economic context and consequences of particular anthropogenic disturbances. In other words, it does not deal with questions encompassing perceptions and motivations that lead to a particular use (and associated disturbance) nor does it deal with how the consequent change of biophysical state affects the value to humans of a particular disturbed area. For these questions to be addressed requires disturbance considerations to be embedded within a socio-economic framework/s (see later discussions). Nevertheless, factors affecting the internal nature and dynamics of patches will also influence the choice of land-use options. Hydrology, which is the primary determinant of the internal functioning, structure and composition (e.g. the assemblage of plants it supports) of wetland patches, in turn also determines the resources a particular patch would supply without major anthropogenic modifications to the system. For example, *Phragmites australis*, which provides an important source of thatch material in particular social contexts, generally occurs in patches subject to permanent inundation or soil saturation. Internal dynamics factors will also determine the degree to which a patch will need to be modified (which is a fundamental component of the pressure applied to the wetland) in order to carry out a particular agricultural or other development. For example, in order for ryegrass to be cultivated in a permanently saturated patch it would require extensive modification because ryegrass has a low tolerance to anaerobic soil conditions, while its cultivation in a temporarily saturated patch would require considerably less modification.

3.2.3 The economic valuation of wetlands

Choices between alternative uses of natural areas frequently have to be made (WETLAND-USE is designed to assist in this type of choice). Should a given wetland area, for example, be drained and converted to cropland, or should it be maintained in its natural state? When an individual or group chooses among alternative uses of a natural area, they indicate (at least implicitly) which alternative is deemed to be worth more (Goulder and Kennedy, 1997). As many of the services delivered by natural systems are commonly not accounted for, these systems are often undervalued (Costanza *et al.*, 1997; Daily, 1997). Philosophical bases and empirical frameworks for assessing values of natural areas are required in order to address this situation. The philosophical bases provide the means to articulate what constitutes the source of value, and empirical frameworks provide techniques for the measurement of value, as defined according to the chosen philosophical bases.

Two contrasting philosophical bases for valuing nature can be identified. The intrinsic rights approach puts all other living things on a moral plane comparable with that of humans. In contrast, the utilitarianism approach values natural areas insofar as they confer satisfaction to humans. Utilitarianism does not rule out the possibility of making substantial sacrifices to protect and maintain other living things. However, it asserts that we can assign value (and therefore help other forms of life) only insofar as humans take satisfaction from doing so (Goulder and Kennedy, 1997). Conventional economics endorses the utilitarianism approach. Economics is the study of how, with or without the use of money, scarce resources are allocated to produce, distribute, and consume various commodities (goods and services) over time among various groups of people (Leitch, 1983). In economics, wetlands are viewed as composite assets that, through their functioning, provide many different goods and services which are of benefit to humans.

Economic values related to biological systems can be categorized according to their underlying motives. Common components of total economic value are motivated by current direct and indirect use, possible future use, and existence value (Fig 3.4) (Pearce and Turner, 1990; Turner, 1991). Direct values refer to the tangible outputs or products (e.g. crop sales from a drained wetland) that directly benefit humans. Indirect benefits derive from the functioning of natural systems (including enhancement of water quality, erosion control, streamflow regulation and maintenance of biotic diversity) and result in the indirect support and protection afforded to people, economic activity and property (Turner, 1991). Option values concern possible future use. An option value is an expression of preference for the preservation of a certain environment against some probability that the individual(s) will make use of it at a later date (Leitch and Shabman, 1988). Option not to foreclose on access to the resource includes the popular perception of biodiversity as a future source of new pharmaceuticals. Existence value is the value placed on an environmental resource which is apart from any actual or potential use of the good (Pearce and Turner, 1990). In other words it derives from the sheer contemplation of the existence of the resource (Goulder and Kennedy, 1997).

While ecological goods and services are not entirely synonymous with direct and indirect benefits respectively, goods are by definition of direct benefit to users and most services are of indirect benefit in that they do not require the active involvement of the recipient. When a wetland is developed (e.g. drained for crop production) it provides a completely different set of goods and services: direct benefits are often gained at the expense of indirect benefits. The valuing of ecosystem services is complicated by the fact that many services are not directly expressed in market prices and are positive externalities. The flood control, water quality enhancement, and habitat provision services provided by wetlands are usually external to the parties involved in the market decision as to whether and at what price a habitat will be sold. As a result, natural areas tend to be sold too cheaply in the absence of outside intervention since the value of these services is not captured in the price.

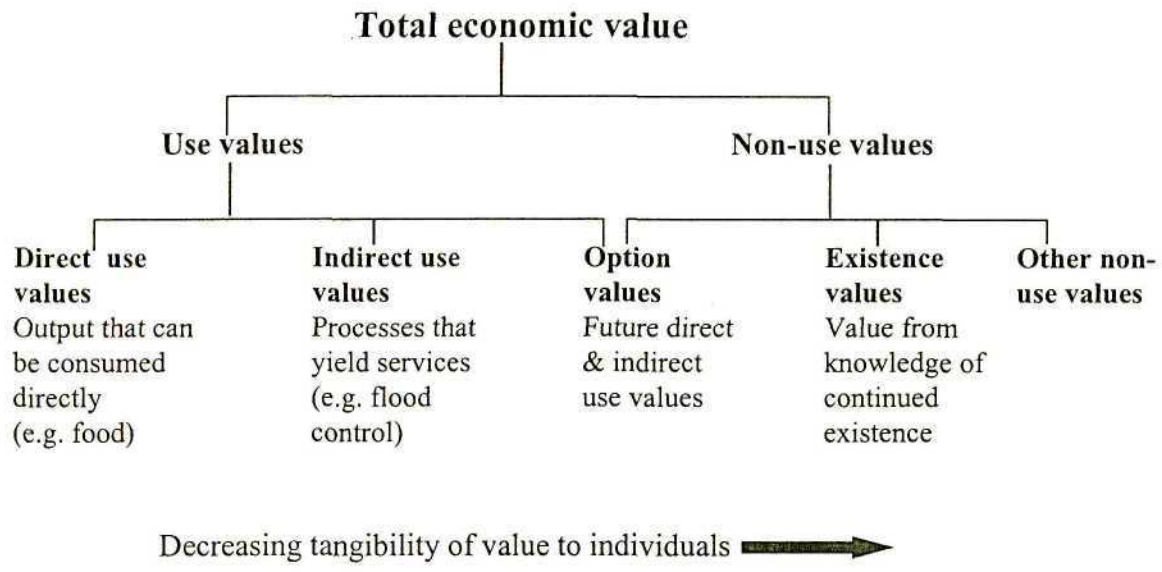

Fig. 3.4 Components of total economic value of biological resources (after Turner, 1991; and Pearce and Moran, 1997).

Various empirical methods are available to determine the magnitude of the different categories of value. These may be classified as "direct" or "indirect"[2]. Nearly every method assumes that the value of a given natural amenity is revealed by the amount people are willing to pay or sacrifice in order to enjoy it. Willingness to pay for a given good or service (including people's actual payments in market transactions, as well as more indirect measures such as hypothetical markets) is therefore regarded as the measure of satisfaction. It is important, however, to distinguish between marginal and total value associated with the willingness to pay for particular goods and services (Goulder and Kennedy, 1997). Economists regard the prices that people are willing to pay as indicators of marginal value, which refers to the value they place on the last unit purchased. For example, consider what someone would be willing to pay for residential water in a given month. He/she is likely to pay a relatively large sum for the privilege of consuming the first cubic metre, as forgoing it would deprive him of even the most fundamental uses of water, notably drinking. The next cubic metre, which would allow additional opportunities (e.g. an occasional shower), is unlikely to be worth as much. Thus, the marginal value

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[2] Direct methods measure the monetary value of environmental gains (e.g. enhanced water quality or improved scenic views). Examples of such methods include: the use of market prices (e.g. to value the service a wetland provides as habitat for commercially harvested fish); the travel cost method, where the time and money spent travelling to a particular site is used as a proxy for willingness to pay; and contingent valuation methods, where a hypothetical market is created and decisions are contingent upon this market, and people are asked what they are willing to pay for a benefit. (See Oellermann *et al.* (1994) where contingent valuation methods were applied to Wakkerstroom.) Indirect methods include: the least cost alternative to replace a good or service (notably water quality enhancement) which is used as a proxy for economic value; and damage cost avoided analysis, where a wetland service (notably flood attenuation) can be valued in terms of the cost of property damage which would occur if the wetland were no longer providing the service (notably flood attenuation).

of water, the amount that one is willing to pay for each successive increment, falls steadily. Many real-world circumstances involve the actual or proposed alteration or loss of *part* of a natural area. Thus, it is often more important to know the change or loss of ecosystem value associated with such loss than to know the total value of the entire original area. Even if the delivery of a service is independent of area (counter to fact), the loss of value associated with the service yielded by a particular natural area may depend (on economic grounds) on how much of the total area is extant (Goulder and Kennedy, 1997).

Benefit-cost analysis provides a framework for determining the net benefits associated with a particular project or development. Traditional benefit-cost analysis gives the same ethical status to every person's valuation. Although the key role of benefit-cost analysis in the valuation of ecosystems is acknowledged, Goulder and Kennedy (1997) point out that fundamental issues of fairness and distribution are ignored. Thus, benefit-cost information needs to be accompanied by a recognition of the distribution of benefits and costs, both across the current generation and between current and future generations. Furthermore, the translation of some consequences in benefit-cost analysis is often neither well understood nor broadly accepted (Stewart *et al.*, 1997). Scenario-based Policy Planning (SBPP) provides a possible tool to assist in addressing such issues. This tool incorporates diverse and conflicting objectives into public policy evaluation in a systematic and coherent manner by providing a uniform framework for handling and comparing tangible and intangible goals of society without reducing these to monetary or similar terms (Stewart *et al.*, 1997). However, whatever tool is used several ethical questions need to be faced. Who decides how much weight should be given to the well being of future generations, as compared with that of the current generation? Should those more informed have more influence in decision making than those less informed? These questions cut to the centre of society and the relationship between organizations (including the state) and individuals.

Valuation ultimately refers to the contribution of an item to meeting a specific goal (i.e. a value is stated in relation to a goal being served). In conventional economics, a commodity is valuable to the extent that it contributes to the goal of individual welfare, as assessed by willingness to pay. Other goals, and therefore other values exist. Three broad goals relating to managing economic systems within the context of natural life support systems have been identified (Daly, 1992):

1. assessing and ensuring that the scale of human activities within the biosphere is ecologically sustainable;

2. distributing resources and property rights fairly, both within the current generation and between this and future generations (i.e. ensuring equitability); and

3. efficiently allocating resources as constrained and defined by items 1 and 2 above, and including marketed and non-marketed resources, especially ecosystem services.

Thus far the discussion has been on efficiency, and although methods for valuation relative to the efficiency goal are well developed, methods relative to the other two goals need much further development (Costanza and Folke, 1997). Within generation equity is dealt with later in the discussion on property rights. While the three goals are in some senses independent, it is useful to integrate them and their consequent valuations. Integrating multiple goals or criteria is complicated by the fact that there are no clear-cut, unambiguous, systematic solutions (Arrow and Raynaud, 1986).

Conventional economic valuation is based on a social decision-making rule sometimes referred to as "consumer sovereignty". This means that individual consumer preferences, whatever they happen to be and how they are formed, should determine relative value. This rule embodies the assumption that tastes and preferences are fixed and that the economic problem consists of optimally satisfying these preferences. Costanza and Folke (1997) identify a continuum of degree of preference endogeneity states. At one extreme, preferences are both fixed and given (i.e. stated preferences of individuals are accepted at face value as indicative of the individual's welfare). Further along the continuum, preferences may change but no attempt is made to change them in an explicit or systematic way as preferences are regarded as highly individual and there is no justification in environmentalists or anyone else telling individuals what there preferences should be. Still further along the continuum is the state referred to as "democratic preference change" where, so long as a democratic process, including safeguards for individual rights of people, is in place then questioning and criticizing individual's sincerely felt current preferences is acceptable.

If "democratic preference change" is considered acceptable, how should the three goals of sustainability, fairness and efficiency be integrated? In the conceptual model proposed by Costanza and Folke (1997) both economic models and ecological models are embedded in a larger social process that encompasses the setting and monitoring of goals. (This is essentially the structure of the pressure-state-perceptions-policy framework) Ostrom (1990) recommends that in order to operationalize democracy at least a two-tiered structure should be used. This is necessary in order to eliminate "preference inconsistencies" between the short term and the long term and between local and global goals. There must first be general, democratic consensus on the broad long-term goals of society. At this level "individual sovereignty" holds in the sense that the rights and goals of all individuals in society must be taken into account, but in the context of a shared dialogue and discussion aimed at achieving the broadest consensus possible. Once these have been developed they can be used to limit and direct preferences at lower levels so as to change local behaviours that are inconsistent with broadly agreed-upon goals.

The degree to which it is necessary to link an economics framework with a biophysical framework in order to quantify particular goods and services is likely to vary greatly depending on the particular goods and services. In the case of goods which are traded it is less likely to be important than the case of services, which do not have a direct market value. Least cost alternative and damage cost avoided analysis methods, which are characteristically used for valuing ecosystem services, require an empirical understanding of how and to what degree a wetland is delivering a particular service.

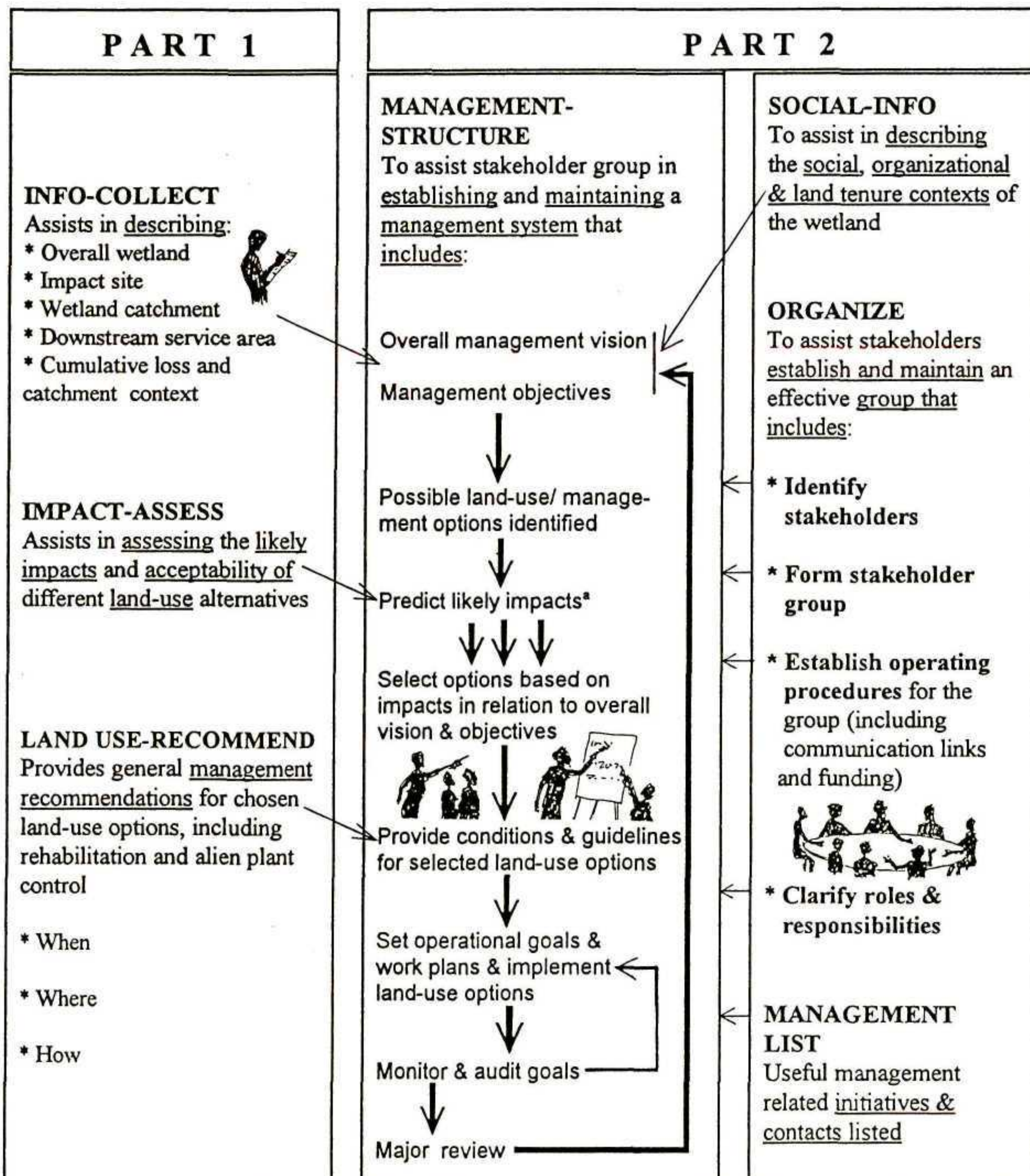
3.2.4 The property rights framework

A key component of the fair distribution of resources is characterizing the particular property rights regime/s that are operating. As elaborated on further in Section 10.2, this refers to the set of rights and obligations governing the access of an individual or group to the stream of benefits which can be derived from a resource (Turner, 1995). Under state property regimes, rights of ownership and management of the natural resources are vested in the state. Under private property regimes, these rights are vested with an individual "owner"; and under common property regimes they are vested with a specified group of people. In situations of open access no resource regime applies and no property rights are recognized (Turner, 1995). Contrary to the assumption of the "tragedy of the commons" model (see Hardin, 1968) common property rights accrue to specified groups or communities of people and sets of rules define use (Ciriacy-Wantrup and Bishop, 1975) and can therefore potentially provide an environment conducive to promoting sustainable and equitable use.

Although resources vary according to the degree to which they can be bounded (e.g. land for cultivation is readily bounded, while water is less readily bounded), property rights are by nature generally spatially orientated. This assists in relating them back to the biophysical nature of the wetland through means of a patch dynamics framework.

3.3 The overall design of WETLAND-USE

WETLAND-USE is designed to enable non-specialists to undertake wetland assessments and promote sustainable management among wetland users. Its application requires that they have introductory training and that they seek the input from specialized disciplines where necessary. WETLAND-USE comprises two parts, the first dealing primarily with the biophysical aspects of wetland management and planning and the second dealing with the social and organizational aspects (Fig 3.5).



* If the predicted impacts are high and the intention is still to continue with the proposed land-use option then a full impact assessment is required before proceeding. Guidelines for conducting such an assessment, which is beyond the scope of WETLAND-USE, are given in DEA (1992) and DEAT (1998a and b).

Fig 3.5 The overall structure of WETLAND-USE

3.3.1 WETLAND-USE Part 1

WETLAND-USE Part 1 is a rapid assessment system with three main components: (1) INFO-COLLECT, which guides the user in collecting useful information relating to the state of the wetland; (2) IMPACT-ASSESS, which assists in selecting appropriate land-use alternatives for a given wetland area by predicting the likely impacts of disturbances associated with the proposed land-uses on the state of the wetland and the indirect benefits it provides to society; and (3) LAND USE-RECOMMEND, which recommends how the wetland area be managed for the chosen land-use, in order to minimize impacts on the state of the wetland of disturbances associated with ongoing management. Part 1 may be used for three main purposes, requiring different components of the system (Box 3.1). The assumptions on which WETLAND-USE Part 1 is based and the scientific support for these are given in Appendix D, Part 1, pages 51-54.

Box 3.1: Purposes of WETLAND-USE Part 1	**Components required**
To provide an overall description of the wetland, which will serve as the basis for management and for identifying areas (e.g. an actively eroding head-cut) which require urgent attention	INFO-COLLECT (excluding its final sub-component: IMPACTSITE-INFO)
To assess the acceptability of a proposed land-use and assist in implementing Integrated Environmental Management (DEAT, 1998 a and b) at a pre-application and scoping level in relation to wetlands	INFO-COLLECT and IMPACT-ASSESS
To provide ongoing management guidelines for particular land-uses (e.g. stocking rate) or management problems (e.g. erosion)	LANDUSE-RECOMMEND

INFO-COLLECT prompts and guides the collection of data, including:

* the overall wetland site (e.g. extent of wetness zones; presence of anthropogenic disturbances) and assists in identifying management concerns in the wetland (e.g. erosion sites);

* the extent of cumulative loss of wetlands;

* land-use activities in the wetland's catchment;

* the extent of water use and floodable properties downstream of the wetland; and

* that portion of the wetland to which the proposed land-use is to be applied (e.g. data about the erosion hazard of the site).

Field procedures for gathering the above data are given by WETLAND-USE (See Appendix D, Part 1, pages 12-22).

IMPACT-ASSESS [3] assists in predicting the likely environmental impact and acceptability of the chosen land-use by assessing its likely effects on those wetland functions indirectly benefiting society, namely: water purification, streamflow regulation, flood attenuation, erosion control, ecological (biodiversity support), and global climate stabilization (through their function as carbon and sulphur sinks). IMPACT-ASSESS provides a set of principal general factors that are considered in characterizing land-use impacts (Box 3.2), which were derived from a review of the literature (see Appendix B) and wetland valuation systems and were designed for rapid assessment by extension workers.

IMPACT-ASSESS provides guidelines for determining the acceptability of generic land-use categories (e.g. planted pastures) for the specific conditions at a given wetland. "Threshold levels" are given for key descriptors (e.g. erosion hazard) beyond which the land-use is considered likely to have an unacceptably high impact on the indirect benefits of the wetland. These levels, which are based on the literature and expert opinion, assume features of particular land-uses (e.g. crop production involves wetland drainage and extensive and frequent disturbance of the soil). The thresholds vary according to land-use category. For example, crop production has a lower erosion hazard threshold than perennial planted pasture production, largely because of the fact that in crop production the soil is disturbed considerably more frequently than perennial pastures.

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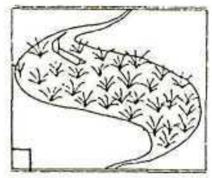
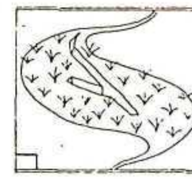
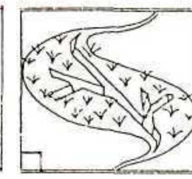
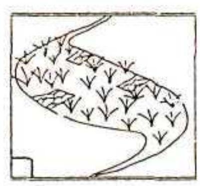
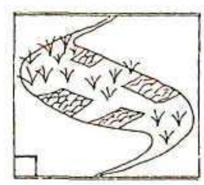
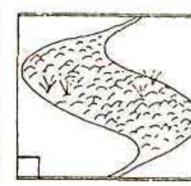
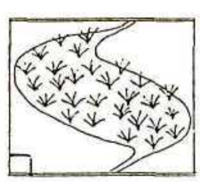
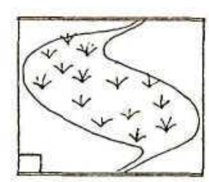
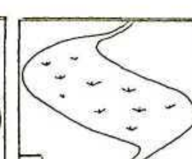
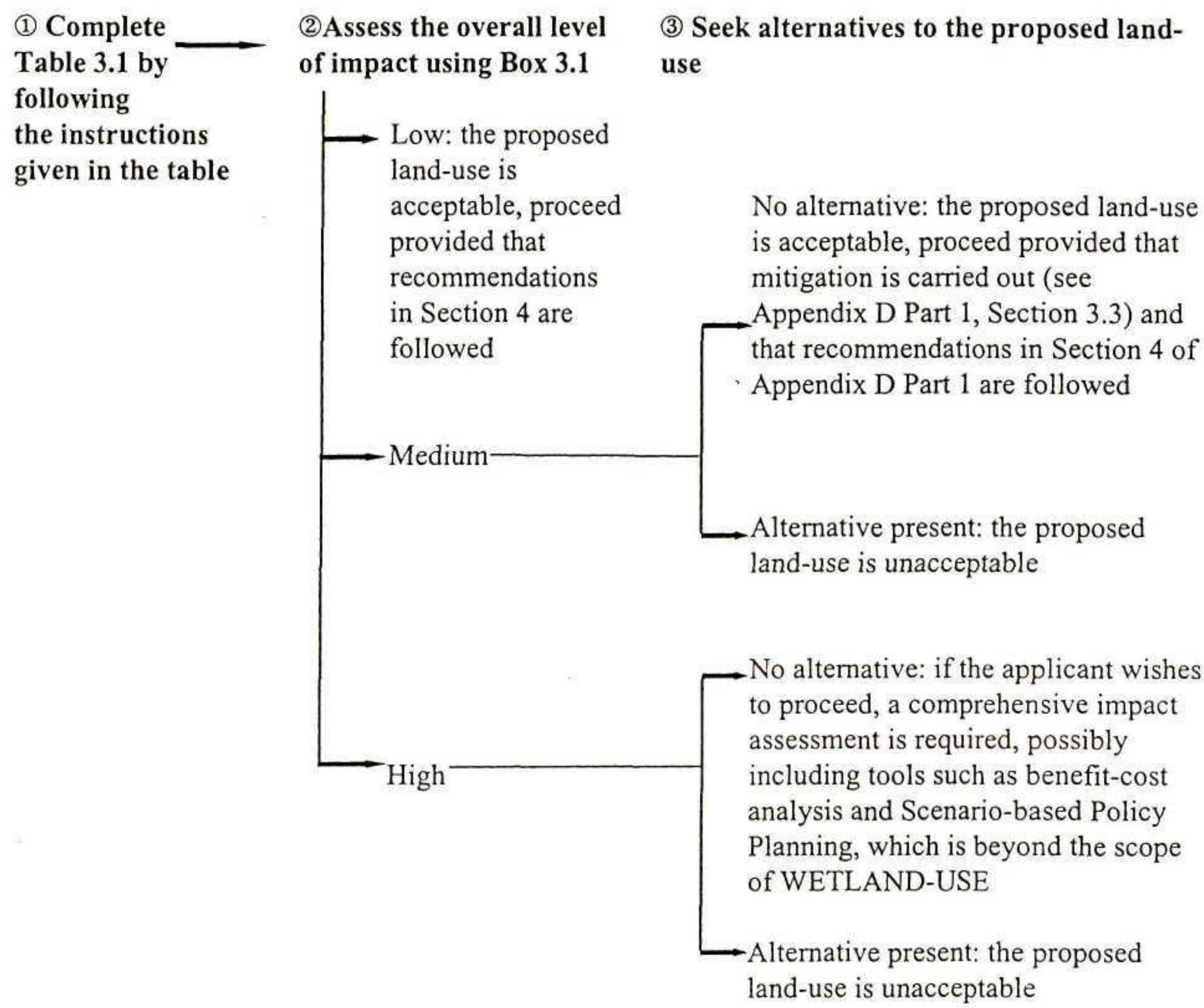
[3] Impacts on wetlands result from both 'on-site' activities at the wetland site and from 'off-site' activities in the wetland's surrounding catchment. WETLAND-USE is designed to assess on-site impacts. The land-uses considered are agricultural, including crop and pasture production, damming and natural grazing. While the general criteria of WETLAND-USE for assessment of land-use impacts are applicable to other land-uses (e.g. peat mining), additional information about the wetland site would be required to assess these.

Box 3.2 Principal factors to consider in assessing land-use impacts on a wetland area

	Level of impact: **Negligible/low**	**Medium**	**High**
1. What is the cumulative loss[4] of wetland over a broader area (i.e. in the overall wetland, the Veld Type and the quaternary catchment)?	☐	☐	☐
2. How much is the flow pattern of water through the wetland area being altered through on-site modifications (e.g. through drainage channels or infilling) and/or from off-site modifications to runoff quantity and timing into the wetland (e.g. as a result of afforestation of the wetland's surrounding catchment)?			
3. How great is the addition of pollutants to the wetland (e.g. as a result of leaching from fertilized fields)?	☐	☐	☐
4. How extensively, and how frequently, is the soil disturbed (making it more susceptible to erosion) and how close is the disturbed area to the wetland outlet or a channel linked directly to the outlet?			
5. What amount of organic soil material is mechanically removed or oxidised as result of altered flow patterns causing the drying out of the wetland and/or increased soil disturbance?	☐	☐	☐
6. How much is the roughness of the wetland surface (which offers resistance to the movement of water) reduced and/or vegetation cover reduced?			
7. What amount of natural wetland vegetation is replaced by introduced/alien plants (which may not necessarily be associated with a change in vegetation structure or flow patterns)?			
8. To what extent are wetland-dependent species, particularly Red Data species, negatively affected?	☐	☐	☐

[4]A wetland is considered lost when it has been altered so much that its functioning and the indirect benefits it supplies are severely limited (e.g. when it is drained and cultivated).

In order to assess the level of impact and the acceptability of a proposed land-use, users are instructed to follow these three steps:



In the example site given in Table 3.1 (which has an erosion hazard of 1.2), if traditional crops were being considered then the impact level for site erosion hazard is high and the likely overall impact would therefore be high. If, however, the erosion hazard is <0.4 the overall impact would be medium as four of the relevant descriptors are medium and none are. The theoretical basis for this evaluation is examined further in Section 12.2.1.

WETLAND-USE allows for the fact that additional factors that the assessor or stakeholders raise as further issues may need to be added to the assessment. For example, a wetland may be particularly important in providing natural habitat which acts as a corridor for the movement of certain animals and if the wetland were cultivated this would be lost.

Table 3.1 Checksheet for determining the likely impacts of particular land-uses

Descriptors (obtained in INFO-COLLECT)		Site	Example	Impact level for individual land-uses: *Traditional crops* Low	Med.	High	*Mechanized. crops* Low	Med.	High
F14& F15	Red Data species or Threatened habitat types	.....	No	No □		Yes □	No □		Yes □
A12, B1&2	Cumulative wetland loss	.....	30%	<20%□	20-50%□	>50%□	<20%□	20-50%□	>50%□
F12	Site erosion hazard	.....	1.2	<0.4 □	0.4-1.0 □	>1.0 □	<0.4 □	0.4-1.0 □	>1.0 □
F13	Wetness zone	.....	S	T/S □		P □	T □		S/P □
D1	Downstream water use	.....	N	N □	Y □		N □		Y □
C5	Pollutant input	......	M	N/L □	M □	H □	N/L □	M □	H □
F16	Severity of existing erosion	......	L	N/L □	M □	H □	N/L □	M □	H □
F17	Extent of impact area untransformed	......	2 ha	<0.5ha□	0.5-5ha□	>5ha□	<0.5ha□	0.5-5ha□	>5ha□
F18	Roughness coefficient	.....	0.06	<0.05□	>0.05□		<0.05□	>0.05□	
F19	Current direct benefits to owner	.....	L	N/L □	M □	H □	N/L □	M □	H □
F20	Catchment unsuitable for dams	.....	N	-	-	-	-	-	-

That portion of the table dealing with grazing, mechanized cutting, dams and mechanized pastures has been omitted and is shown in Appendix D, Part 1, Table 3.1

T= Temporarily wet S= Seasonally wet P= Permanently wet

N=Negligible L=Low M=Medium H=High

Instructions for use of the checksheet

- Fill in the site column for all descriptors relevant to the land-use that is being proposed (e.g. traditional crops). Those descriptors which are not relevant to a particular land-use are indicated by a '-' in the land-use column in question.
- Based on the descriptor values, indicate with a cross in the appropriate box the level of impact associated with each descriptor.
- For all of the land-use types assessed it is assumed that the ongoing recommendations given in Section 4 will be followed (e.g. the area will not be grazed more heavily than recommended).

Note for A12, B1, & 2 (Cumulative loss): include the proposed area to be transformed with the existing values for A12, B1 and B2 (e.g. if 25% of the wetland was developed and the proposed development would add a further 5% to the area developed then A12=30%). Out of the respective values for A12, B1 and B2 take that which has the highest percentage. For example, if A12=30, B1=28, and B2=41 then the cumulative loss would be taken as 41.

Note for F17: the loss of indirect benefits that society would incur as a result of transformation of a wetland which has already been developed/transformed is less than that which would otherwise result if the wetland was not transformed.

Note for traditional crops: it is assumed that artificial drainage channels are not involved, crops tolerant of waterlogging are planted and pesticides and herbicides are not used. If these assumption do not hold then it should be considered as mechanized crops.

Box 3.3 Criteria for assessing the likely overall level of impact of the land-use on the indirect benefits of the wetland:

High= At least one of the relevant descriptors is high

Medium= At least three of the relevant descriptors are medium, and none are high

Low= Less than three of the relevant descriptors are medium, and none are high

Once the overall level of impact has been assessed and found to be medium or high, the user is instructed to consider if there is an alternative site available for the proposed development which has habitat that is less threatened or which has already been transformed or if there is opportunity for an alternative lower impact land-use. WETLAND-USE encourages the consideration of alternative land-uses (e.g. harvesting wetland plants for crafts) which involve minimal transformation of the wetland, and have little or no loss in indirect benefits provided by the area. In terms of the pressure-state-perceptions-policy framework, by increasing the direct benefits derived from a wetland in a non-transformed state relative to its benefits in a transformed state it is assumed that the incentive to modify/transform the wetland (e.g. by drainage) will be reduced. Consequently, the loss of value of the wetland to society that would occur with modification, would be avoided.

In terms of the national environmental legislation, WETLAND-USE does not provide rigid legal requirements for wetland development. Instead it provides a framework to assist in a pre-consultation meeting or scoping study as defined by DEAT (1998a and b) in the Environmental Impact Assessment (EIA) procedure. If the scoping report shows that there are likely to be significant impacts and the intention is to continue with the proposed land-use then a full impact assessment (which is beyond the scope of WETLAND-USE) would be required. The EIA procedure is nested within Integrated Environmental Management (IEM) (DEA, 1992; and DEAT, 1998b) and WETLAND-USE follows the underlying principles of IEM, including: decision making is informed, accountable, and open, involving the relevant authorities and stakeholders; alternative options are considered; all of the above are done from the beginning of the process; and development is equitable and sustainable (see DEAT, 1998b). WETLAND-USE also assists in highlighting important factors to consider in granting permits for agricultural development of a wetland according to the Agricultural Resources Conservation Act 43.

LAND USE-RECOMMEND provides recommendations, which could be described as "best management practices", aimed at minimizing the environmental impacts of the chosen land-use, while at the same time maximising the land user's benefit. The user is provided with broad recommendations and directed to key reference documents and expertise for a wide range of land-uses (e.g. roads and ecotourism). The focus is, however, primarily on agricultural land-uses, for which more comprehensive recommendations are given. For crops and planted pastures, the recommendations deal mainly with minimizing the impact of such activities as fertilizer application on the hydrological values of the wetland. Both traditional, hand cultivation and mechanized cultivation are included. For the grazing of natural wetlands, the recommendations focus on regulating the stocking rate and timing of grazing. Burning recommendations concern timing and frequency of fires as well as measures designed to influence fire behaviour. For cutting of natural vegetation, recommendations concerning the timing, frequency, and location relative to the zonation in the wetland are given.

3.3.2 WETLAND-USE Part 2

WETLAND-USE Part 2 is designed to provide relevant and accessible information and clear operating procedures to assist local people address the organizational aspects of wetland management. Part 2 has four components:

1. SOCIAL-INFO assists in describing the social, land tenure and policy contexts of individual wetlands by providing: (a) methods and general principles for gathering information (b) a set of specific leading questions for structuring the gathering of information relating to property rights and the social and policy context within which wetlands are used; (c) suggestions for integrating the information into the management process; and (d) a summary of the results from a case-study, the Mbongolwane wetland.

2. ORGANIZATIONAL-ARRANGEMENTS assists in establishing and maintaining organizational arrangements required for wetland management by providing a step-wise procedure for: (a) identifying stakeholders; (b) establishing an appropriate organizational structure; (c) establishing operating procedures and norms; and (d) clarifying roles and responsibilities of stakeholders. Hints, based on the experiences of field workers, are also provided relating to the extension worker's attitude (e.g. be open minded and willing to learn) and approach (e.g. if you have written material, go through it verbally).

3. MANAGEMENT-STRUCTURE provides a step-wise, iterative structure for local wetland users and managers to plan the management of their wetland (Fig. 3.6). As an aid to assisting extension workers focus their activities in the most appropriate areas of the management process, guidelines are also provided which are structured according to the pressure-state-perceptions-

policy. MANAGEMENT-STRUCTURE is based on the management framework given by the Ramsar Convention (Ramsar Convention Bureau, 1997) and a simplification of the protocols given by Rogers and Bestbier (1997). According to these protocols, 14 steps are required for translating an organization's vision into goals and a further 10 steps for a goal maintenance system in a single party system. Further steps are provided for adapting the protocols to a multi-party system. The protocols also encompass many different terms (e.g. system strengths, constraints, threats, thresholds of potential concern). The "managers" in all of the three examples cited by Rogers and Bestbier (1997) were professional and management staff of protected areas. Thus, while the value of the protocols is recognized, particularly in protected areas, it is considered to have severe limitations as a tool that can be used directly by an extension worker working with natural resource users, some of whom may have limited or no formal education.

4. MANAGEMENT-LIST provides a catalogue of the regulations, programmes, initiatives and organizations relevant to wetland use and management, and which may be enabling to the management process.

Stakeholders jointly develop guiding principles, an overall vision and management objectives (relating to the desired state of the wetland) required to achieve that vision, considering the nature of the wetland and its context. These outcomes constitute a policy for the wetland.

↓

Stakeholders identify possible land-uses and assess their likely impacts using LAND USE-ASSESS

↓

Based on the predicted impacts and social context, stakeholders select those land-use option/s that are compatible with the overall vision and objectives and the desired state.

↓

With guidance from LAND USE-RECOMMEND, the pressure on the wetland is regulated by providing explicit criteria and guidelines for the selected land-use options.

↓

Stakeholders set operational goals and supporting work plans and implement land-use options

↓

Achievement of operational goals are monitored

↓

Major review of vision and objectives.

Fig. 3.6 A summary of the management process given in WETLAND-USE

An important factor affecting the success of environmental workers in influencing human behaviour is their disposition in dealing with people. This is a key theme emphasised by both Taylor (1997) with regard to environmental education and by Jiggins (1997) with regard to agricultural extension. While it is obviously not within the scope and capacity of WETLAND-USE to address deficiencies in the disposition of field workers towards wetland users, a sub-component was included in the system (see Appendix D, Part 2, Box 3) which emphasises the importance of an appropriate approach and provides some practical guidelines for fieldworkers.

Although WETLAND-USE, including both Part 1 and 2, is designed primarily for use in commercial agriculture, forestry and rural communal areas, it may also be used in areas protected specifically for biodiversity conservation. In a protected area context, as in the other contexts, WETLAND-USE provides a framework for defining broad habitat patches (based on degree of wetness and landform), placing the particular wetland in a catchment and landscape context and screening potential on-site land-use impacts. Owing to the priority that is obviously placed on biodiversity considerations in protected areas, it may often be necessary in these areas to describe in more detail the constituent parts of the broad patches and their functioning in order to determine whether biodiversity conservation objectives are being met. This is, however, outside of the scope of the system, and a more comprehensive approach is given by Rogers and Bestbier (1997).

Most wetlands, be they within and outside of protected areas, provide both direct benefits (e.g. agricultural products or tourism) and indirect benefits (e.g. maintenance of biodiversity). There is, therefore, no absolute difference between wetland management inside and outside of formally protected areas. Rather, in protected areas the interests of society are generally accorded higher priority in relation to direct use interests. Although increasingly protected areas, particularly those in developing countries, are being required to provide direct benefits in the form of various natural resources harvested sustainably in these areas, fewer trade-offs are likely to be faced by management than would be the case outside. The task of achieving integrated management is therefore likely to be more difficult outside of protected areas. Thus, in refining WETLAND-USE, examples were chosen outside of protected areas where a diversity of uses, some of these being competing uses, were present.

3.4 WETLAND-USE in relation to the conceptual frameworks

3.4.1 WETLAND-USE in relation to the pressure-state-perceptions-policy framework

As previously discussed, a key component of WETLAND-USE Part 1 is characterizing the pressure applied by a particular land-use in terms of disturbance regime (e.g. intensity and frequency) and the likely effect on the state, which in turn affects the services delivered by the wetland. The pressure-state-services linkage is essentially the "hub" of WETLAND-USE. Its first component, INFO-COLLECT, comprises a set of descriptors for rapidly describing the wetland and its landscape context in a manner that will allow the prediction (on a qualitative basis) of the effect of a particular disturbance on the state of the wetland. Eight principal factors are used in assessing impacts on the wetland (e.g. how extensively and how frequently is the soil disturbed?). Further to this, generic land-use categories have been defined. Land-uses falling within particular categories share common features in terms of the eight principal features given in Box 3.2. For example, large-scale mechanized cultivation generally involves extensive artificial drainage, frequent disturbance of the soil and the addition of nutrients. Additional generic categories could be added to WETLAND-USE if land-uses are encountered which fit poorly into all existing defined generic land-use categories, and the general principles would be used to characterize the nature of the impact of the particular generic category.

Although assessed on a qualitative basis, the goods and services delivered by a wetland are not quantified by WETLAND-USE. This is recognized as an important limitation of the system, but is necessary because assessments must be rapidly conducted by extension workers and other practitioners operating at a similar management level and there is a paucity of available empirical data. It is nevertheless identified as a priority for further research.

An analytical understanding of how perceptions are formed and influenced would obviously assist in influencing perceptions within a democratic process. WETLAND-USE does not, however, go into this depth of analysis for describing perceptions, and instead makes some general assumptions. (1) Perceptions are shaped strongly by the goods and services which wetland users observe to be yielded by the wetland. (2) Because services are generally less tangible than goods, users are often not informed of the services provided by a wetland, resulting in their perceptions being shaped largely by observed goods or potential goods. (3) Perceptions are ultimately expressed as land-use choices or articulated intended uses of wetlands.

An important function of WETLAND-USE is to alert wetland users to the services provided by the wetland. However, as indicated earlier in the thesis, it is recognized that a wetland user may, for example, consider the diminished benefits to society that result from a particular use to have a very low priority compared with the direct benefits that the user receives. Furthermore, it is also recognized that even if perceptions are altered, users may not have the means, particularly if they are poor, to change patterns of resource use.

WETLAND-USE does not provide specific protocols for eliciting the perceptions of users and how these, in turn, are translated into policy. This would be difficult to undertake, especially when there are many interested and affected parties, because perceptions are often implicit. Policy, by nature, should be explicit, and in being such reveals, to some extent, the principles that guide people's actions. It is generally considered to be desirable that guiding principles are made explicit in a multi-stakeholder system where consensus is being sought. In WETLAND-USE Part 2, recommendations are provided to assist wetland users at a local level in making their guiding principles more explicit (i.e. in developing policy). While WETLAND-USE was not designed to operate at higher organizational levels, it could be used in the development of case-studies across a range of socio-economic contexts that inform the development of higher level policy (see Chapter 11). As recommended by Daily (1997) there should be a constructive interplay between research (including that of local case studies) and policy development whereby each influences the other in devising solutions to problems facing society.

The final component of WETLAND-USE includes a listing and description of policies and initiatives of relevance to wetland management in general. Thus, even if users and practitioners operating at a local scale consider these policies as "remote" they can at least see where their guiding principles accord with those of the higher level policies. In observing this congruency they are likely to identify more closely with the higher level policies and, importantly, see how their operations and efforts fit into a wider context. Thus, the final component of WETLAND-USE is considered to have an important potential function in linking policy at the local level with that at higher organizational levels. Links across organizational levels have also been strengthened by initiatives associated with WETLAND-USE, notably the South African Wetland Action Group (SAWAG) (see Chapters 8 and 12) and the Wetland Information Network (see Chapter 8).

The pressure-state-perceptions-policy framework forms the hub of WETLAND-USE. The other four frameworks examined were aggregated conceptually by integrating them within the pressure-state-perceptions-policy framework, thereby adding depth to particular elements and relations between elements in the overall framework. The patch dynamics framework, in particular, gives depth to the pressure and state elements and the relation between the two (Fig. 3.7).

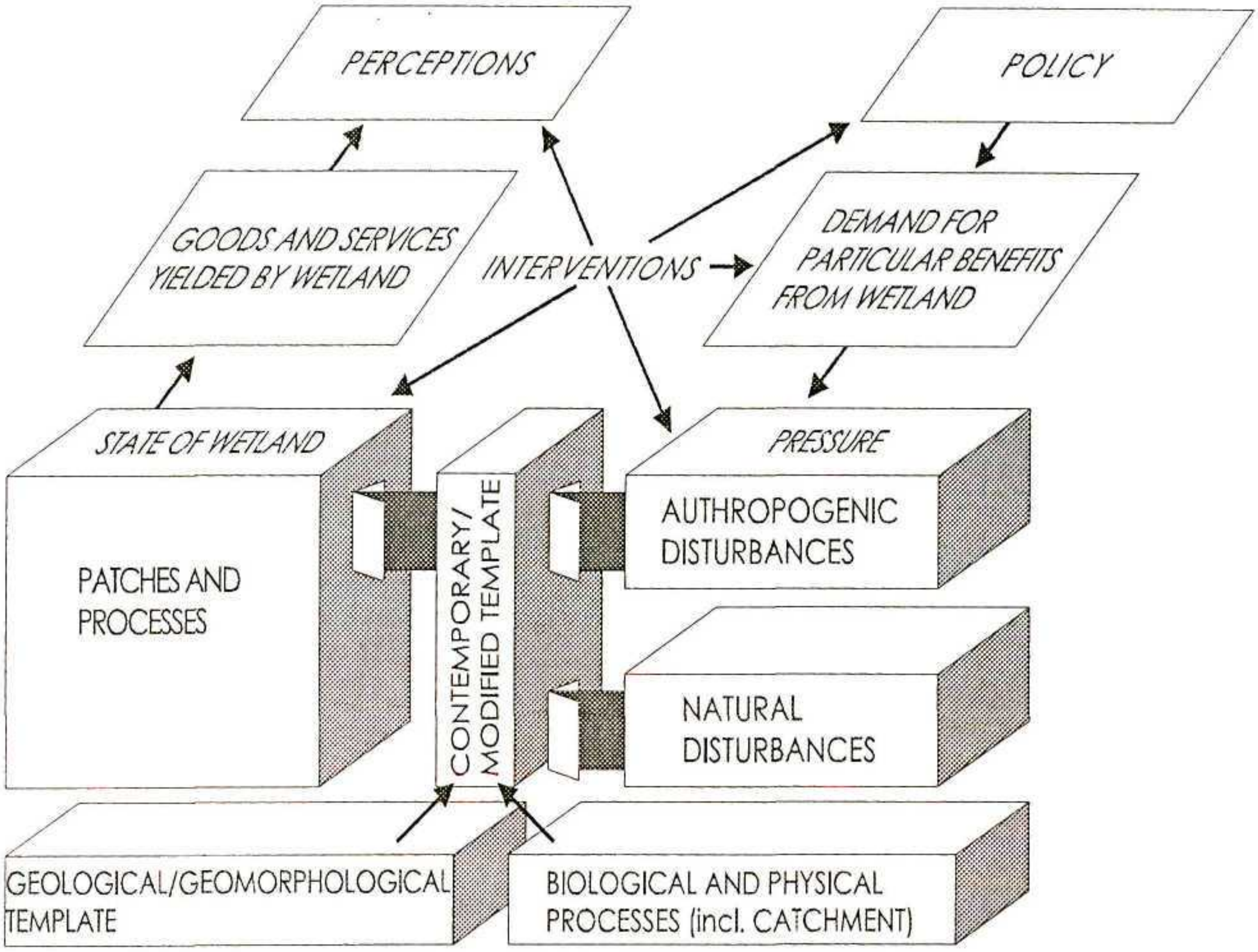


Fig. 3.7 Integration of the pressure-state-perceptions-policy framework with a patch dynamics/disturbance framework.

It is considered important to recognize from the outset that the pressure-state-perception-policy framework and WETLAND-USE have underlying structural functionist assumptions. Structural functionalism is related to modernism[5] and is characterized by a mechanistic, linear and causal perspective on social change. Structures (e.g. a decision support system) with particular functions (e.g. to promote more sustainable use of wetland resources) are assumed to have direct linear effects on social change (Docherty, 1993; Taylor, 1997). Such logic, which presumes an unfolding of solutions on the basis of scientific research, has underwritten much scientific research in South Africa (Quinlan, 1997). However, social change is seldom a linear process (Popkewitz, 1984) and a strong structural functional orientation to environmental education, for example, had important shortcomings and often led to disillusionment (Taylor, 1997).

[5] Modernism refers to the ideological underpinnings of modernity, a world view associated with the rise of science and the industrial revolution (Docherty, 1993).

Acknowledging this underlying assumption of WETLAND-USE, it is recognized that there are many factors, particularly relating to human behaviour, that may have a profound effect on attempts to influence the use of wetlands that WETLAND-USE does not assist in revealing or influencing. The revised WETLAND-USE system gives greater acknowledgement to the human process of management and the social context of the wetland than was originally the case for the prototype system. Although, WETLAND-USE requires trained fieldworkers for its application rather than being a resource designed to be used directly by wetland users, it stresses the importance of the fieldworker acting as facilitator. Taylor (1997) argues for a shift in environmental education from an "us-and-them approach", where well-informed, authoritative educators (us) with strong structural functional assumptions, put across the conservation message (to them) to a "participative approach" involving supportive demonstrators of resource materials that can be used for understanding and addressing issues, particularly those most pertinent to people's context. WETLAND-USE aims for the latter approach, but it is anticipated that further application and refinement, possibly requiring major changes to the system, will be required for WETLAND-USE to fully embrace and facilitate this participative approach.

3.4.2 WETLAND-USE in relation to patch dynamics and disturbance theories

Patch dynamics

On the whole, the grain scale at which WETLAND-USE operates is coarse but varies among descriptors. The hydrological regime, which is multidimensional and encompasses such factors as the duration and timing of soil saturation and flooding, has, for practical reasons, been reduced to a one dimensional measure of degree of wetness. Landforms are described coarsely through a simple generic system. WETLAND-USE does not extend to the level of vegetation dominance types or individual vegetation stands. The wetland's catchment is described in terms of its total area and the approximate extent of different land-uses, but their spatial distribution is not included. The area downstream of the wetland is described only in terms of whether there are human uses present. The cumulative impact of wetland loss is considered only in terms of whether the loss of wetland area in the landscape, catchment or wetland is high (50%), medium (20%-50%) or low (<20%), with the assumption made that if the cumulative loss is great then the impact of further loss would be higher than if the cumulative loss was low.

The spatial extent considered varies greatly according to the descriptor. Cumulative impacts are considered in: the individual wetland, the surrounding quaternary sub-catchment and the Veld Type (Acocks, 1953). Cumulative impact considerations are based on existing information, which is, however, often deficient.

While WETLAND-USE includes descriptors that are of relevance to species populations, it does not involve the description of populations as such. As indicated, wetlands are generally distributed as discrete patches in a wider matrix of non-wetland, and empirical evidence for metapopulations, such as that given for frog species in pond habitats (Sjögren, 1991) indicates that metapopulation theory is applicable to wetlands (Gibbs, 1993). It is suggested that this theory would apply particularly to inward-draining wetlands (pans), which are isolated from the drainage network (a feature that would be described by WETLAND-USE).

The extent to which WETLAND-USE includes the four themes used for defining the structure of a landscape mosaic varies according to the particular themes.

1. Patch quality for individual species is only considered for Red Data species with known life histories (e.g. wattled crane: *Grus carunculata*). Even this, however, is quite deficient in that the life histories of many Red Data species (e.g. the White-winged flufftail: *Sarothrura ayresi*) are poorly understood. A general assumption is made that the greater the hydrological modification, the lower the patch quality for wetland-dependent species in general. The degree of hydrological modification is determined based on the extent to which the degree of wetness and vegetation cover and roughness are reduced. A further general assumption is made that burning has a positive effect provided that unburnt areas to serve as refuges are present nearby the wetland.

2. Patch boundaries are not considered explicitly but the boundary effects of forest plantations (planted alongside wetlands) and dams (which present an obstacle to the movement of many aquatic species) are included.

3. Patch context is considered at a relatively coarse scale, with individual wetlands being considered in the context of: the overall catchment, the wetland catchment, the ecoregion, and the downstream service area.

4. Connectivity of patches is not examined explicitly other than consideration of dams interfering with the movement of aquatic species. There is a paucity of empirical data of the connectivity of South African wetlands as well as poor understanding of how this, in turn, affects wetland-dependent species.

A general assumption is, however, made that the greater the loss of wetland area, the lower will be the connectivity, for which there is general empirical evidence (Wiens, 1997b). The spatial configuration of the loss, which may have an important influence on connectivity, particularly at high levels of loss, is not considered, primarily because these data are largely lacking. Edge-to-area effects are largely not considered, except for the effect of forestry plantations in close proximity to the wetland.

Seasonal and year-to-year changes in patches are accounted for to some extent by WETLAND-USE. The hydrological zones in the wetland are defined in terms of seasonal changes in wetness (i.e. temporary, seasonal and permanent), and year-to-year variability (e.g. consecutive dry years) is included in some of the rules for burning. Changes taking place over time scales >10 years, over which geomorphological changes characteristically take place (see Chap 5), are not explicitly accounted for.

Disturbance theory

For the qualitative, rapid-assessment level for which it was designed, WETLAND-USE includes the majority of the disturbance regime descriptors listed by Pickett and White (1985) in Section 3.2.2. First, the system considers the extent of the area disturbed, and one of its general assumptions is that the larger the area disturbed, the greater will be the severity of impact. Details of the relationship would vary according to the particular process or species being examined as well as to the level of other factors (i.e. interaction effects). Such details are not, however, accounted for by WETLAND-USE because of the lack of empirical data and the complexity of the relationships.

Second, the spatial distribution of disturbance is considered by WETLAND-USE in relation to: degree of wetness, ecoregion, landform, and downstream area. A broad assumption is made that the greater the degree of wetness of a disturbed patch the more severe the general impacts are likely to be. Again, complexities and possible interactions are not considered. Disturbance within a landform setting which is inward draining is assumed to be less severe than the same disturbance in a landform setting which has open drainage as the erosion hazard is likely to be less and the effects of the disturbance are more likely to be contained. Third, the frequency of disturbance is considered for fire and disturbance of the soil through cultivation.

Fourth, the intensity of disturbance is considered for fire, grazing and mechanical disturbance of the soil. Descriptors of relevance to fire intensity (e.g. humidity and air temperature) are considered in a qualitative sense but fire intensity is not measured or calculated. The intensity of soil disturbance is only accounted for in making the distinction between mechanized and hand cultivation. Intensity of grazing is accounted for very simplistically, with stocking rate recommendations being given based on empirical observations of stocking rates of wetlands which were grazed without any obvious degradation in terms of accelerated erosion and vegetation structure (see Oellermann *et al.*, 1994).

Fifth, although some synergisms are accounted for (including: grazing and cutting; autumn burning and grazing; and drought and burning) and the cumulative impact of wetland area loss is considered, synergistic effects are generally poorly accounted for. This stems mainly from the complexity involved and the difficulty of isolating the interaction of individual factors.

Sixth, severity is determined based on the above five items. The severity and intensity of the disturbance are obviously very closely linked, and WETLAND-USE makes a few very general assumptions in describing this link. The more intense the more severe it will be, with the exception that low levels of disturbance would have a positive effect. This is in agreement with the intermediate disturbance theory, and would apply particularly to systems that evolved under disturbance by large herbivores. Severity is also assumed to be dependent on landscape configuration. For example, if an entire wetland was burnt, the severity of that disturbance on wetland-dependent rallids would depend on the presence of non-burnt wetland refuges in close proximity. Further details regarding the disturbance (e.g. its timing) are only considered for selected Red Data species with known life history features.

The four parameters commonly described which respond to disturbance are largely not included in WETLAND-USE owing to a lack of data to serve as baselines and the limited resources for conducting assessments. The life histories of only Red Data species are included, and the phenology of the vegetation is considered only in terms of the very broad categories of the growing season and non growing season of the vegetation in general.

Although wetlands are not described at a level of detail which would allow the two hypotheses of intermediate disturbance and disturbance and species richness to be tested, the system recommends intermediate disturbances in that it allows for fire and grazing but discourages extensive removal of the natural vegetation.

3.4.3 WETLAND-USE in relation to the economic valuation of wetlands

WETLAND-USE ascribes to the utilitarianism philosophy in that it considers services insofar as they confer satisfaction to humans. The overarching framework for characterizing values of natural system (see Fig. 3.4) is used in WETLAND-USE. However, while reference is made to option and existence values, they are not included in the decision making protocols owing to the inherent difficulties of accounting for these values and the specialist economic expertise required for their determination (see Pearce and Moran, 1997), which is beyond the scope of the system. The only local study available is that of Oellermann *et al.* (1994) who determined option and existence for Wakkerstroom vlei. These results are, however, obviously specific to this wetland and the specific group of people surveyed, which were members of the Wakkerstroom Natural Heritage Association (see Chapter 10).

Indirect use values are considered on a qualitative basis. For the purposes of the system these include: water quality enhancement, streamflow regulation (including flood reduction), groundwater recharge and discharge, erosion control, maintenance of biotic diversity, and global climate stabilization. The system is, however, deficient in that it does not express these values in monetary terms. This is owing to both a paucity of local data, the difficulties and costs of conducting such assessments and the limited resources and expertise available for doing so. While they are outside the scope of WETLAND-USE, the system recognizes the existence of useful economic tools (e.g. benefit-cost analysis) and, where appropriate, directs users to these systems, which would require specific economic expertise to apply. If the likely impacts on the services provided by the wetland are found to be high and the proponent still wishes to examine the possibility of continuing with the proposed land-use then a more comprehensive impact assessment is recommended by WETLAND-USE. If, however, the likely impacts on the services provided by the wetland are found to be low then no further assessment is required.

In terms of the consumer sovereignty framework (see Costanza and Folke, 1997) WETLAND-USE ascribes to the "democratic preference change" position in that it aims to influence individuals' land-use choices, primarily by alerting them to the likely effect that different land-use choices will have on the services provided by the particular wetland area. WETLAND-USE addresses the inter-generational goal insofar as these services are also likely to benefit future generations. Inter-generational fairness is included in the system to the extent that beneficiaries which are spatially removed from the wetland (downstream water users) are considered. WETLAND-USE takes externalities into account in that costs and benefits are considered from the point of view of downstream water users and society in general. This, together with consideration of property rights accounts to some extent for intra-generational fairness.

3.4.4 The relation of WETLAND-USE to the property rights framework

The prototype WETLAND-USE system was developed for a private, single owner context and no explicit reference was made to property rights. In expanding this system, the property rights framework was explicitly included as the central framework for dealing with the social context of a wetland. Based on the empirical evidence linking open access with the undermining of sustainable use, if open access regimes are detected then WETLAND-USE recommends the re-instatement or development of rules to control use in state, private or communal systems. It does not, however, recommend state or private ownership over communal use based on the arguments and evidence presented by Ciriacy-Wantrup and Bishop (1975) and Turner (1995) of sustainable communal use regimes (see Chapters 9 to 11). A further important assumption of the system is that it is possible to maintain the services provided by a wetland through civil society, be it under private or communal tenure, and without having to transfer the wetland to the ownership of the state.

The focus of property rights is on access to resources and ultimately to the decision making process. However, there are many other interacting factors within the broader social context that determine property rights which are not encompassed in the property rights framework. Property rights therefore represent only one of the dimensions along which the social aspects of wetland use are described. Further social aspects are incorporated in the pressure-state-perceptions-policy framework itself, particularly in the perceptions and policy elements and the state-perceptions, perceptions-policy, and policy-pressure linkages.

3.5 Conclusion

Current policies in southern Africa have proved to be ineffective in achieving integrated management of riparian systems (including wetland areas). An important factor in these failures is disjunct management arising from the interactions between the various perceptions, needs and policies of local cultures, agencies and national governments (Breen *et al.* 1997b). WETLAND-USE will contribute to enhanced integration at a local level. Very few systems have attempted to integrate so broad a range of elements in representing the use of wetlands. The approach used in developing WETLAND-USE was to start very simply and, through successive iterations, to increase in scope and operational capacity. The system was developed from a biophysical starting point, with a focus on the services that derive from the structure and functioning of wetland patches, and how different land-use practices impact on these services. The development of the system could, for argument sake, also have started with perceptions of different stakeholders.

The resolution of WETLAND-USE is determined largely by the fact that it is of necessity a simple rule-based system to be used by extension workers for conducting rapid assessments and working with local wetland users to promote the sustainable use of wetlands. It focuses on those spatial and temporal scales most relevant to management and which can be realistically considered. Human and financial resources are severely limited for carrying out the majority of wetland assessments, there is a paucity of local research, and there is no indication that either will appreciably improve in the foreseeable future. Thus, many of the elements and linkages are represented shallowly by WETLAND-USE. Clearly, WETLAND-USE was not designed as a research tool or framework for conducting research. Nevertheless, its development has revealed several gaps where local research is required (see Section 12.2.2).

Revealing the underlying philosophical bases for WETLAND-USE has contributed to providing a justification for the overall system and its particular components. The most fundamental of these is: "is there justification in outside intervention in the perceptions and behaviour of local people in relation to a wetland for which they have legitimate rights of use?". It was concluded that if these interventions take place within a democratic process then their philosophical basis is considered legitimate, emphasizing the importance of engaging in open dialogue. As cautioned by Steedman and Haider (1993), many experts and environmental practitioners believe they understand what the public needs, and therefore, include this in the decision making process intuitively and informally. This will obviously be counter to informed and participative decision making, and a more explicit and integrative approach is required.

As can be seen from the description of WETLAND-USE, it does not assign numerical values to functions (e.g. erosion control) and add these up to arrive at a final value for the wetland. The ecological value of a wetland, in particular, is very difficult to define. Also extremely problematic is the task of comparing and weighing up different commodities. For example, is a wetland which provides breeding habitat for a single pair of the endangered White-winged Flufftail (*Sarothrura ayresi*) more valuable than one which provides breeding habitat for hundreds of the very common

Spur-winged Goose (*Plectropterus gambensis*)? Leitch and Shabman (1988) level strong criticism at elaborate rating schemes, which they contend are built on a very shaky intellectual foundation. The conceptual difficulties of overall rating schemes will be discussed further in Section 12.2.1.

Thus, it is clear that it would be impossible to design a decision support system that removes value judgement from the decision making process. However, the model can be expected to make the decision making process more repeatable by providing a structured approach for describing a wetland, predicting the likely environmental impact of the different land-use choices, and deciding on appropriate land-uses. Hydrology, which is expressed in features of the soil, is considered important in characterizing the state of a wetland and its likely response to land-use pressures. In the following chapter, one of a series of six chapters in Part 2 of the thesis which report particular investigations undertaken to enhance the predictive capacity of WETLAND-USE, protocols are developed for describing hydric soils.

PART 2

INVESTIGATIONS TO ENHANCE PARTICULAR BIOPHYSICAL AND SOCIAL CONSIDERATIONS OF WETLAND-USE

CHAPTER 4

IMPROVED CRITERIA FOR CLASSIFYING HYDRIC SOILS IN SOUTH AFRICA

4.1 Introduction

The United States NTCHS (National Technical Committee for Hydric Soils, 1991) defines hydric soil as "soil that is saturated, flooded or ponded long enough during the growing season to develop anaerobic conditions in the upper part". Although the current NTCHS definition is independent of hydric plants, it identifies soils that support hydrophytic vegetation (Hurt and Brown, 1995). Anaerobic conditions are stressful to plants because oxygen is in very short supply and metals (e.g. manganese) are in their chemically reduced and, thus, more toxic forms. This precludes the growth and survival of most plants, except hydrophytes (Tiner and Veneman, 1988).

Wetlands occur as transitional areas between terrestrial and aquatic systems (Cowardin, *et al.*, 1979). The depth and duration of waterlogging varies considerably depending on where on the wet/dry continuum the wetland lies. A general term often used to describe the position of a given wetland area on this continuum is the degree of wetness. The water regime describes when, and to what extent, the soil profile is saturated or flooded (i.e. it describes the rise and fall of the water table through time). The water regime is the most important factor that affects both the plant species composition and the agricultural limitations of a wetland (Cowardin *et al.*, 1979; Mitsch and Gosselink, 1986). Thus, a water regime classification system with a practicable means of identification in the field is essential for describing hydric soils and a necessary element of WETLAND-USE.

In this chapter the variety of soils found in wetlands are described and the applicability of current systems for describing wetland water regimes and soil drainage classes discussed. Further, based on a review of studies on soil morphology/soil water regime relationships and an evaluation of systems that have been used in KwaZulu-Natal (see Kotze *et al.*,1994f; and Kotze *et al.*, 1996), a provisional management-orientated system for the classification of hydric soils in South Africa and inclusion in WETLAND-USE is recommended. Finally, preliminary testing is undertaken.

4.2 Types of hydric soils

Organic soils

Anaerobic soil conditions promote the accumulation of organic matter by impeding decomposition. Consequently, those wetland zones subject to the longest wet periods generally have the highest organic matter contents in a given wetland (Tiner and Veneman, 1988). Low temperatures also promote organic matter accumulation, so that for a given water regime, more organic matter will accumulate in a cool climate than in a warmer one.

The minimum proportion of organic carbon (OC) required for soil material to be classed as organic ranges from 12 to 18% (Soil Survey Staff, 1975; Avery, 1980). The variable OC limits are based on the observation that a given proportion of organic matter modifies the properties of a sandy material more than it does those of clay (Avery, 1990). An organic soil must have either, at least 400 mm of organic material within the upper 800 mm of the soil or organic material of any thickness extending from the soil surface to rock or gravel (Soil Survey Staff, 1975).

In South Africa, the minimum OC limits and minimum thickness are 10% and 200 mm respectively, which are less restrictive than the other systems discussed. The definition is tentative and it is recognized that it, as well as the classification of soils with an Organic O horizon, will undergo refinement (Soil Classification Working Group, 1991).

Mineral soils

Soil material that has less OC than the amounts given above is classed as mineral material. Hydric mineral soils vary greatly with regard to properties such as texture, pH and mineralogy, and hydric soils are found in all Orders of *Soil Taxonomy* (Soil Survey Staff, 1992, 1994). The most widely recognized process that reflects intense reduction of mineral soils as a result of prolonged saturation with water, is gleying. Grey, and to a lesser extent blue and green, colours predominate in gleyed soil material. Periodic saturation results in the soil material being alternately anaerobic when wet and aerobic when dry. Repeated re-precipitation of reduced iron in localized areas in mineral soil material each time the soil is aerobic, results in the formation of yellow, orange, red or black mottles. Mineral soils that are permanently saturated are usually uniformly gleyed throughout the saturated area and show less mottling development, usually only along root channels (McKeague, 1965; Tiner, 1993).

4.3 Systems potentially useful for describing wetland water regimes

When discussing water regimes it must be emphasised that it is not wetness *per se* that has the primary influence on the geochemistry and morphology of wetland soils, but rather the anaerobic conditions that result from prolonged soil saturation/flooding. Although the association between the duration of saturation and that of anaerobic conditions is generally close, some studies have shown that they do not always coincide. Field measurements showed that in some soils with small pores (usually clays) reducing conditions prevailed for longer than the duration of saturation and *vice versa* for soils with large pores (usually sands) (Vepraskas and Wilding, 1983). Therefore, it would be more appropriate to refer to the aeration regime rather than the water regime of a wetland soil but there is no generally accepted measure of soil aeration (Patrick, 1981). Although there is information on the amount of time required for anaerobic conditions to develop, the relationship between the frequency and duration of these conditions and the particular hydric soils and vegetation that develop is poorly understood (S P Faulkner, *Pers. comm.* 1992, Louisiana State University, Baton Rouge, LA, 70803).

Soil drainage classes

The soil drainage class system is agronomically based and describes the soil water conditions in terms of limitations to crop growth (Soil Survey Staff, 1951). Seven drainage classes have been recognized ranging from excessively drained to very poorly drained (Soil Survey Staff, 1951; Avery, 1980). Hydric soils are characteristically very poorly to poorly drained but certain somewhat poorly drained soils may also be hydric (Tiner and Veneman, 1988).

The Soil Survey Staff (1951) drainage class definitions do not include distinguishing field characteristics. In the USA, soil properties used to identify specific drainage classes vary between States and even within a State (Tiner, 1993). The areas for which distinguishing field criteria have been developed are mainly those with humid temperate climates, where the concept of drainage class evolved (Guertal, 1987). Thus, the soil drainage class system is unproven as a repeatable field technique for identifying degree of wetness for the hydric soils of South Africa because distinguishing field characteristics appropriate for the country have not been developed.

The system of Cowardin et al. (1979)

This is one of the most widely used wetland classification systems and it identifies eight water regimes ranging from permanently flooded to intermittently flooded. This system is unsuitable for categorizing the water regimes of hydric soils in South Africa because: (1) the classes at the wetter end of the continuum are very narrow resulting in there being too many classes to suit the needs of a management-orientated hydric soil classification; (2) Class 5 (saturated) includes a wide range of soil water regimes which, although they all seldom have surface water, range from permanently saturated to temporarily saturated; and (3) the system does not include distinguishing soil morphological criteria and cannot be readily applied in the field unless long-term hydrological data are available.

Soil Taxonomy

Soil Taxonomy (Soil Survey Staff, 1975; 1992), which is probably the most commonly used soil classification system worldwide, recognizes a single, broad, water regime (the aquic water regime) which includes all hydric soils. The aquic water regime is defined as a reducing regime in a soil that is virtually free of dissolved oxygen (permanently or periodically) because it is saturated by groundwater. The duration of saturation is not defined as the development of a reducing regime also depends on factors such as temperature and soil texture, but must be at least a few days. Aquic soils are recognized at the suborder level, based on their having redoximorphic features of wetness (e.g. mottling and a low chroma matrix) that are visible at $<$0.5 m from the soil surface (Soil Survey Staff, 1975; 1992). Almost all soils recognized as having an aquic water regime at the suborder level would be considered as hydric. Aquic subgroups are also recognized, but the depth criteria are generally 750 to 1000 mm from the soil surface. Thus, many of these soils recognized at this lower category in *Soil Taxonomy* would not be hydric (Mausbach, 1994). Generally, if signs of wetness occur only below 0.5 m then this is likely to be too deep to result in the area being dominated by hydrophytes and therefore it is not considered a wetland (Tiner, 1993).

Although the groundwater level normally fluctuates, there are situations where the groundwater is always at or very close to the surface, termed a peraquic water regime. Field indicators for the recognition of this regime are not, however, given (Soil Survey Staff, 1975; 1992). Although signs of wetness are recognized at different taxonomic levels, field indicators for distinguishing degree of wetness in a particular soil horizon are not provided by *Soil Taxonomy*. Even at the subgroup and series levels, classes include soils with a wide range of water regimes and redox conditions (Faulkner, *et al.*, 1991; Faulkner and Patrick, 1992). Thus, *Soil Taxonomy* provides a means for the field identification of only a single water regime applicable to wetlands. Consequently, it is not ideally suited for determining the degree of wetness in the field. Field indicators are, therefore, needed which allow morphological features to be interpreted more specifically in relation to water regime.

Criteria used by the National Technical Committee for Hydric Soils (NTCHS) (1991)

The criteria given by the National Technical Committee for Hydric Soils (1991) for identifying hydric soils are:

1. All Histisols except Folists, or
2. Soils in the Aquic suborder, Aquic Subgroups, Albolls Suborder, Salothrids Great Group, Pell Great Group of Vertisols, Pachic Subgroups, or Cumulic Subgroups that are:
    a. somewhat poorly drained[6] and have a frequently occurring water table at less than 150 mm from the surface for a significant period (usually more than 2 weeks) during the growing season, or
    b. poorly or very poorly drained and have either:
        i. a frequently occurring water table at less than 150 mm from the surface for a significant period (usually more than 2 weeks) during the growing season if textures are coarse sand, sand, or fine sand in all layers within 500 mm, or for other soils;
        ii. a frequently occurring water table at less than 300 mm from the soil surface for a significant period (usually more than 2 weeks) during the growing season if permeability is equal to or greater than 150 mm/hour in all layers within 500 mm; or
        iii. a frequently occurring water table at less than 450 mm from the soil surface for a significant period (usually more than 2 weeks) during the growing season if permeability is less than 140 mm/hour in all layers within 500 mm, or
3. Soils that are frequently ponded for long duration or very long duration during the growing season, or
4. Soils that are frequently flooded for long duration or very long duration during the growing season.

[6] Drainage class is used as a substitute for duration of water table at a certain depth.

These criteria were not designed to be used in the field for on-site identification or verification of hydric soils (Mausbach, 1994). Regional indicators of hydric soils, such as those developed by Hurt and Brown (1995) for Florida are required for this purpose. The NTCHS criteria are therefore unsuitable as field indicators of wetland water regimes. In the USA research emphasis is currently being focused on the development of these hydric soil field indicators for the different regions in the country.

4.4 Soil morphology/water regime relationship studies

There are very few wetlands in South Africa for which long-term water table measurements exist, so the water regime must be identified by using the vegetation and/or soil morphological features (e.g. Tiner, 1991; 1993). If the long-term hydrological regime is altered (e.g. by drainage), the morphology of the soil tends to reflect the previous water regime for much longer than does the vegetation. Consequently, evaluation of soil properties is usually important for the accurate identification and delineation of wetlands (Tiner, 1991). In the USA, for example, all federal regulatory and wildlife management agencies, recognize that vegetation alone is not sufficient for identifying wetland boundaries (Tiner and Veneman, 1988; Mausbach, 1994).

Numerous studies in North America (e.g. McKeague, 1965; Crown and Hoffman, 1970; Daniels *et al.*, 1971; Richardson and Hole, 1979; Franzmeier *et al.*, 1983; Zobeck and Ritchie, 1984; Guertal, 1987; Evans and Franzmeier, 1988; Mokma and Creemens, 1991) and Europe (e.g. Schelling, 1961; Van Heesen, 1970; Van Wallenberg, 1973; Moore, 1974; Blume and Schlichting, 1985) have attempted to relate water regime to soil morphological features, such as matrix and mottle colour patterns, and their distribution within the soil profile. Most of these studies apply only to localized sets of soils and many do not describe soils across the full saturation/flooding continuum occupied by hydric soils. Factors such as climate and soil parent material make developing a universal system very difficult; but perhaps once a sufficient number of wetlands have been studied it will be possible to develop a universally applicable model. Some broad generalizations can, however, be extracted from these studies concerning the soil morphology changes that occur when moving from the dry to the wet extreme of the continuum. These are: (1) matrix chroma steadily decreases; (2) mottle hue and chroma initially increase but as the wet extreme of the soil saturation continuum is approached, they decrease; (3) the most intensively mottled zone in the soil profile gets progressively shallower and mottle size increases; and (4) predominantly black nodules are replaced by red nodules, and overall mottle abundance initially increases, then steadily decreases as the wet extreme of the continuum is approached.

A pilot investigation was undertaken at seven wetlands within the study site representing a range of climatic conditions (Table 4.1). The geomorphological features of six of these wetlands are examined in Chapter 5. The seventh wetland, Nylsvley was added as an example, along with Boschoffsvlei, of a wetland under a high rainfall deficit (1587 mm, see Higgins *et al.* [1996]). In this study, at each of the seven wetlands, the soil morphology was described at points (encompassing obvious changes in observed vegetation structure and species composition) along an elevational sequence, replicated twice in each wetland. The elevational sequence started outside of the wetland and ended at the lowest, what was assumed to be, the wettest part of the sequence. At each point, the soil was described at 0-100 mm and at 300-400 mm depths below the soil surface in terms of the chroma of the matrix, the abundance of mottles, and whether or not it had a sulphidic nature as indicated by a "rotten egg" odour. Elevation was taken as a composite indicator of water regime (Table 4.2).

Table 4.1 General features of the six primary study sites

Wetland sites	Area (ha)	Mean annual precipitation (mm)	Mean annual potential evaporation (mm)	Mean annual water deficit (mm)	Catchment area (km^2)	Mean annual runoff ($m^3 x 10^6$) [from Pitman *et al.*, 1981]	Altitude (m)
Mgeni vlei	300	980	1630	650	11	2	1830
Wakkerstroom	950	900	1776	876	207	30	1750
Ntabamhlope	285	980	1752	772	34	3	1480
Blood River	6000	799	1842	1043	557	54	1250
Boschoffsvlei	1800	723	1916	1193	526	78	1150
Mbongolwane	440	910	1729	819	40	9	550

The soil morphology trends observed along the topographical sequence (shown in Table 4.2) at all of the seven wetlands described were: (1) matrix chroma steadily decreased from >2 outside of the wetland to <1 at approximately midway along the gradient, remaining <1 to the wettest end of the gradient and, (2) sulphidic soils were confined to the wetter end of the gradient; (3) overall mottle abundance increased, then decreased in five of the wetlands but remained high in two of the wetlands, Boschoffsvlei and Nylsvley. It appears that in these two wetlands, the high mottle abundance in the potentially wettest areas of each wetland result from an absence of permanently saturated/flooded (and therefore anaerobic) conditions in these areas owing in particular to the drier climatic conditions of these wetlands, where potential evaporation is well in excess of rainfall. Higgins *et al.* (1996) indicate that a consequence of the rainfall pattern and high evaporative demand is that the Nyl Floodplain is subject to unpredictable periodic flood events interspersed by longer or no-flow periods, resulting in a floodplain which is essentially ephemeral.

Mottling in the overall elevational sequence was noticeably lower in high altitude wetlands than in low altitude wetlands. As can be seen from the wetland at the highest altitude, the Mgeni vlei, the morphological changes along the elevational sequence are less marked than in the other six wetlands. In fact, even the change from outside into the wetland is not as marked. In the case of Replicate 2, the soils outside of the wetland were characterized by humic A horizons (200-300mm deep) resulting in a low chroma within the 0-100mm zone. If this A horizon was >400 mm this would also result in the 300-400 mm zone having a low chroma, making it even more difficult to distinguish between wetland and non-wetland areas using soil morphology. Such soils have been observed by the author in close proximity to Mgeni vlei and have also been reported in the high altitude areas of Blyde River Mpumalanga (A Linström, 1998. *Pers. comm.* Mpumalanga Parks Board, Lydenberg) and the eastern Free State (N Collins, 1998. *Pers. comm.* Department of Agriculture and Environmental Affairs: Free State, Harrismith) and were confirmed through field inspection by the author.

Although the broad trends observed in the seven wetlands in this study correspond with those in the literature they do not provide a sufficient basis to draw final conclusions about local hydric soil morphology. Because of the scarcity of local data, local soil morphology/water regime studies are required, including a wide range of wetland types and with water regimes described directly. Wetlands at high altitudes and under more arid climatic conditions would be particularly important in this study.

Table 4.2 Soil morphological features (chroma[1], mottles[2], and sulphidic nature[3]) described at 0-100 mm and 300-400 mm below the soil surface respectively along a elevational sequence at eight South African wetlands, with two replicates from each wetland

Wetland site		Highest point non-wetland)		ELEVATIONAL SEQUENCE				Lowest point (permanently/semi-permanently wet)
Mgeni vlei	0-100 mm	2[ ]	2[ ]	<1[*]	<1[ ]	<1[ ]	<1[ ]	<1[ ]S
Replicate 1	300-400 mm	3[ ]	2[ ]	<1[**]	<1[*]	<1[ ]	<1[ ]	<1[ ]
Mgeni vlei	0-100 mm	1[ ]	1[ ]	1[*]	<1[ ]	1[ ]	<1[ ]	<1[ ]
Replicate 2	300-400 mm	4[ ]	1[*]	<1[***]	<1[*]	<1[ ]	<1[ ]	<1[ ]
Wakkerstroom	0-100 mm	2 [ ]	2 [ ]	1 [ ]	<1[*]	<1[ ]	<1 [ ]	<1[ ]S
Replicate 1	300-400 mm	3 [ ]	2 [ ]	1 [*]	<1[**]	<1[**]	<1 [*]	<1[*]
Wakkerstroom	0-100 mm	3[ ]	1[ ]	<1[*]	<1[ ]	<1[*]	<1[ ]S	<1[ ]S
Replicate 2	300-400 mm	2[ ]	1[*]	<1[**]	<1[***]	<1[**]	<1[*]	<1[ ]
Ntabamhlope	0-100 mm	3[ ]	3[ ]	1[ ]	<1[ ]	<1[ ]	<1[ ]	<1[ ]S
Replicate 1	300-400 mm	3[*]	1[*]	1[**]	<1[*]	<1[*]	<1[ ]	<1[*]
Ntabamhlope	0-100 mm	4[ ]	3[ ]	2[ ]	<1[*]	<1[ ]	<1[ ]	<1[ ]S
Replicate 2	300-400 mm	3[ ]	1[*]	<1[*]	<1[**]	1[ ]	<1[ ]	<1[ ]
Blood River	0-100 mm	2[ ]	1[*]	1[*]	<1[ ]	<1[*]	<1[ ]S	<1[ ]S
Replicate 1	300-400 mm	3[*]	1[*]	1[**]	<1[**]	<1[***]	<1[*]	<1[ ]
Blood River	0-100 mm	3[ ]	2[ ]	1[*]	1[*]	<1[***]	<1[*]S	<1[*]S
Replicate 2	300-400 mm	3[ ]	1[ ]	1[*]	1[*]	<1[**]	<1[*]	<1[*]
Mbongolwane	0-100 mm	2[*]	1[ ]	1[ ]	<1[*]	<1[**]	<1[ ]S	<1[ ]S
Replicate 1	300-400 mm	2[ ]	1[*]	<1[*]	<1[**]	<1[***]	<1[*]	<1[ ]
Mbongolwane	0-100 mm	3[ ]	2[ ]	1[*]	<1[*]	<1[*]	<1[*]S	<1[ ]S
Replicate 2	300-400 mm	2[ ]	1[*]	<1[*]	<1[***]	<1[***]	<1[*]	<1[ ]
Boschoffsvlei	0-100 mm	2[ ]	1[*]	1[*]	1[*]	<1[**]	<1[*]S	<1[ ]S
Replicate 1	300-400 mm	3[ ]	1[*]	1[**]	<1[**]	<1[***]	<1[***]	<1[***]
Boschoffsvlei	0-100 mm	2[ ]	1[ ]	1[**]	1[*]	<1[**]	<1[**]S	<1[*]S
Replicate 2	300-400 mm	3[ ]	1[*]	1[***]	<1[***]	<1[***]	<1[**]	<1[***]
Nylsvley	0-100 mm	2[ ]	1[*]	1[**]	<1[**]	<1[*]	<1[**]S	<1[*]S
Replicate 1	300-400 mm	3[*]	1[**]	1[***]	1[***]	<1[***]	<1[**]	<1[***]
Nylsvley	0-100 mm	2[ ]	1[*]	1[*]	<1[**]	<1[***]	<1[**]S	<1[*]S
Replicate 2	300-400 mm	rock	1[*]	1[**]	<1[***]	<1[***]	<1[***]	<1[***]

[1] Chroma, which refers to the relative purity of the spectral colour, decreases with increasing greyness

[2] Mottle abundance:
[ ]=no mottles present
[*]= mottles present but covering <2% of the exposed surface (few mottles)
[**]= 2 to 20% of the exposed surface (mottles common)
[***]= >20% of the exposed surface (many mottles)

[3]Sulphidic nature S= soil material has a "rotten egg" smell

4.5 A provisional basis for relating soil morphology to water regime

In the Wetland Policy Document for KwaZulu-Natal, Begg (1990) provides a tabular basis for differentiating between the main types of wetlands. This was the first attempt to incorporate soil criteria into a regulatory and management-oriented classification system for local wetlands, but it has some deficiencies. For example, subsoil mottling is given as being most intense under the most prolonged saturation conditions, which does not agree with the findings of other studies (e.g. McKeague, 1965; Moore, 1974; Richardson and Hole, 1979; Parker *et al.*, 1984) which showed that mottling is better developed in seasonal than in permanent wetlands.

In an attempt to improve upon the system of Begg (1990), a provisional four class water regime scheme for determining degree of wetness of wetland soils is proposed (Table 4.3). This is based on the known general relationships between soil morphology and water regime (discussed above), and soil morphology descriptions at seven South African wetlands (see Table 4.2).

Table 4.3 A provisional four class scheme for determining the degree of wetness of wetland soils based on soil morphology

	DEGREE OF WETNESS			
SOIL DEPTH (mm)	Non-wetland	Temporary	Seasonal	Permanent/ Semi-permanent
0-100 mm	Matrix chroma: generally >1 Generally no mottles Generally low OC[a] Non-sulphidic	Matrix chroma: 0-3, usually 1or 2 Mottles few/nil Low/intermediate OC Non-sulphidic	Matrix chroma: 0-2 Mottles common Intermediate OC Seldom sulphidic	Matrix chroma: 0-1 Mottles nil/few High OC Often sulphidic
300-400 mm	Matrix chroma: >2 Mottles nil/few	Matrix chroma: 0-2 Mottles few	Matrix chroma: 0-1 Mottles common/ many	Matrix chroma: 0-1 Mottles nil/few

[a] High OC: soil organic carbon levels are greater than 5%, often exceeding 10%; and Low OC: soil organic carbon levels are less than 3%. Measurement of soil organic carbon requires laboratory analyses and is therefore included only as supplementary information in the scheme when applied by fieldworkers.
Mottle abundance: see Table 4.2

Among the problematic soil types which need to be accounted for when applying the system are hydric soils which lack hydromorphic features because of, for example, their early stage of formation (i.e. Entisols) and non-hydric soils with features such as low chroma, which are not caused by hydric conditions (e.g. some Mollisols and Vertisols).

The provisional scheme is still in the 'developmental' stage and requires field testing beyond the initial soil descriptions given in Table 4.2. Soil morphology will need to be described along replicated elevational sequences in a range of wetland types (i.e. wetlands found in different climatic and topographic settings) and the trends observed compared with the scheme. It will be preferable to measure the water regime directly at the description points using piezometers to confirm that the elevational sequences effectively represent hydrosequences. The proposed local studies will provide a basis for developing hydric soil field indicators specific to different bioclimatic regions in South Africa.

4.6 The South African system (Soil Classification Working Group, 1991)

The soil forms common to South African wetlands are Champagne (Abbrev. Ch), Katspruit (Ka), Willowbrook (Wo) and Rensburg (Rg) (Scotney and Wilby, 1983). The Champagne form consists of only an Organic O horizon; the others are all characterized by the presence of a G horizon (either calcareous or not) overlain by an orthic A (ochric epipedon, Ka), melanic A (mollic epipedon, Wo) or a vertic A (Rg) respectively. Scotney and Wilby (1983) included other soils which occur predominantly in non-wetland areas but which are also found in temporary wetlands. These are the Kroonstad, Westleigh, Longlands, Estcourt, and Dundee forms (Soil Classification Working Group, 1991). The Dundee form, however, is seldom subject to extended periods of saturation and therefore is technically not hydric. The Kroonstad form has an E horizon between the A and G, and thus the G horizon is often too deep for the soil to be hydric. The Westleigh and Longlands forms both have a soft plinthic B horizon, which indicates a fluctuating water table, but this horizon is also often too deep for the soil to be considered hydric, especially in the Longlands. In the Estcourt form, wetness may occur in the prismacutanic horizon, which would make it hydric if this horizon was close enough to the soil surface. Added to the list of Scotney and Wilby (1983) are forms such as the Tukulu form (orthic A, neocutanic B, unspecified material with signs of wetness). These forms may be hydric depending on the depth of the material with signs of wetness.

The South African soil classification system (Soil Classification Working Group, 1991) does not require that the soil water regime be determined, unlike *Soil Taxonomy*. The depth to the upper limit of the G horizon, or any other horizon with signs of wetness, is not specified. It may range from <200 mm to >800 mm below the soil surface. This is an important weakness of the system when applied to hydric soils since, as emphasised earlier, the depth of waterlogging is crucial from an agricultural and ecological perspective.

Clearly, the water regime is of paramount importance from a management viewpoint. Begg (1990) suggested a provisional classification of the differences between the main types of wetlands and a general interpretative guide to the sustainable use of wetlands in bottomland situations. This guide represents all the soil forms as being restricted to specific water regimes. However, work by Kotze *et al.* (1994c and d) has shown, for example, that the Lammermoor family of the Katspruit form can occur under the full range of saturation/flooding conditions found in wetlands and it's properties were found to vary across the wetland continuum (Table 4.4).

Table 4.4 Properties of the Lammermoor soil family across the wetland continuum at Wakkerstroom and Ntabamhlope vlei

SOIL PROPERTY	**DEGREE OF WETNESS**		
	Temporary	**Seasonal**	**Permanent**
Depth (below the soil surface) to first signs of wetness	50-400 mm	surface	surface
Organic carbon content of the A horizon	1-4%	3-9%	5-9%
n Value[3]	<0.7	0.7-1.0	>0.7

[3] The *n* Value refers to the relationship between the percentage of water under field conditions and the percentage of inorganic clay and humus. It can be approximated in the field by a simple test of squeezing the soil in the hand. It is helpful in predicting the degree of subsidence that will occur after drainage and the load bearing strength of the ground (Pons and Zonneveld, 1965; Soil Survey Staff, 1992).

Figure 4.1 shows a revised classification of wetland soils which is provisional and requires field testing. It must be noted that it does not indicate how common the different water regimes are in the different climates. Permanently saturated areas, for example, are far less prevalent in semi-arid regions than under more humid climatic conditions. Owing to the fact that the taxa contain a wide range of possible water regimes and associated soil properties, they also contain a range of land capabilities. Thus, although the South African soil classification system may be adequate for categorizing wetland soils at a broad regional level, it is clearly inadequate for management and land planning purposes in individual wetlands. In order to improve the South African soil classification system, degree of wetness or depth of waterlogging could possibly be recognized at the series level.

CLIMATE — DEGREE OF SATURATION/FLOODING

Temporary, seasonal, semi-perm., permanent

humid (interior)

Champagne

Katspruit (N-C)

humid (coastal)

Champagne

Katspruit (N-C)

Willowbrook (N-C)

Rensburg (N-C)

sub-humid

Katspruit (N-C/C)

Willowbrook (N-C/C)

Rensburg (N-C/C)

mild sub-arid

Katspruit (N-C/C)

Willowbrook (C)

Rensburg (C)

Legend

______	frequent occurrence
- - - -	infrequent occurrence
N-C	upper G horizons are predominantly non- calcareous
C	upper G horizons are predominantly calcareous
N-C/C	both non-calcareous and calcareous upper G horizons occur frequently

Note: the Champagne form may occur under sub-humid and mild sub-arid conditions if the climate is sufficiently cold to slow down the decomposition of organic matter. However, such situations appear to be very limited in South Africa.

Fig. 4.1 Range of water regimes in which the soil forms common to the wetlands of KwaZulu-Natal occur, for different climatic regions; based on Downing (1966), MacVicar (1970), Scotney (1970), Scotney and Wilby (1983) and Kotze *et al.* (1994a and b) and Kotze *et al.* (1994c,d and e).

4.7 The repeatability of the four class system for determining degree of wetness

The repeatability of the four class scheme for determining degree of wetness, given in Table 4.3, was field-tested in the Howick area, KwaZulu-Natal and in the Harrismith area, eastern Free State. In the Howick area, the scheme was independently applied by six teams of operators to 15 different sampling points and in the Harrismith area the scheme was applied by four independent operators to 18 different sampling points. In both areas the results were compared with that of the author's application of the scheme to the same sampling points. A desktop evaluation of the system was also undertaken by supplying four independent operators with written descriptions of 24 soil sample sites and requiring that they assign each of these to one of the four soil wetness classes and then comparing these with the author's application.

The results are given for the individual points for the first application in Table 4.5 and are summarized for the three applications in Table 4.6. The two field applications revealed similar results, with a generally high level of correctness across soil wetness classes. The least consistently allocated was, however, the seasonal class, and two sources of confusion in describing soils in this class were identified: (1) soil with low overall level of mottling across the wetness zones such as that described for Mgeni vlei in Table 4.2 (these soils were present at the Harrismith site); and (2) soils with a very high level of mottling, where mottles are so abundant that they occupy more of the exposed soil surface than the intervening matrix (encountered at one of the sites in the Howick area). In the incorporation of Table 4.2 into the revised WETLAND-USE system, notes to assist users in overcoming these potential difficulties were included.

The desktop application showed a similar high level of correctness across wetness classes to the field applications (Table 4.6). Overall therefore, the scheme is considered to have performed well in both the field and desktop applications.

Table 4.5 Results of the application in the Howick area of the four class degree of wetness scheme given in Table 4.3 by six independent operator groups (Operators 1 to 6) compared with that of the author's application of the scheme (A)

Sample number	Operators							Correct matches
	A	1	2	3	4	5	6	
5	P	P	P	P	P	P	P	6/6
6	P	P	S	P	P	S	P	4/6
15	P	P	P	P	P	P	P	6/6
Total correct matches = 16/18 (89% correct)								
3	S	S	S	S	S	S	S	6/6
4	S	T	S	S	S	S	T	4/6
9	S	T	S	S	S	S	S	5/6
10	S	T	S	S	S	T	T	3/6
13	S	S	S	S	S	S	S	6/6
14	S	S	S	S	S	S	S	6/6
Total correct matches = 30/36 (83% correct)								
2	T	N	T	T	T	T	T	5/6
8	T	T	T	T	T	T	T	6/6
12	T	T	T	T	T	T	T	6/6
Total correct matches = 17/18 (94% correct)								
1	N	N	N	N	N	N	N	6/6
7	N	N	N	N	N	N	T	5/6
11	N	N	N	N	N	N	N	6/6
Total correct matches = 17/18 (94% correct)								
		11/ 15	14/ 15	15/ 15	15/ 15	13/ 15	12/ 15	81/90 (90%)

P=Permanent S=Seasonal T=Temporary N=Non-wetland

Table 4.6 Summary of the results of the application of the four class degree of wetness scheme given in Table 4.3 by independent operators/operator groups, with their correctness being compared with that of the author's application of the scheme

	Howick application	Harrismith application	Desktop application
Total number of independent operators/ operator groups	6	4	4
Permanent	16/18 (89% correct)	11/12 (92% correct)	19/20 (95% correct)
Seasonal	30/36 (83% correct)	23/28 (82% correct)	14/16 (88% correct)
Temporary	17/18 (94% correct)	12/16 (75% correct)	32/36 (89% correct)
Non-wetland	17/18 (94% correct)	15/16 (94% correct)	22/24 (92% correct)

4.8 Conclusions

As a long-term objective, *Soil Taxonomy* should be used to classify the hydric soils of South Africa. *Soil Taxonomy* will require a higher level of expertise from fieldworkers than the present, simpler system and it will need to be actively promoted as it is unfamiliar to the majority of agricultural and nature conservation extension workers. Such problems do not, however, outweigh the advantages that *Soil Taxonomy* has for the classification of hydric soils in South Africa, most importantly that it accounts for depth of waterlogging. Despite these advantages, additional field indicators of degree of wetness will be required, because even at the subgroup and series levels, classes include soils with a wide range of water regimes and redox conditions. The four class system proposed in this chapter could be used provisionally to separate these extremes.

At least for the foreseeable future, the South African system will remain the most widely used system in the country. It is therefore recommended that the proposed class system be used in conjunction with the South African system as the basis for defining phases, which is the third hierarchical level in the South African system. The four class system is also the primary criterion used in WETLAND-USE for describing wetland hydrology, and it will therefore make an important contribution to characterizing the state of a wetland and its likely response to a particular pressure.

It is important to note, however, that this proposed system has been subject to only preliminary field testing and it is recommended that local studies of soil morphology/water regime relationships be undertaken to improve the capacity for adequately describing hydric soils in South Africa. In the following chapter, protocols for describing further hydrologically-related parameters, notably landform, are developed, which are seen as complementary to the protocols developed in this chapter.

CHAPTER 5
THE DEVELOPMENT OF A CLASSIFICATION SYSTEM FOR HYDRO-GEOMORPHOLOGICAL SETTINGS

5.1 Introduction and objectives

Owing to the fundamental influence of hydrology on the functioning of wetlands, it is considered necessary for WETLAND-USE to characterize the hydrology of a wetland in order to predict how it will be affected by different land-use activities (see Chapter 3). While degree of wetness is important in determining plant species composition (see Chapter 6), habitat quality, and on-site soil biogeochemical processes (e.g. denitrification) (see Mitsch and Gosselink, 1986) it does little to explain the transport of water and water-borne materials through the landscape (Brinson, 1993a). Clearly therefore, the hydrology of a wetland encompasses considerably more than simply the degree of wetness, and one of the most important and readily described hydrologically-related parameters is the hydro-geomorphological setting of the wetland. A geomorphological classification of wetlands refers to a classification according to the wetland landform setting and its relationship to surrounding landforms. In this study the landform setting of a wetland refers to the shape of the landsurface at the scale of an overall wetland. Geomorphology strongly influences: (1) local patterns of water movement (surface and sub-surface) and (2) the degree to which wetlands are open to lateral exchanges of water, sediment, nutrients and pollutants (Bedford and Preston, 1988). The overall goal of this investigation is to develop and investigate the applicability of a landform classification system for inclusion in WETLAND-USE which could be used by extension workers for application to inland freshwater wetlands. To this end the following are undertaken.

1. Development of a prototype, generic landform classification system based on a review of the literature and reconnaissance field observation of wetlands in the study area.

2. An investigation of the application of the system to freshwater palustrine wetlands spanning an altitudinal range from 550 m to 2 200 m, and including: (a) six large wetlands described in detail in order to examine landform in relation to site wetness and the dynamics of landforms; and (b) 66 wetlands of various sizes, and including the original six, described in less depth in relation to the broader landscape features of position relative to overall terrain and the drainage network.

3. An investigation of the functional significance of the landforms in the classification system.

4. Revision of the proposed classification system in the light of the results of the investigation.

5.2 Development of a prototype classification system for hydro-geomorphological settings

A review of existing hydro-geomorphological systems that would be suitable for use by extension workers was undertaken, including the systems of Semenuik (1987) and Brinson (1993a). As no system existed which was considered entirely suitable for the purposes and circumstances encompassed in this investigation, a simple functional classification system of wetland hydro-geomorphological settings (based on surface water flow and geomorphological characteristics) was developed. The first generation prototype, which was based on the wetland habitat system of Semenuik (1987) and the system of Brinson (1993a) and reconnaissance field observations of Wakkerstroom vlei and Natabamhlope vlei, is shown in Figure 5.1.

The settings are defined in terms of surface flow which is usually not directly visible and must be inferred from the landform (e.g. whether or not the area is channelled). Thus, it was considered preferable to describe the classes directly in terms of landform, from which inferences concerning surface flow can be made. Furthermore, based on the fact that some of the definitions make reference to landsurface position, while others do not, the system was considered inconsistent and potentially confusing. Thus, it was considered useful to separate the description of the shape of the wetland setting from a description of the wetland's landsurface catenal position, and the system was modified by incorporating the terrain classification system used by the Land Type Survey Staff (1986) to be used in concert with a landform system. Six landform setting classes (Fig. 5.2) and five terrain unit classes (Fig. 5.3) are recognized in the revised system.

Inferences can be made concerning the surface flow patterns of the different landforms. Flow within channel settings is obviously channelized. In depressions, inflow is characteristically diffuse, drainage is closed and outflow does not occur until the depression has filled with water, as may happen to depressions on floodplains. On slopes and flats lacking channels, flow is typically diffuse. Water movement on fringing settings results from tides and winds.

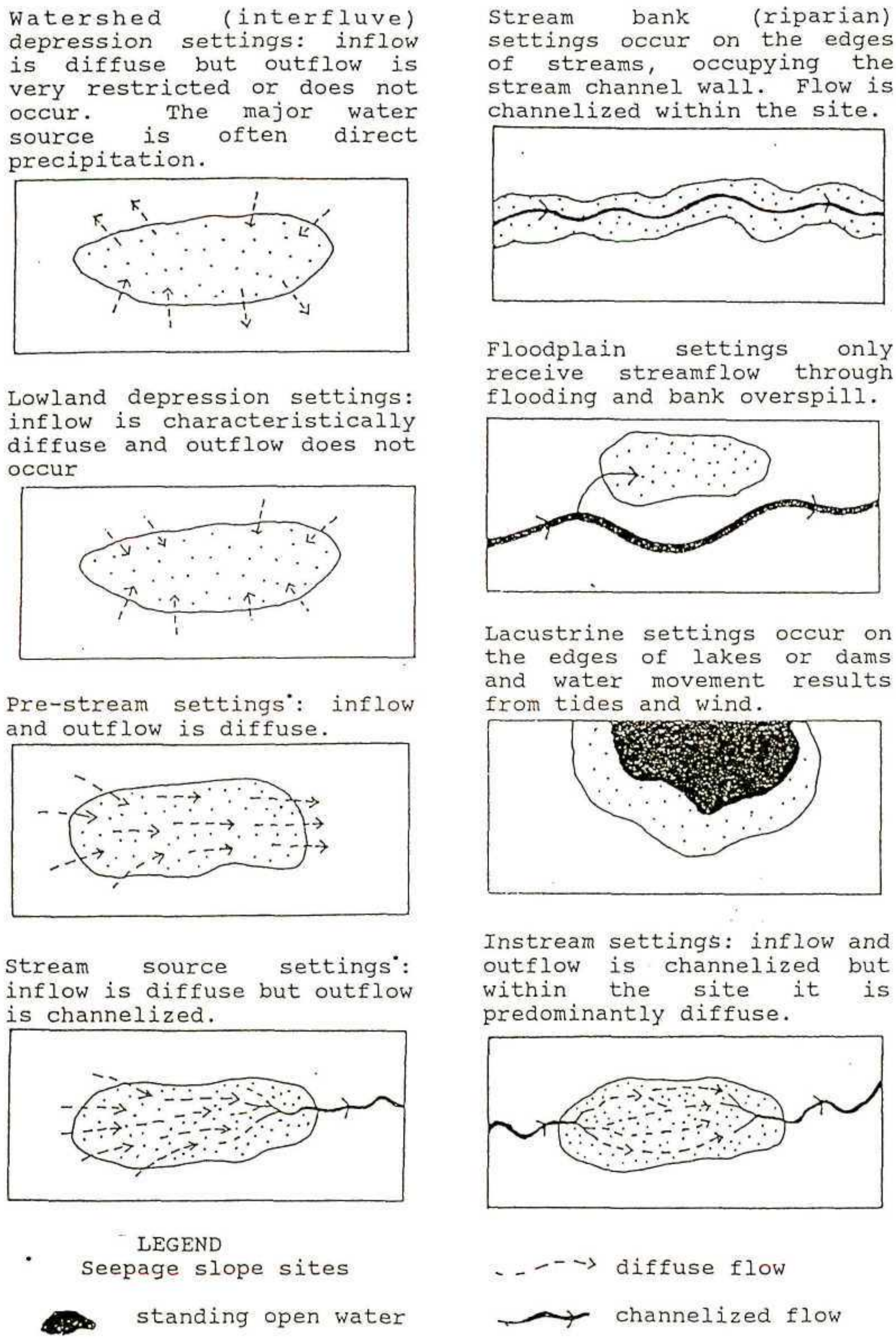
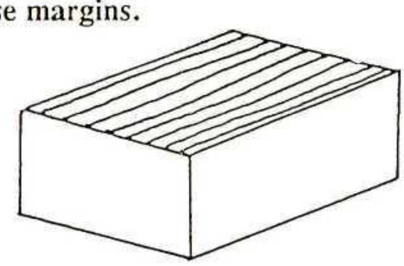
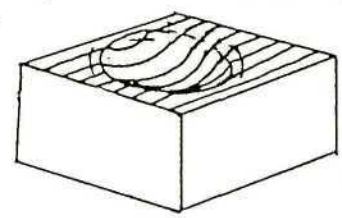


Fig. 5.1 Prototype classification of hydro-geomorphological settings

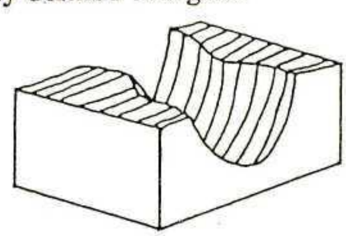
Flats have a slope of < 1 %, little or no relief and diffuse margins.



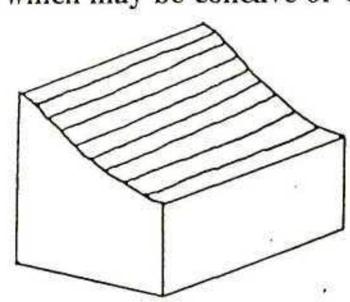
Depressions are depressed basin-shaped areas in the landscape with no external drainage. Depressions may be shallow or deep and may have flat or concave bottoms. They usually do not have clearly defined margins.



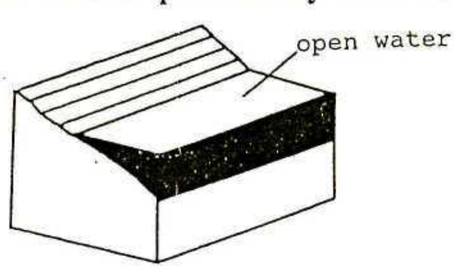
Channels refer to any incised water course. Channels may be shallow or deep but always have clearly defined margins.



Slopes are areas with a gradient of greater than 1 %, which may be concave or convex.



Fringes refer to areas on the edges of open water, such as that provided by lakes or dams.



Channelled flats comprise a flat incised by a channel

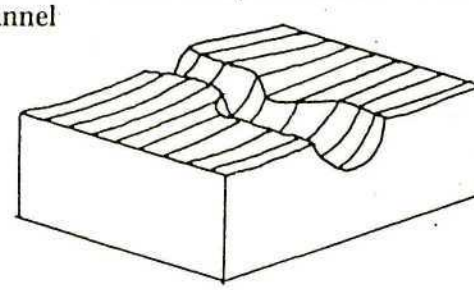


Fig. 5.2 Classification of landform settings

KEY

1 Crest

2 Scarp

3 Midslope

4 Footslope

5 Valley bottom

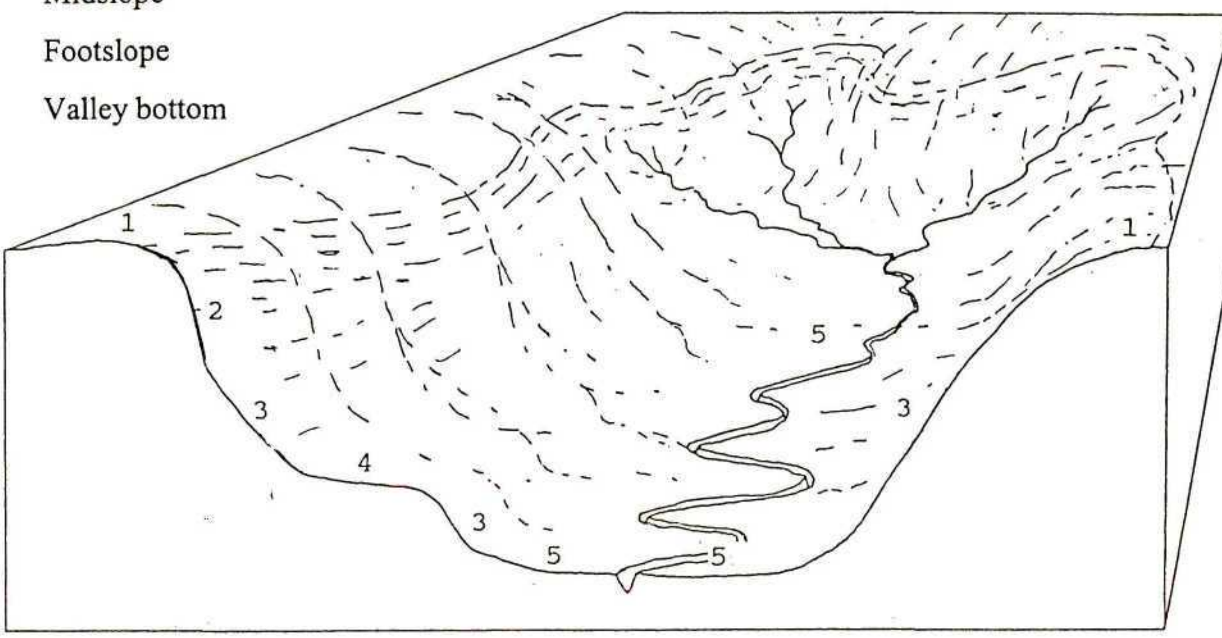


Fig. 5.3 Terrain units (from Land Type Survey Staff, 1986)

Terrain classes refer to areas of the land surface with homogenous form and slope. Terrain may be seen as being made up of all or some of the following catenal units: (1) crest, (2) scarp, (3) midslope, (4) footslope and (5) valley bottom (Fig. 5.3). Although the terrain units are not without genetic implication, morphology and not genesis form the basis for their delineation and description (Land Type Survey Staff, 1986). A valley head, which is the uppermost part of the valley, situated immediately above the head of order 1 stream channels, would be classed as either crest or midslope depending on its position. The terrain unit classification system of the Land Type Survey Staff (1986) is widely used in South Africa by extension workers and much agriculturally- related information has been gathered according to this system. Its inclusion in a scheme for describing the hydro-geomorphological settings of wetlands is therefore likely to promote the adoption of the scheme and its compatibility with existing systems and data-sets. It is nevertheless recognized that alternative systems, notably the nine unit system of Conacher and Dalrymple (1977), have classes which are defined more in functional terms (e.g. considerations of colluvial deposition of sediment) but require a much greater level of expertise for their application than the terrain unit classification.

5.3 Field application of the landform setting and terrain unit classification systems

Methodology

Landform setting classes making up the 66 wetlands were identified and the occurrence of the landform settings was examined in relation to terrain unit, stream order and wetland size. Nine of the larger of these 66 wetlands comprised a combination of two to four of the landform setting classess and these were described separately, effectively giving 95 landform descriptions. The χ^2 test was used to examine the association of landform setting with terrain unit and stream order respectively, with the null hypotheses being that the distribution of wetland sites across terrain unit classes and stream order classes respectively is independent of landform setting. The landform setting and terrain unit classes were described in Section 5.2. Stream order, determined from the 1: 50 000 topographical maps according to the convention of Strahler (1964) was taken as an indication of the relative size of streams. It was recognized that stream order is partly a function of the mapping scale and procedure and it was therefore accepted that stream order provided only a broad indication of the relative size of a stream. The spatial extent of individual wetlands in relation to the landform setting was examined using an ANOVA test. The relation of vegetation to the landform settings is examined in Chapter 6.

Six of the larger wetlands, from a range of climatic conditions (see Table 4.1) were selected for more detailed examination. For each of these wetlands, the spatial distribution of the landform settings was mapped (based on interpretation of topography visible on orthophotographs and the 1: 50 000 topographical maps with verification in the field). The distribution of soil wetness zones was mapped based on interpretation of soil samples (described using the scheme developed in Chapter 4) and supplemented by interpretation of tone and texture on the aerial photographs). The description of soil wetness was therefore conducted independently of any reference to landform (i.e. landform was in no way used to infer the degree of wetness).

The literature reveals that geomorphologically wetlands may be very dynamic (see Meadows, 1988; McCarthy *et al.*, 1992; and Rogers, 1997b). The landform dynamics of each of the six wetlands were investigated for short term changes (i.e. those taking place over the time scale of decades) using a comparative analysis of aerial photographs spanning the period 1936-1944 to 1991-1994. Inferences were made regarding longer term changes based on interpretation of geomorphological features (e.g. cutoff channels) and reference to literature.

Finally, based on existing studies, the relation between landform/terrain and material fluxes (of sediment and nutrients) was discussed with reference to existing literature in order that comments could be offered regarding the likely functional significance of landform settings.

Results of application of the system to the 95 wetland landform sites

The landform settings of wetlands varied considerably according to the terrain units and stream orders with which they were associated (Table 5.1 and 5.2). The null hypotheses that the distribution of wetland sites across terrain units (χ^2[0.01,DF=12]=2.7 E-16) and stream orders (χ^2[0.01,DF=12]=2.5 E-8) were independent of landform setting class were rejected. Depression settings had a somewhat bimodal distribution, and were largely present in the highest and lowest lying areas in the landscape. Slope settings were situated high in the catchment but below the watershed. These settings, in turn, often led into streams of the lowest order (i.e. 11 of the 13 slope settings were associated with a stream of order 1). However, some slope settings (i.e. 2 of the 13 wetlands) were not associated with any stream channel.

The midslope terrain unit and the sloped landform setting class were both defined in terms of steepness of slope and it would therefore be anticipated that they would be correlated. The channelled flat and non-channelled flat were also defined with reference to slope such that it would be impossible to find these landform settings in a midslope position. Similarly, it would be impossible to have a channel or channelled flat with a stream order of "0".

Table 5.1 Frequency of occurrence for the 95 wetland sites of landform settings across terrain units

	Terrain unit			
Landform setting	Crest	Midslope	Footslope	Valley bottom
Channelled flat	1	0*	5	20
non-channelled flat	2	0*	12	17
Channel	1	3	0	10
Depression	4	0	2	5
Slope	1	7	3	2

Note: a stream order = 0 is where no stream channel is present

Table 5.2 Frequency of occurrence for the 95 wetland sites of landform settings across stream order classes

	Stream order			
Landform setting	0	1-2	3-4	>4
Channel	0*	3	4	7
Channelled flat	0*	7	11	8
Non-channelled flat	3	15	9	4
Depression	4	1	1	5
Slope	2	10	1	0

Note: a stream order = 0 is where no stream channel is present

Non-channelled flats were found predominantly associated with streams having a stream order of less than 6, with only two wetlands, Mvoti vlei and Blood River vlei, exceeding this. This suggests that features which cause channel failure (notably a gentle gradient) are generally not strong enough to counter the high levels of discharge associated with very high order streams (see following Section). Channelled flat settings were present predominantly low in the landscape in valley bottoms associated with stream orders greater than 3, and were less constrained by very high stream orders than non-channelled flats.

Although channel wetland settings were one of the most ubiquitous type, occurring in all but the highest positions in the catchment, in all cases they were of limited spatial extent. Wetland areas within channel settings could potentially extend for considerable distances as narrow strips but these are often broken by pools, rapids and steep, well drained streambanks. Fringe settings occur naturally on the edges of lakes. In South Africa, natural lakes are very uncommon, and none of the study sites were found to belong to this setting. Lake Fundudzi in the northern part of South Africa is cited by van der Waal (1997) as the only true inland lake in South Africa, and owes its origin to a landslide across a river. In the inland areas of South Africa, fringe settings are therefore largely confined to the edges of impoundments.

The wetland landform settings varied considerably according to size (Table 5.3). Channel, depression and slope settings were characteristically small (i.e. <3 ha), while channelled flats and non-channelled flats varied greatly in size but were on average much larger. An important factor contributing to differences in size of the flat landform setting sites were the terrain units on which they were found, with channelled flat and non-channelled flat sites having a mean size of 0.48 ± 0.05 ha and 2.9 ± 1.06 ha respectively on footslopes compared with a mean size of 469.8 ± 251.01 ha and 227.3 ± 76.2 ha respectively in valley bottoms. As indicated in Table 5.3, sites are larger in the valley bottom terrain unit than in the other units.

Table 5.3 Wetland size (ha) of different landform settings and terrain units in the 95 wetland sites

	Mean±SE		Mode	n
Landform settings				
Channel	0.8	± 0.12	0.7	14
Channelled flat	379.6	± 205.14	15.0	26
Non-channelled flat	122.1	± 44.68	7.5	31
Depression	1.7	± 0.52	1.3	11
Slope	1.2	± 0.24	0.8	13
Terrain units				
Crest	1.6	± 0.30	1.5	9
Midslope	1.1	± 0.25	0.7	12
Footslope	2.3	± 0.92	0.5	20
Valley bottom	250.1	± 100.7	10.0	54

Of the 66 wetlands examined, none was found to be hydrologically isolated in the sense of lacking a surrounding catchment supplying water to the wetland through sub-surface or surface flow (see Section 4.5), which was anticipated based on the high water deficit in the study area (see Table 4.1). The overall results are summarized in Table 5.4.

Table 5.4 Summary of landform setting occurrence in relation to terrain unit, stream order and size, based on the results from the 95 wetland sites

Landform setting	**Terrain unit**				**Stream order**					**Size**
	crest	foot-slope	mid-slope	valley bottom	0	1-2	3-4	4-6	>6	
Slope	*	*	***	*	*	**				generally <1 ha
Channel		*	*	***		**	**	**	**	generally <1 ha
Channelled flat		*		***		*	**	***	*	Variable, up to ca. 2000 ha
Non-channelled flat		**		***	*	***	***	**		Variable, up to ca. 1000 ha
Depression	**	*		**	**			**	*	generally < 2 ha

* infrequent   ** moderately frequent   *** very frequent

Results of application of the landform setting and terrain unit systems to the six wetlands

The relation of degree of wetness to landform setting

All six wetlands were located in valley bottom positions and dominated by flats (channelled and/or non-channelled) these wetlands varied greatly in the relative proportions of channelled and non-channelled flats. At one extreme was Boschoffsvlei where non-channelled flats were 10 times less extensive than channelled flats and at the other extreme was Mgeni vlei which was comprised of virtually all non-channelled flat (Table 5.5). Despite this variation, the relative extent of permanently/seasonally wet zones for the two landform settings was relatively consistent across the six wetlands, with non-channelled flat areas being occupied by a significantly greater proportion of these zones than the channelled flat areas. Furthermore, as illustrated by Fig. 5.4 and 5.5, the wettest portions of channelled flats generally correspond to areas where tributary streams enter the flat which is associated with the main channel. It is important to note in Fig. 5.4 that Area A, for example, is a channelled flat in relation to the main stream. However, in relation to the tributary stream, the Bloubankspruit, it is a non-channelled flat.

Table 5.5 Ratio of the two dominant landform settings and the proportional extent of hydrological zones in these respective landform settings for each of the six study site wetlands

Study sites	Ratio of area occupied by non-channelled flat and area occupied by channelled flat	Percentage area occupied by permanently or seasonally saturated soils within a particular landform setting	
		Non-channelled flat	Channelled flat
Mbongolwane	3.1	91%	16%
Boschoffsvlei	0.1	79%	11%
Blood River	0.2	83%	21%
Ntabamhlope	9.0	92%	24%
Wakkerstroom	1.5	90%	29%
Mgeni vlei	>40.0	86%	-

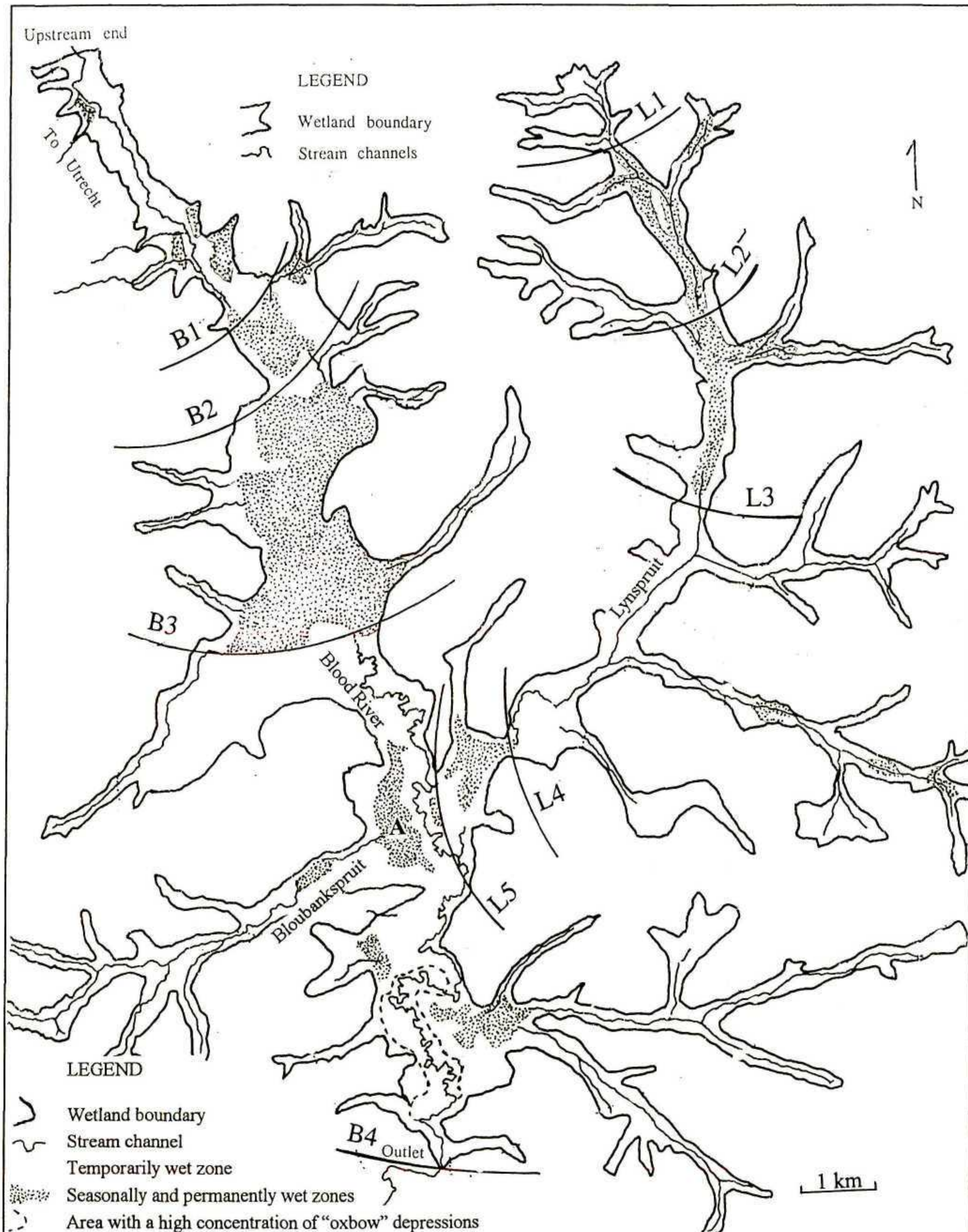


Fig. 5.4 Blood River vlei showing distribution of sectors (B1-B4 and L1-L5), defined on the basis of dominant landform settings.

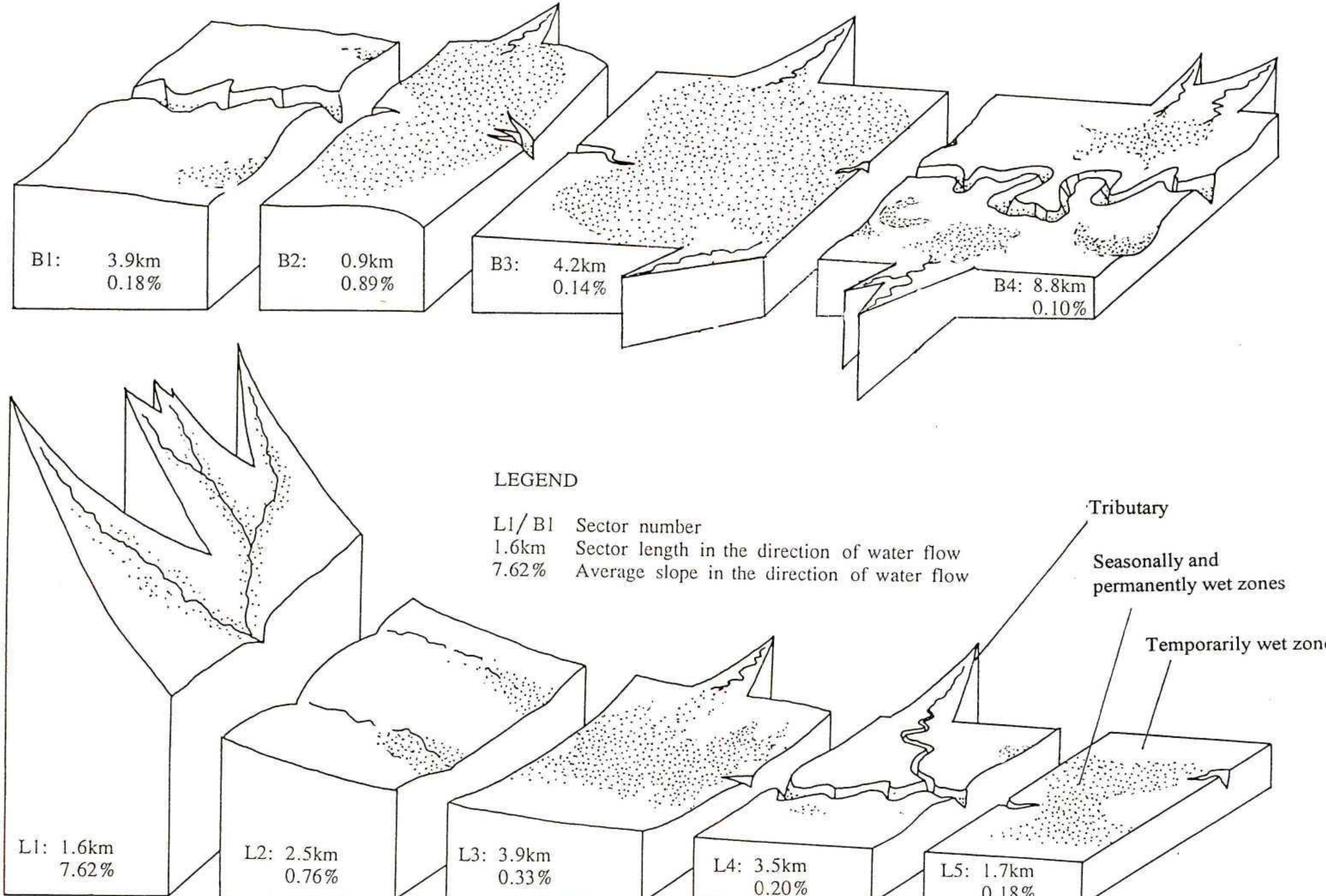


Fig. 5.5 Schematic representation of Blood River vlei showing the dominant landforms for each of the wetland's nine sectors (not drawn to scale)

A feature of the extensive permanently saturated areas within the non-channelled landform setting of the wetlands examined was the presence of a deep (usually >1 m and often exceeding 2.5 m) unconsolidated upper B horizon with a low *n* Value (as defined by Pons and Zonneveld, 1965). The *n* Value refers to the relationship between the percentage of water under field conditions and the percentage of inorganic clay and humus (Pons and Zonneveld, 1965). In these soils the A horizon usually had a relatively high abundance of roots that generally "quaked" when jumped upon, sometimes referred to as a floating marsh.

Although not formally examined in this study, depressions and channels within a channelled flat are generally wetter than the flat areas because of their lower elevation. It is difficult to generalize about the degree of wetness of slopes as this appears to be strongly dependent on localized sub-surface discharge patterns. This investigation did, however, reveal some permanently saturated slopes of >20%.

Geological/geomorphological origin of the different landform settings

Although not examined in detail, preliminary inferences can be made regarding the origin of the different landform settings. Channelled flats and non-channelled flats are generally associated with low gradient portions of streams resulting from some form of obstruction to downward accretion by the stream, including:

1. erosion resistant rock (e.g. dolerite dykes/sills);
2. an obstruction by deposited sediment; and
3. faulting as a result of tectonic activity.

Of the 14 inland wetlands described by Begg (1989) in the priority wetland study for KwaZulu-Natal, 11 of these wetlands, including Wakkerstroom vlei, were found to have a dolerite sill or dyke lying across the river at the outlet of the wetland, and two of the wetlands, one being Mgeni vlei, occurred together with several other wetlands on a plateau underlain by dolerite. Begg (1989) inferred that as dolerite is characteristically resistant to erosion, it acts to arrest downward erosion of natural drainage channels which, in turn, impedes drainage overlying and upstream of its location, resulting in the development of the wetland/s. It should be noted however, that the resistance of dolerite to erosion may vary, depending on the nature of the dolerite and the prevailing climatic conditions (Brink, 1985; Bekedahl H, 1999. *Per comm.* University of Natal, Pietermaritzburg).

Of the 14 wetlands mentioned above, only a single wetland, Boschoffsvlei, was cited by Begg (1989) as having sediment deposits as a controlling factor in the formation of the wetland. This form of control is uncommon in large wetlands as forces of deposition need to be greater than erosive forces of the main drainage channel. For a tributary this is likely to take place at its confluence with a larger river, with rates of deposition across the path of the tributary taking place more rapidly than its removal by the tributary. This is illustrated by the situation at Boschoffsvlei where sediment deposition from the main river in the wetland, the Dorpspruit, which has a high bedload, serves as the impediment to water flow in its tributary, the Wasbankspruit. This, in turn appears to have resulted in a disruption of the channel flow just upstream of where the Wasbankspruit enters the Dorpspruit. It is here that the wettest and most extensive non-channelled area in the wetland is found.

Faulting has a strong disrupting influence on fluvial erosional processes, and may be an important controlling factor particularly in large wetlands (Ellery, *Pers. comm.*, 1997, Department of Geography and Environmental Science, University of Natal, Durban). For example, the ultimate reason for the existence of the Okavango Delta, the largest wetland in southern Africa, is faulting (McCarthy, 1993). This has resulted in the collapse of a segment of the Earth's crust perpendicular to the river feeding the wetland, namely the Okavango River (Cooke, 1980; McCarthy, 1993). It is probably also no coincidence that of the 14 inland priority wetlands (sensu Begg, 1989) two of the three largest wetlands, namely Blood River vlei and Mvoti vlei, are associated with faulting.

Wetland areas which are restricted within the stream channel tend to occur where the stream is confined and the adjacent slopes are relatively steep. Where river channels are unconfined the adjacent flat areas do not, however, automatically support wetland. In all of the wetlands examined such non-wetland areas were found most commonly adjacent to the main stream channel, which tended to be more elevated relative to areas further from the channel.

The origin of depression settings not associated with the current drainage network has received considerably more research effort than most of the other landform settings (see Goudie and Thomas, 1985; and Marshall and Harmse, 1992). These depressions, referred to locally as pans or in the international geomorphological literature as playas, tend to occur in arid and semi-arid regions on landsurfaces of low relief overlying a substrate susceptible to erosion by wind. The orientation of the long axis of many pans perpendicular to the winter wind pattern suggests that aeolian deflation is important in their evolution, and the activities of animals may also contribute to promoting the formation of this landform setting (Goudie and Thomas, 1985; and Marshall and Harmse, 1992). Pans may also be located in paleochannels, formed as a result of a change in drainage patterns, such as in the Lake Chrissie area (Allan *et al.*, 1995).

Depressions associated with the current drainage network tend to have more variable shapes and are often more elongated than depressions not associated with the drainage network. Fluvial processes, notably channel switching, are assumed to have a fundamental controlling influence over the origin of these depressions.

Wetlands on slopes appear to be associated with foci of sub-surface water discharge where impermeable substrata direct groundwater to the landsurface. Such situations result in a small but consistent supply of water, which explains why these wetlands are characteristically small and present on sometimes very steep slopes, with one of the study sites having slopes of >30%.

Landform dynamics

For the 45-55 year period examined, the observed changes in the landform settings, channel flow patterns and zonation for the six wetlands were primarily the result of direct on-site human impacts in the form of dams, drainage channels and roads (see Kotze *et al.*, 1994c, d and e; and Chapter 9). However, some landform setting changes were detected that were the result of natural geomorphological processes that were probably also influenced by anthropogenic effects (e.g. accelerated erosion rates in the wetland's catchment).

Mbongolwane had the only examples of a non-channelled area advancing into a channelled area. Most of the Mbongolwane wetland comprises a non-channelled flat, which is characterized by diffuse flow and predominantly permanently to seasonally saturated soil and herbaceous, emergent marsh vegetation. However, for some of its length the wetland comprises a floodplain with a well defined stream channel, with temporarily wet soil and grassland vegetation on either side of the main channel. Comparison of photographs shows that since at least 1953, non-channelled, diffuse flow areas have been extending into the channelled areas, thereby increasing the extent of marsh in the wetland. In the central channelled area this advance has been at an average of ca 100 m per decade, while in the northern channelled area the advance has been more rapid, with a 1.6 km advance taking place between 1953 and the 1964 (Fig. 5.6). These geomorphological changes in the wetland appear to have resulted largely from the stream channel being filled with deposited sediment, the amount of which is likely to have increased because of increased erosion in the catchment. This is evidenced by the development and expansion of gullies in the wetland's catchment, and an increase in the extent of cultivated land in the catchment from ca. 40% of the area in 1937 to >70% in 1995. It may, therefore, be that accelerated sediment yield from the catchment has greatly accelerated the natural geomorphological process of non-channelled flat development through sedimentation, a characteristic of inland riparian wetlands in the study area. It is hypothesised that with continuing sedimentation, over decades to millennia, these non-channelled flats will become increasingly susceptible to erosion as their landsurface increases in elevation relative to the outlet of the wetland.

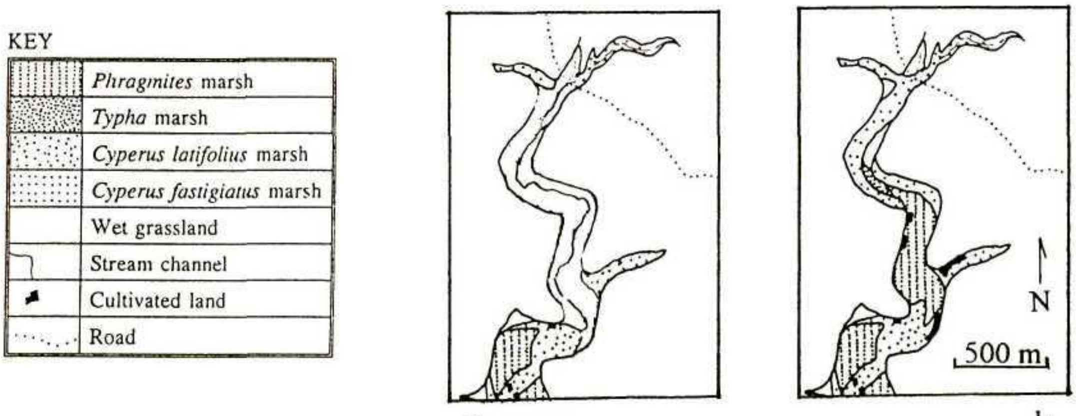


Fig. 5.6 The upper portion of the Mbongolwane wetland: (a) in 1936, showing the clearly defined stream channel and grassland dominated floodplain; and (b) in 1995, showing the lack of a clearly defined stream channel and predominantly marsh vegetation. The relation of this upper portion to the overall wetland is shown in Fig. 9.2.

Two examples of channel advancement into non-channelled flats causing a change in landform setting from a non-channelled flat to a channelled flat were found at Blood River. The most rapidly eroding area in the wetland is on the main Lynspruit stream, where the flow in Sector L3 concentrates to become channelized in Sector L4 (Fig 5.4 and 5.5). Dicks (1992) points out that the donga head, which was ca. 2 m high, advanced into the non-channelled marsh area of Sector L3 at ca. 15 m per year, and by 1992 had converted ca. 150 ha of non-channelled flat into a channelled flat, thereby reducing the degree of wetness of the converted area.

The second example consists of a 0.9 km flat followed by a drop in elevation of over 4 m within a horizontal distance of less than 100 m. This, in turn, is followed by another channelled flat, and the head of the channel is cutting back into the marsh-dominated flat of B2 (see Fig. 5.4 and 5.5). Although its rate of advance is slower than that of the Sector L3 gully, aerial photograph comparison indicates that it has advanced ca. 50 m at two head points over the last 45-year period examined. Field examination (January, 1993) indicated there was no recent back-cutting: large cracks (> 50 cm wide) and slumping were visible, but no blocks of soil had freshly broken away from the face. Although cattle have largely been excluded from the gully head region, they may have contributed to erosion in the past. Aerial photograph comparison suggests that a shift in the position of the head of the channel, caused by deposition of sediment, may also have contributed to increased erosion of the channel. Comparative analyses of aerial photographs at Wakkerstroom shows that the head of the channel at the downstream end of the main non-channelled in the wetland has not advanced upstream during the 50 year period examined. This is despite the fact that the drop in elevation from the flat to the floor of the channel is approximately 2 m and the level of livestock activity in the area has been moderate to high.

The above examples from Mbongolwane and Blood River illustrate two opposing processes, namely deposition and erosion, that characterize large wetlands associated with medium to high order streams. Evidence presented by Kirkby (1976), Meadows (1987) and Dewey (1988) show that patterns of erosion and deposition in wetlands may be influenced by global glacial/inter-glacial climatic cycles. For example, during the last temperate glacial maximum (ca. 18 000 BP) cooler and drier climates would have reduced vegetation cover, leading to greater soil stripping and headward erosion or gullying. Considered at the scale of millennia, areas of the wetland may alternate over time from being channelled to non-channelled and vice versa in response to long term climatic cycles that promote erosional and depositional conditions respectively. According to the hypothesis of Meadows

(1987) the effect of climate is mediated to a large extent through effects on the vegetation. Thus, other factors (e.g. disturbance by grazing and trampelling from ungulates) also potentially affect the erosional/depositional state of the wetland through their effect on vegetation. It could be argued that the erosion of wetlands, as described at Blood River vlei, is part of a natural sedimentation/erosion cycle that characterizes these wetlands. However, counter to this argument, attention should be drawn to the fact that degradation of wetlands in general from anthropogenically accelerated erosion and artificial drainage is high (see Begg, 1988). Thus, intervention to control erosion and exclude aggravating factors such as cattle in these key geomorphological points in the wetland is likely to be justified in many cases.

5.4 Functional significance of the landform settings

Generalizations can be made about the erosional/depositional nature of landform settings. Landform setting classes are essentially nominal but they can, based on the above discussion and the existing studies of Brinson (1988; 1993a and b), be ordered according to their inferred erosional/depositional nature: (1) slopes, which are largely erosional areas (but as indicated by Conacher and Dalrynple (1977) may not necessarily be so); (2) channels, which are erosional/redistribution areas; (3)channelled flats (depositional areas for the flat component and erosional/redistribution for the channel component); (4) non-channelled flat largely a depositional area but with open drainage; and (5) depressions, which are primarily depositional areas but through deflation, particularly under more arid conditions where dieback of vegetation takes place, may be erosional. Empirical evidence from this study further indicates that the localized area where diffuse flow in a non-channelled flat concentrates into a channel are particularly susceptible to gully erosion. These erosional characteristics of the respective landform settings were included in the protocol employed by WETLAND-USE for determining the erosion hazard of a particular wetland area (see Appendix D, Part 1, page21-22).

In South Africa there is a lack of empirical and process-based research linking wetland landform settings with particular functions (e.g. assimilation of nutrients) as is being undertaken in the hydro-geomorphological approach (see Brinson and Rheinhardt, 1996). In this investigation the link was developed at a general level based on limited empirical observation and literature findings, primarily from the U.S. (see Swanson *et al.*,1988; Brinson, 1993a and b). As an aid to making this connection, the donor/receptor/conveyor model of Brinson (1993b) which goes beyond the concept that wetlands merely act as sinks (Fig. 5.7) was expanded to account for wetlands typically found in the study area (Fig. 5.8).

Donor wetlands have no surrounding catchment (i.e. the wetland's catchment comprises nothing more than the wetland surface area) with the result that precipitation is the only source of water. As indicated, owing to the high evaporation to precipitation ratio, donor wetlands are largely absent from South Africa and of the 66 wetlands examined in this study none were found to match this model.

Receiver and conveyor wetlands have surrounding catchments contributing surface and sub-surface water, with the proportions varying considerably depending on the local geological and geomorphological setting, the wetland surface area, and its catchment to wetland area ratio. Although WETLAND-USE does not provide a geological and process-based geomorphological description of this setting it is accounted for to some extent by the generic terrain unit class (e.g. slope or valley bottom), the wetland to catchment area ratio and a record of human activities in the catchment. Receiver wetlands are inward draining, resulting in their having a closed drainage system. Although some water may leave the system through sub-surface flow, most of the water leaves through evaporation, resulting in the concentration of solutes within the system.

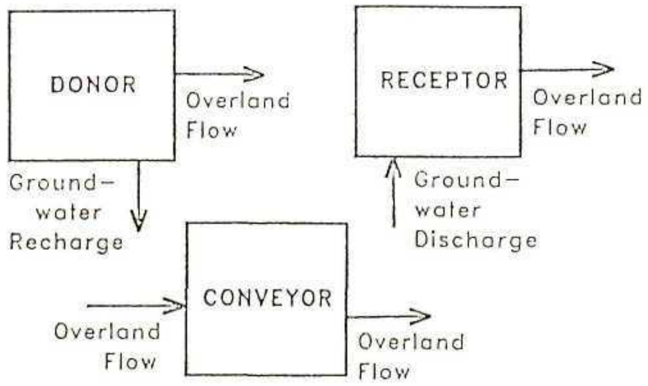


Fig. 5.7 Nomenclature for wetland types based on landscape-level hydrological movement. Donor wetlands "donate" downstream or to ground water but receive water only via precipitation. Receptor wetlands receive mostly groundwater discharge and lose water by overland flow. Conveyor wetlands are dominated by overland flow and are most capable of moving sediment (from Brinson, 1993a).

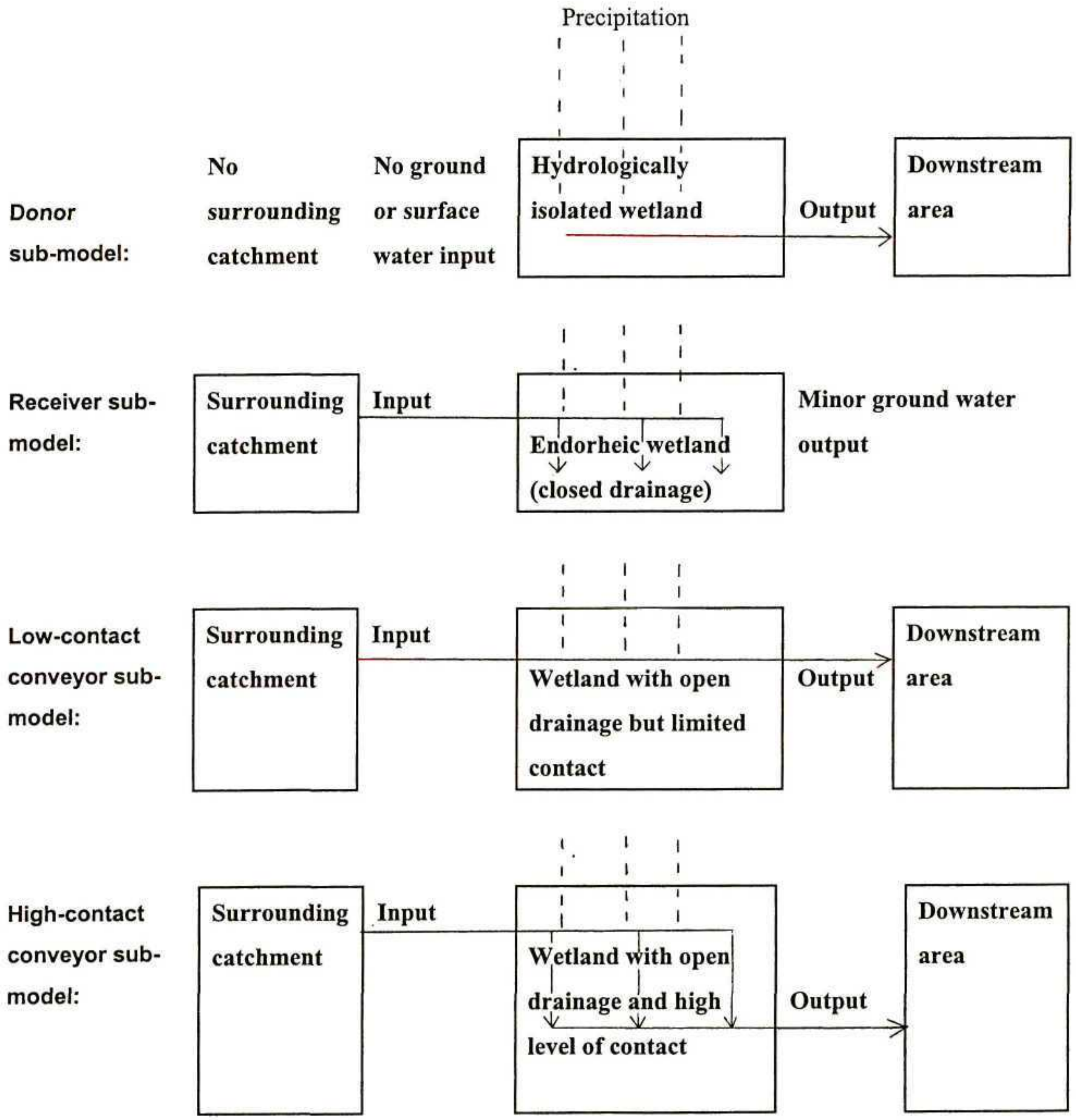


Fig. 5.8 A conceptual model of wetlands according to their openness to lateral exchanges (input and output) of water, and water-borne materials.

Conveyor wetlands have open drainage, with a significant proportion leaving the wetland as surface and sub-surface flow. Results from Ntabamhlope wetland show that during a full year of monitoring, groundwater levels surrounding the wetland were higher than wetland water levels and very limited groundwater recharge was presumed to have taken place, with most of the water leaving the wetland as surface flow or evaporation (Donkin 1994). This is likely to apply to other wetlands with similar local climate, namely Mgeni vlei and Wakkerstroom vlei. In wetlands with a drier climate (e.g. Boschoffsvlei) the likelihood is higher of subsurface groundwater levels surrounding the wetland being at least periodically lower than in the wetland. Conveyor wetlands vary greatly in the extent to which the various patches making up the wetland are isolated from the flow of water and water-borne materials through the wetland, as opposed to being open to the exchange of materials. In a wetland characterized by diffuse flow across its surface, exchange is likely to by high, contrasted with a wetland where flow is concentrated in only a portion of the wetland.

Various allogenic and autogenic processes operate to either strengthen or weaken the degree of isolation, for which Breen *et al.* (1988) provide a conceptual model. For example, the deposition of sediment adjacent to the channel to form a levee (and the stabilization of this feature by plant growth) promotes isolation of the floodplain by increasing the magnitude of runoff events required before flooding will take place. Again, the landform setting classification system and other descriptors employed by WETLAND-USE do not deal directly with these processes but rather with some of their expressions (e.g. extent and distribution of hydrological zones).

The functional significance of a particular type of lateral exchange pattern would also depend to a large extent on the pattern of water supply to the wetland and the materials carried by this water. Although WETLAND-USE considers on a qualitative level, sources of sediment (e.g. actively eroding areas) and nutrients (e.g. fertilized fields) in the catchment supplying a wetland, it does not consider the natural sediment/nutrient budget of a wetland which varies considerably among wetlands (see Mitsch and Gosselink, 1986; Halsley *et al.*, 1997).

The extent to which generalizations can be made about effect of different landform settings on the lateral exchange of materials is now examined. Most receiver wetlands would fall within the depression class, which by definition lacks an outlet. Depressions high in the catchment which are isolated from the drainage network are likely to have smaller catchment to wetland ratios and act strongly as receiver wetlands. However, depressions in valley bottom settings are likely to have much larger catchment to wetland ratios and be subject to high hydraulic energy and flooding that fills the depressions to beyond their capacity. Thus, they more likely to be transitional between the receiver and the conveyor wetlands, and may provide important areas for depressional storage of floodwaters, thereby contributing to flood attenuation. Consequently, from a geomorphological point of view it is important to separate depressions in valley bottoms associated with the drainage network from those isolated from the drainage network.

Non-channelled flats are characterized by diffuse flow across the wetland surface, and a consequent high likelihood of exchange. Thus, these landform settings will generally fit well within the high-contact conveyor wetlands. In channelled flats, a continuum exists from wetlands where throughflow is confined predominantly to only a small portion of the wetland, typically in a channel which has the capacity to hold all but the very highest runoff events (e.g. a 1 in 10 year flood) to wetlands where, even under much lower flow conditions, bank overspill takes place and water flow is spread across the majority of patches in the wetland area, providing a high opportunity for the exchange of materials. Thus, from a functional point of view it would be useful to separate the channelled flat class into a frequently flooded and an infrequently flooded class. Channelled flats also vary according to the retention of this water depending on such features as levees and the extent of depressions in the flat (floodplain). Such features are described only to a very limited extent by the landform setting classification system. However, WETLAND-USE is able to account for these features in part by describing the degree of wetness of the channelled flat, which would be a reflection of the frequency of inundation and the retention of this water as influenced by these features.

Based on the preceding discussion, a general relationship between the landform settings and the indirect benefits supplied by wetlands can be established (Table 5.6). Specific relationships would obviously also depend on several additional features of the wetland such as the erodibility of the soil, slope of the landsurface, and sediment and nutrient budgets of the wetland.

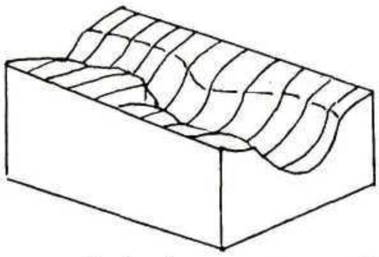
Table 5.6 Matrix showing the general contributions of wetlands on different landform settings to indirect benefits provided by wetlands

Landform setting	Water quality enhancement	Streamflow regulation	Flood attenuation	Erosion control
Slope	**	**	*	***
Non-channelled flat	***	**	***	**
Channelled flat (high-contact)	**	**	***	**
Channelled flat (low-contact)	*	**	**	**
Depression in valley bottom	**	*	***	*
Depression outside of valley bottom	*	*	*	*
Channel	**	*	*	***

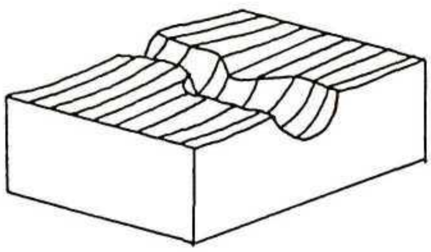
***=High **=Medium *=Low

5.5 A return to the landform setting classification system

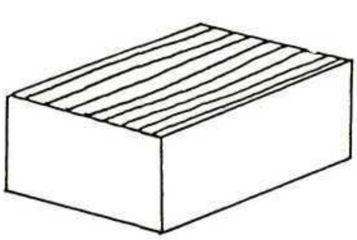
Based on the association of landform settings with particular terrain units (see Section 5.3) and on the discussion of the functional significance of the respective landform settings (Section 5.4) a second revision of the landform setting classification system was undertaken (Fig 5.9) for incorporation into the revised WETLAND-USE system. In this revision, geomorphological considerations are more explicit than in the previous revision and it can be applied independently of the terrain unit classification system, making it simpler to apply by fieldworkers. It is largely a return to the first generation system given in Fig. 5.1 but makes more explicit reference to landform setting and catenal position. The revised system gives nine different landform settings and the flow concentration zone, which describes a geomorphologically important transition between particular landform settings.



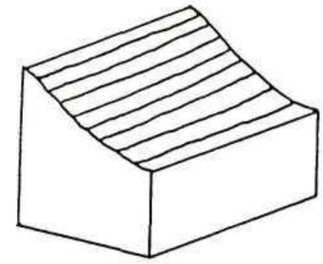
Channels are any incised water course, which may be shallow or deep but always have clearly defined margins



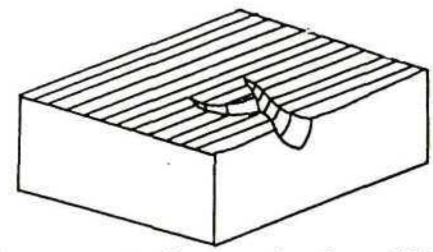
Channelled valley bottoms comprise a valley bottom area of low relief, often described as a floodplain, through which a channel passes. A distinction is made between those where flooding from the main channel is frequent (i.e. more frequent than one out of every three years) and those where flooding is infrequent. Valley bottoms refer to the low lying areas of a valley characterized by the alluvial transport and deposition of material.



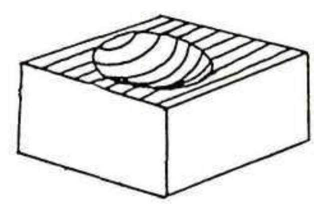
Non-channelled valley bottoms have little relief, lack a channel (and are therefore characterized by the diffuse flow of water across their surface) and occur in valley bottoms.



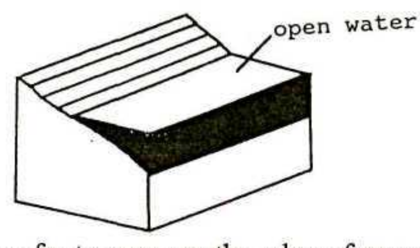
Hill slopes, which may be concave or convex, are situated outside of valley bottom areas and are characterized by colluvial (i.e. transported by gravity) movement of material.



A flow concentration area is where diffuse flow, either across a non-channelled valley bottom or down a slope, concentrates to flow within a channel.



A depressions is a basin shaped area which is inward draining and has no outlet and usually does not have clearly defined margins. A distinction is made between those depressions found within valley bottom areas and those which are outside of valley bottom areas, usually referred to as pans.



Fringes refer to areas on the edge of open water, provided by lakes or dams.

Fig. 5.9 Classification of landform settings used in the revised WETLAND-USE system.

5.7 Conclusions

In order to effectively describe the hydro-geomorphological setting of a wetland, both the landform setting and its relationship with other landform settings need to be described. The application of the landform setting and terrain unit classification systems to 66 wetlands in this investigation provided useful insights into the relationship between the two. Certain landform settings are strongly associated with particular terrain units, while others were ubiquitous in their occurrence. Investigation of the spatial and temporal dynamics and underlying geomorphological origin of six of some of the larger of the 66 wetlands revealed the following.

1. The wetter portions of the wetland were confined mainly to the non-channelled valley bottom areas and it was here that "floating marshes" were found.

2. Although large scale changes in landform settings were uncommon during the 50 year period examined, an example of a channel advancing into a non-channelled flat through erosion was found and in another wetland of a non-channelled flat advancing into a channelled flat through sediment deposition. These examples illustrate two opposing forces through which wetlands develop and change over time.

3. Four of the six wetlands appear to owe their existence to erosion resistant geological strata at their downstream end, the disruption of the drainage pattern by faulting appears to account, together with erosion resistant geological strata for one of the wetlands; and the final wetland appears to owe its existence, in part, to the deposition of sediment at its downstream end.

A conceptual model was developed representing lateral exchanges within wetlands as an aid in determining the functional significance of the different landform settings. This aided in revealing the extent to which WETLAND-USE is able to account for wetland functioning and highlighted the need for local studies on reference wetlands representing a range of different landform settings, as undertaken by Brinson and Rheinhardt (1996).

The landform setting classification system was revised again in light of the investigation of the relation of 98 landform settings to terrain units and the discussion on the functional significance of the landform settings. From a geomorphological point of view this revised system is still superficial and by no means does it provide a complete geomorphological description of a wetland. As illustrated in the landform setting diagram in Fig. 5.5, the protocols developed in this chapter provide only a general indication of the surface flow patterns, together with an estimate of the slope of the overall landform setting. It omits many important factors such as geological controls of a wetland, slope of any channel present, sub-surface hydrology and the direct description of geomorphological processes such as colluvial and alluvial movement and deposition of sediment Nevertheless, it can be applied rapidly, it does not require a high level of expertise and it is considered useful for improving the description of a wetland from a management and functional response point of view. Of note is the influence of the landform setting on the erosion hazard of a wetland, a consideration incorporated into WETLAND-USE. As indicated by Higgins *et al.* (1996) landform settings are easily identifiable by land managers, which will facilitate the extension of research results to land management. Thus, incorporation of the landform setting system into WETLAND-USE is likely to enhance the capacity of the decision support system for providing meaningful management-related information.

Finally, it should be noted that in South Africa, the primary contribution of research to wetland management, at least that reflected in WETLAND-USE, has been by biologists and hydrologists. Very little geomorphological research exists on fresh water palustrine wetlands (sensu Cowardin *et al.*, 1979) in South Africa, particularly in the study area, and trans-disciplinary studies have been sorely lacking. It is strongly recommended that such studies be undertaken. This would certainly enhance the capacity of landform setting classification systems and WETLAND-USE for accounting more directly for wetland function and specifically for such elements as nutrient/sediment budgets and sub-surface flow of water and the relation of these with vegetation pattern. Vegetation is, to a large extent, a reflection of hydrology and, in turn, influences system functioning (see Mitsch and Gosselink, 1987). In the following chapter, the relationship was examined between vegetation and degree of wetness, as characterized by the system developed in Chapter 4, and the landform setting system developed in this chapter.

CHAPTER 6

VEGETATION PATTERN WITHIN AND AMONG PALUSTRINE WETLANDS ALONG AN ALTITUDINAL GRADIENT IN KWAZULU-NATAL

6.1 Introduction

In the face of continuing degradation and loss of wetlands there is a need for protocols and information for assisting in the identification of wetland areas which warrant conservation effort. Also needed are baselines against which to assess the success of management practices and the predicted impact of proposed developments. It is, however, evident from the literature on South African wetlands that there have been no attempts to measure either between-system or within-system diversity and to understand the mechanisms regulating diversity (Breen and Begg, 1989). In KwaZulu-Natal, some wetland community studies have been undertaken on isolated wetlands (e.g. Downing, 1966; Guthrie, 1996), but no comparisons among palustrine (sensu Cowardin *et al.*, 1979) wetlands have been made, and the biodiversity considerations by the prototype WETLAND-USE system were recognized as being deficient and based largely on considering Red Data species. As discussed in Chapter 3, in the United States and elsewhere, there has recently been a shift in biological conservation and management from the conservation of single species and their habitats toward conservation and management of the interactive networks of species and large-scale ecosystems on which species depend (Ostfeld *et al.*, 1997). For this to be realized a basic understanding of the determinants of the structure and functioning of these systems is required. This is potentially extremely complex and the grouping of species into functional types is gaining increased acceptance as a means of understanding ecosystem functioning (Epstein *et al.*, 1997).

In KwaZulu-Natal, wetlands span an altitudinal range of over 2000 m and occur in a diversity of geomorphological settings, and within these wetlands there is tremendous spatial variation in physical features, notably hydrological regime. Based on the literature describing species composition in relation to climate (e.g. Killick, 1963; Halsley *et al.*, 1997), hydrology (e.g. Downing, 1966; Mitsch and Gosselink, 1986; Davis *et al.*, 1996; Runhaar *et al.*, 1997), and landform (e.g. Higgins *et al.*, 1997), a corresponding variation in species composition and diversity is anticipated.

The objectives of this exploratory investigation, aimed at assisting in refining the biodiversity considerations of WETLAND-USE, are the following.

1. Describe biotic variation in terms of graminoid species composition, species diversity and the distribution of C_3 and C_4 functional types, among a range of palustrine wetlands and within selected individual wetlands.
2. Relate the above variation to measured physical parameters, notably local climate and degree of wetness.

6.2 Study area and methodology

The study area, in KwaZulu-Natal, South Africa, included two broad geographic areas surrounding Pietermaritzburg and Vryheid respectively (Fig. 6.1). Within these areas, 66 wetlands lacking clearly visible human impacts, such as artificial drainage channels, were selected for description across an altitudinal range from 550 m to 2120 m and representing a range in size and landform setting. Two levels of description were applied to the wetlands. First, in order to gain an understanding of diversity among the 66 wetlands, each was described as an overall unit in terms of graminoid species composition , and examined in relation to local climate, altitude, and landform setting. Second, a sub-set of six of the 66 wetlands was described in greater detail in order to gain an understanding of within-system species diversity, with the primary focus being the occurrence of plant species in relation to degree of wetness. The six wetlands were spread across the altitudinal range sampled (see Table 4.1).

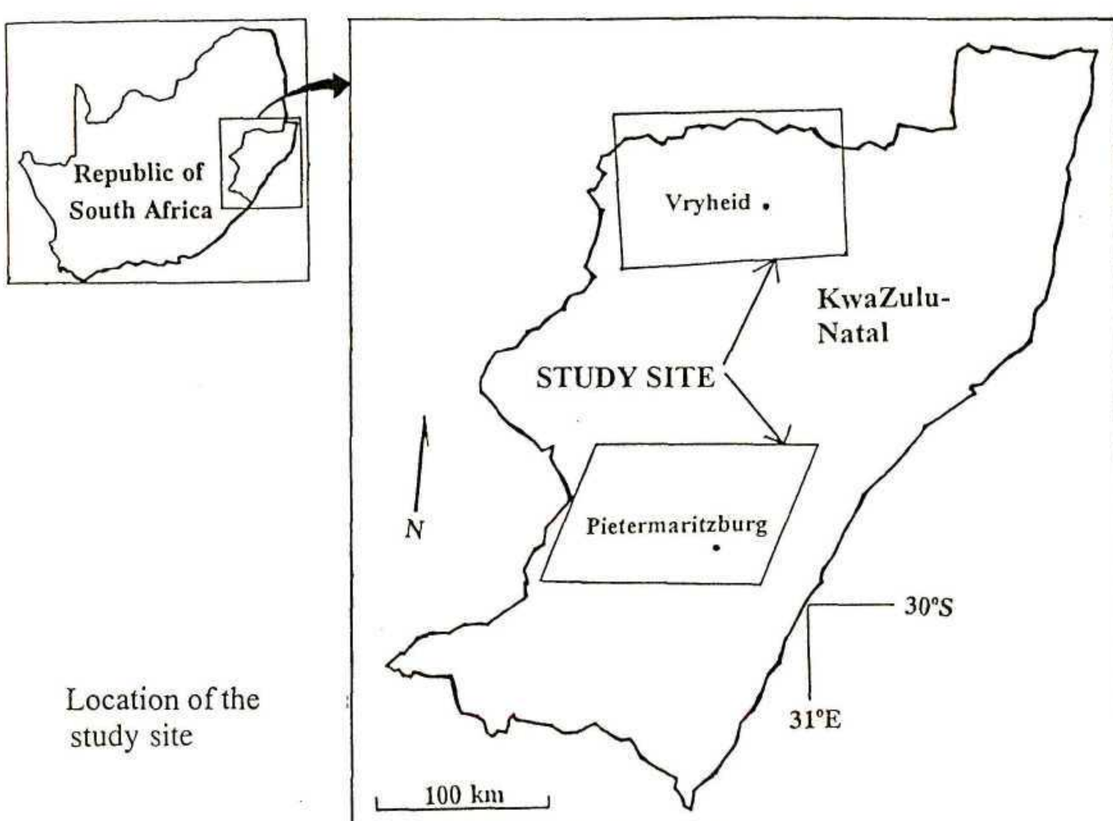


Fig. 6.1 Location of the study site

Graminoid taxa, including Poaceae, Cyperaceae, Juncaceae, and Typhaceae, were selected because a reconnaissance survey of several wetlands in the study area showed that they were all dominated by graminoid plants. Taxon names conform to Gibbs Russell *et al.* (1991), Gordon-Gray (1995) and Obermeyer (1985). It was necessary to restrict the plant taxa considered to graminoid plants owing to the extremely large number of species that would have been encountered and to the problem of identifying cryptophytic plants. Although graminoid species composition constitutes only a component of biotic diversity, the selection of the dominant plant taxa is likely to be meaningful for a wide range of other taxa. Samways (1993), for example, notes that the plantscape has an important bearing on insect behaviour and species survival.

The climate variables described for each wetland, using data from the Computer Centre for Water Research and Department of Agricultural Engineering, University of Natal, included mean annual rainfall and potential evapotranspiration, average daily maximum and minimum temperatures, and average annual water deficit (Dent *et al.,* 1989). The stream order was determined based on that shown in 1: 50 000 maps according to the convention of Stahler (1964), and the landform setting was described using the system given in Chapter 5.

In describing the variation in species composition within the six wetlands, each wetland was stratified into broad zones based on inspection of aerial photographs and a rapid visual appraisal of the dominant plant species and physiognomy. Approximately 10-20 sampling stations were located within each stratum depending on its heterogeneity, assessed visually. The non-wetland area surrounding the wetland was included as an additional stratum. At each sampling station the following were described:

1. the areal cover of the individual graminoid species encountered, rated in a circular 2 m radius sampling plot (1= present but <5%; 2= 5-50%; 3= >50%);
2. hydrological regime, as described by degree of wetness, which was determined indirectly using soil morphological features given in Table 4.3;
3. soil texture, based on a qualitative finger assessment;
4. microtopography in terms of height and spacing of hummocks (raised earth areas about 30 cm in diameter and up to 60 cm high); and
5. landform setting in terms of the classes described in Chapter 5.

As long-term hydrological data were lacking, the water regime was described using the best surrogate measure possible, soil morphology and the four class system developed in Chapter 5 was used for determining the degree of wetness. For each soil description, a core sample was taken to a depth of 0.5 m using a Dutch screw auger. Based on a comparison with the scheme given in Table 4.3, each soil core was identified as one of the four soil wetness classes: permanently/semi-permanently wet, seasonally wet, temporarily wet and non-wetland.

The species were identified as having either C_3 or C_4 photosynthetic pathways based on existing studies. All grass species in the study have been investigated (Ellis *et al.,* 1980; Gibbs Russell *et al.*, 1991) whereas information on local sedge species is available for all genera and sub-genera (most of which have been found to be exclusively C_3 or C_4) and for certain species (Raynal,, 1973; Carolin *et al.*,1977; Bruhl *et al.*,1987; Jones, 1988; Ellery *et al.,* 1992; Ueno and Takeda, 1992).

Several limitations of the study were recognized. First, although an attempt was made to select wetlands lacking anthropogenic impacts it was beyond the scope of this study to quantify levels of impacts and this is likely to have varied among and within wetlands. Second, altitude is an indirect gradient, the influence of which is through temperature and rainfall, and the correlation of these variables with altitude is location specific. Thus, relationships based on such gradients cannot be extrapolated beyond the area that they were measured (Austin and Smith, 1989). Third, the climate data used were generated on a minute by minute basis and may be inaccurate for individual wetlands, particularly in topographically heterogenous areas. Fourth, the hydrology of a wetland is multidimensional, encompassing such factors as the duration and timing of soil saturation and flooding which, for practical reasons, was reduced to a one dimensional measure of the degree of wetness. Fifth, potentially important environmental variables (e.g. soil nutrient levels) were omitted because they were beyond the scope of the study.

6.3 Data analysis and interpretation

For investigation of both the within-system and between-system diversity, Canonical Correspondence Analysis (CCA) (Ter Braak, 1988; 1990) and Correspondence Analysis (CA) (Hill, 1979) were used for revealing patterns in the species composition data and relating the patterns to measured environmental variables. These analyses were conducted with the FORTRAN programme CANOCO

(Ter Braak, 1988; 1990). Species with single occurrences were eliminated from the analyses. Both CA and CCA are ordination techniques that assume a unimodal distribution of species in relation to environmental variables. The environmental gradients of wetness and altitude sampled were wide, suggesting that the response of most species would be unimodal. The assumption of unimodality was checked in an initial analysis. A Monte Carlo permutation test (Ter Braak, 1990), using 99 unrestricted permutations, was used to test whether the included environmental variables had a significant effect on the species distribution.

The outputs of the CCA analyses (which have the constraint that the ordination axes must be linear combinations of the supplied environmental variables) were interpreted according to the rules given in Ter Braak (1987; 1988). The species or sites are represented by points in a biplot (the joint plot of species/sites and environmental variables). An environmental variable is represented by an arrow indicating its direction of maximum variation, and the longer the arrow, the more important is the environmental variable. Nominal environmental variables (e.g. landform setting) are plotted as points located at the centroid of sample scores belonging to each class. The intersection of an orthogonal line from the species point to the environmental arrow represents the weighted average 'centre' of the species distribution along the particular environmental axis.

Individual species were expected to be associated with similar wetness zones across the six different wetlands. For each of the individual species occurring commonly (>20 occurrences) in more than two wetlands, the frequency distribution of individual species across wetness classes and wetland sites was examined using log-linear analysis (Everitt, 1977; STATISTICA, 1995). The significance of the difference between the fit of a saturated log-linear model including the three way interaction of wetness, wetland site, and species occurrence and the same model without this three way interaction was calculated for each individual species examined.

The distribution of photosynthetic pathways in relation to altitude was examined indirectly by observing the relative distribution of species from the four functional groups: C_3 grass, C_4 grass, C_3 sedge and C_4 sedge along the CCA ordination axis (see Section 6.4) which was found to be most closely correlated with altitude. It was then examined directly by expressing the number of species in each of the four functional groups as a percentage of the total number of graminoid species recorded for each of the 66 wetlands and relating this to the altitude of wetland sites through linear regression analysis. In examining the distribution of photosynthetic pathway in relation to degree of wetness for each of the six wetland sites, sampling plots were grouped according to degree of wetness (i.e. non-wetland, temporary, seasonal and permanent/semi-permanent). For each sampling plot described, the cover for each individual species present was determined by assigning each species recorded a percentage cover value comprising the centroid of its recorded cover class, and the percentage cover for each of the four functional groups, C_3 grass, C_4 grass, C_3 sedge, and C_4 sedge, was determined by summing the cover values of species in the respective functional groups. Finally, for each of the six wetlands the mean percentage cover for each the four functional groups across all plots in each wetness zone was calculated and a two-way ANOVA used to determine whether there was an interaction effect between photosynthetic pathway and wetness class on percentage cover; and one-way ANOVA's and Turkey Multiple Comparison Tests were conducted for each of the four functional groups, with the relative cover data arcsine transformed, to examine the specific relationship of individual groups with degree of wetness.

A description of species diversity was undertaken at two levels. First, the relation between the total number of graminoid species recorded per overall wetland and wetland size was examined using regression. Second, the relation between species richness and evenness and degree of wetness was examined for the six wetlands, with the sampling units being grouped according to degree of wetness. The average number of species recorded per 2 m radius plot and the total overall number of species were both calculated for each of the three wetness zones. An ANOVA test was used to test if degree of wetness had a significant effect on species evenness and species richness at the spatial scale of a 2 m radius sampling plot and at the scale of the overall zone, with the six wetlands serving as replicates. Evenness was calculated as $J' = H'/\ln(s)$ (Pielou, 1975) where H' is Shannon's diversity index (Shannon and Weaver, 1949) and s=total number of species recorded in the sample (i.e. for the particular zone).

$$H' = -\sum_{i=1}^{s} (n_i/N \log(n_i/N)$$

where N=total cover recorded for all species in a particular zone, n=total cover recorded for the *i*th species in the particular zone.

6.4 Results and discussion

6.4.1 Pattern within wetlands

The length of the first axis obtained in the CA ordination was greater than 3 s.d. for all of the six wetlands examined, indicating that the choice of a unimodal model was appropriate (Ter Braak, 1987). In all of the six wetlands described, the CA and CCA ordinations accounted for a low cumulative percentage variance of species. The eigenvalue of the first axis was, however, greater than 0.5 in all wetlands except Ntabamhlope vlei, where it was 0.441 (Table 6.1).

Table 6.1 Summary of the CCA outputs for the six wetlands, with CA eigenvalues also included

Wetland sites	Eigenvalues: CCA	CA	Species-environment correlations	Cumulative percentage variance of species data	Cumulative % variance of species-environment relation
Mbongolwane					
Axis 1	0.651	0.783	0.903	7.3	42.9
2	0.291	0.584	0.740	10.5	62.1
3	0.155	0.472	0.635	12.3	72.3
4	0.119	0.391	0.748	13.6	80.1
Boschoffsvlei					
Axis 1	0.595	0.914	0.870	8.5	34.6
2	0.326	0.571	0.855	13.2	53.5
3	0.260	0.510	0.821	16.9	68.6
4	0.136	0.433	0.651	18.9	76.5
Blood River					
Axis 1	0.686	0.850	0.910	7.5	33.3
2	0.336	0.564	0.847	11.2	49.6
3	0.303	0.512	0.800	14.5	64.3
4	0.148	0.464	0.726	16.1	71.4
Ntabamhlope					
Axis 1	0.441	0.862	0.784	5.2	29.2
2	0.317	0.727	0.818	9.0	50.3
3	0.250	0.604	0.700	11.9	66.9
4	0.130	0.480	0.600	13.5	75.5
Wakkerstroom					
Axis 1	0.547	0.845	0.829	8.0	84.4
2	0.101	0.622	0.550	9.4	100.0
3	0.537	0.537	0.000	18.4	00.0
4	0.468	0.468	0.000	26.6	00.0
Mgeni vlei					
Axis 1	0.596	0.916	0.891	9.2	72.6
2	0.138	0.621	0.688	11.4	89.3
3	0.087	0.609	0.570	12.7	100.0
4	0.509	0.509	0.000	24.6	0.0

The difference between the CCA and CA eigenvalues, which indicates the extent to which measured environmental variables account for species composition variation (Ter Braak, 1987), was smaller for Axis 1 than for the remaining axes (Table 6.1). This indicates that although some of the most important environmental variables were accounted for, there were still important outstanding environmental variables. The Monte Carlo test indicated that the measured environmental variables had accounted for a significant amount of the variation ($P<0.01$) both on the first axis and on the overall ordination, except for the Axis 1 of Ntabamhlope vlei which was lower ($P<0.07$) than that of the other five wetlands but was still meaningful.

In the CCA analysis of each of the six wetlands, degree of wetness was the most important environmental factor explaining species variability, and had the highest Axis 1 canonical coefficient of the measured environmental variables. The correlation between degree of wetness and Species Axis 1 was greater than 0.80 in all wetlands except Ntabamhlope vlei, where it was 0.62. When sampling Ntabamhlope vlei, anthropogenic modifications, including drainage channels, were found, which may have affected the relationship between graminoid species composition and soil wetness, as determined using soil morphological indicators.

The distributions of most species in all six wetlands were strongly associated with water regime, with very few of the species occurring frequently across more than two of the water regime classes. With the exception of a few ubiquitous species with high first axis tolerance values (e.g. *Kyllinga erecta*, *Miscanthus junceus* and *Phragmites mauritianus*) there was an almost complete turn-over of species in the wetland along the soil saturation gradient from temporary wetness to permanent wetness. Where species were found in more than one wetland, most occupied similar positions along the wetness gradient (Fig. 6. 2). The optima of *Typha capensis* and *Phragtmites australis* were consistently found to occupy the wettest end of the continuum, together with *Carex acutiformis*, *C. cognata*, *Cyperus fastigiatus* and *Schoenoplectus brachyceras* which were found to occupy positions close to the wettest end of the gradient, with their relative positions varying from wetland to wetland. Similarly, species such as *Pycreus macranthus* and *Fuirena pubescens* were consistently at the central portion of the gradient and species such as *Eragrostis curvula* and *Themeda triandra*, which are found widely outside of wetland areas, were restricted to the driest end of the continuum. It is noteworthy that *P. australis* and *P. mauritianus*, which are taxonomically close and architecturally similar, have wetness gradient optima that are far apart, with *P. mauritianus* being found under less wet conditions.

Some exceptions to the general trend were, however, found in Boschoffsvlei. Here species such as *Eleocharis dregeana* and *Hemarthria altissima* were found noticeably closer to the wettest end of the gradient. This difference may result from the fact that Boschoffsvlei lacks the wettest areas found in all of the other wetlands, as discussed in Chapter 4.

A consistent trend in all the wetlands was that wetness was positively correlated with non-channelled settings and negatively correlated with floodplain settings, as can be seen from the relative positions of the non-channelled and floodplain centroids in the CCA plots (Fig. 6.2). As discussed in Chapter 5, non-channelled settings receive streamflow even when flow volumes are at very low levels. Furthermore they are not drained by a channel. In contrast, floodplain settings receive streamflow only when flow volumes are sufficiently high to result in bank overspill, and they are drained by a channel. Thus, non-channelled settings are generally more conducive to the retention of water than floodplain settings. Some permanent/semi-permanently saturated areas are, however, found in floodplain areas within localized backmarsh depressions or "deltas" fed by tributary streams. In summary, landform affects species composition through its influence on hydraulics which, in turn, influences the resulting water regime zonation within the wetland.

An interesting feature of Boschoffslvei was a depression area separated out as distinct form other areas of equivalent wetness in the CCA ordination. This area shows affinity with endorheic depressions of more arid westerly parts of the country through the occurrence of *Diplachne fusca* and *Eleocharis dregeana*, which are characteristic species found in these wetlands (Geldenhuys, 1979) and was not encountered in any of the other sites.

Soil texture was most strongly correlated with Axis 1, but less so than for degree of wetness. Although the soils were found to be predominantly fine textured in all of the wetlands, there was a positive correlation between soil texture and wetness, with the soils becoming more fine textured with increasing wetness. This relationship may possibly be attributable to the fact that the wettest areas are often the most low lying and gently sloped, where water flow velocity is lowest and the deposition of the finest sediment takes place, or that the moisture holding capacity of fine textured soils is generally greater than coarse textured soils. Several wetland studies (e.g. Halsley *et al.*, 1997; Higgins *et al.*,1997) have found texture to be a good correlate with vegetation pattern. The high level of correlation between wetness and texture in this study does not allow comment on the influence of texture alone on species composition.

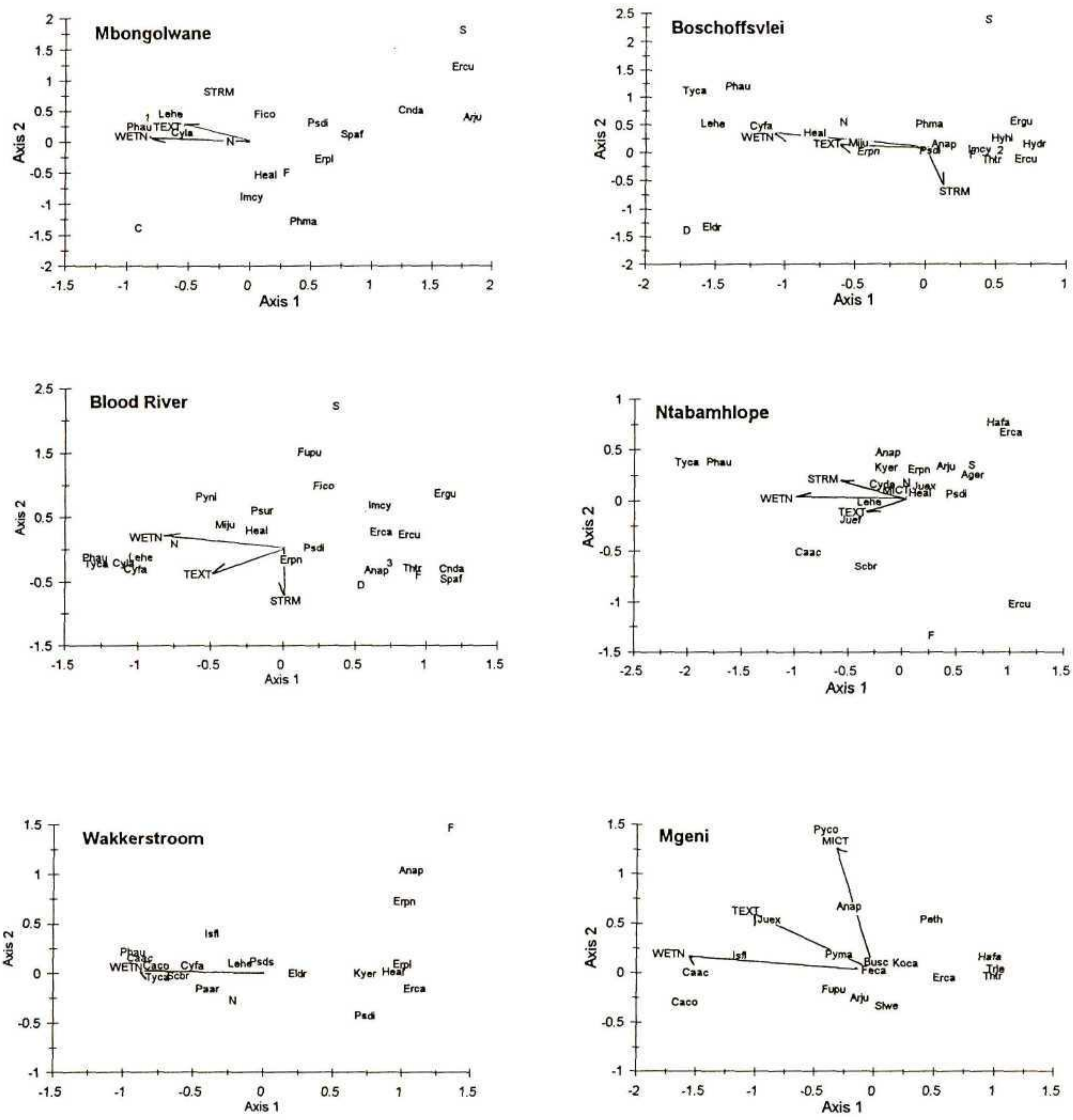


Fig. 6.2 CCA ordination diagrams for the six wetlands, showing only commonly occurring species. **KEY:** Ager, *Agrostis eriantha*; Agla, *Agrostis lachnantha*; Anap, *Andropogon appendiculatus*;Arju, *Aristida junciformis*; Busc, *Bulbostylis schoenoides*;Caco, *Carex cognata*; Caac, *Carex acutiformis*; Cyda, *Cynodon dactylon*; Cyfa, *Cyperus fastigiatus*; Cyde, *Cyperus denudatus*; Cyla, *Cyperus latifolius*; Cydv, *Cyperus dives*; Eldr, *Eleocharis dregeana*; Ercu, *Eragrostis curvula*; Erpl, *Eragrostis plana*; Erpn, *Eragrostis planiculmis*; Erca, *Eragrostis capensis*; Feca, *Festuca caprina*; Fico, *Fimbristylis complanata*; Fupu *Fuirena pubescens*; Hafa, *Harpochloa falx*; Heal, *Hemarthria altissima*; Hydr, *Hyparrhenia dregeana*; Hyhi, *Hyparrhenia hirta*; Imcy, *Imperata cylindrica*; Isfl, *Isolepis fluitans*; Jueff, *Juncus effusus*; Juex, *Juncus exsertus/oxycarpus*; Koca, *Koeleria capensis*; Kyer, *Kyllinga erecta*; Lehe, *Leersia hexandra*; Miju, *Miscanthus junceus*; Pssc, Psdi, *Paspalum dilatatum*; Psur, *Paspalum urvillei*; Psdi, *Paspalum distichum*; *Pennisetum thunbergii*; Phau, *Phragmites australis*; Phma, *Phragmites mauritianus*; *Pycreus cooperi*; Pyma, *Pycreus macranthus*; Pyni, *Pycreus nitidus*; Pymu, *Pycreus mundii*; Scbr, *Schoenoplectus brachyceras*; Slwe, *Scleria welwitschii*; Stsp, *Setaria sphacelata*;; Thtr, *Themeda triandra*; Trle, *Tristachya leucothrix*; *Tyca, Typha capensis*; F, channelled flat; D, depression; N, non-channelled flat; S, slope; ALT, altitude; MICT, microtopography; STRM, stream order; TEXT, soil texture; WETN, degree of wetness; 1=Cydv, Pymu, Tyca; 2=Arco, Cnda, Erpl; 3=Erpl, Phma, Stni.

When examining the relationship between the distribution of individual species and degree of wetness for different wetland sites, the difference in fit between log-linear models with and without the three-way interaction of degree of wetness, wetland site and species occurrence, was found to be non-significant (P>0.05) in 13 of the 16 species examined (Table 6.2). Thus, it can be concluded that generally the relationship between commonly occurring species and degree of wetness, as determined indirectly using soil morphology, does not vary significantly among wetlands.

Table 6.2 Improvement in fit of the log-linear model, as indicated by Maximum Likelihood Ratio Chi-squared, when including the three way interaction of wetness, wetland site and species occurrence for 16 commonly occurring species

Species	df	χ^2	p
Carex acutiformis	6	1.112	.9810
Cyperus fastigiatus	9	10.974	.2775
Eleocharis dregeana	9	14.090	.1192
Eragrostis curvula	12	12.502	.4063
E. plana	9	7.329	.6029
E. planiculmis	9	19.779	.0194
Fuirena pubescens	9	4.571	.8700
Hemarthria altissima	12	27.403	.0068
Imperata cylindrica	9	4.575	.8697
Leersia hexandra	12	84.414	<.0001
Paspalum dilitatum	12	12.404	.4139
Phragmites australis	12	10.686	.5560
P. mauritianus	6	5.434	.4895
Pycreus macranthus	6	3.691	.7184
Themeda triandra	9	14.499	.1057
Typha capensis	12	7.226	.8423

However, in three of the 16 species, *Leersia hexandra, Hemarthria altissima* and *Eragrostis planiculmis*, the difference was significant (Table 6.2), indicating that their association with particular wetness zones was less consistent across wetland sites. This was particularly so for *L. hexandra*, which is a common weed in areas such as rice paddies and irrigation channels and has been shown to rapidly colonize areas with disturbed soils (Imeokparia, 1989; Oka, 1989). *Hemarthria altissima* is a rapidly spreading rhizomatous species that also appears adapted to colonizing such disturbed areas. It is hypothesised that disturbance and other factors which may restrict the competition from tall clonal species have a significant modifying influence on the distribution of certain colonist species such as *L. hexandra.*

6.4.2 Diversity among wetlands

The difference between the eigenvalues for CCA and CA was small for Axis 1 but considerably larger for Axes 2, 3 and 4 (Table 6.3) indicating that there were important outstanding explanatory variables. Nevertheless, the Monte Carlo test indicated that the measured environmental variables accounted for a significant amount of the variation ($P<0.01$) both of Axis 1 and of the overall ordination. Axis 1 of the CCA ordination, which accounted for a large amount of the variability in the species data, as indicated by a high eigenvalue of 0.522, was strongly correlated with altitude (-0.918). A steady change in the eigenscores of the 66 sites was found along the first site ordination axis, with no distinct grouping of sites along this axis. The eigenvalues of the Axes 2 and 3 were appreciably lower than that of Axis 1. Rainfall deficit was the environmental factor most strongly correlated with the second axis. The third axis was difficult to interpret but appeared to be best explained by landform, the channel class being strongly correlated with this axis. Overall, landform explained a fairly low level of variability in comparison with altitude.

Table 6.3 Summary of the CCA and CA outputs for the analysis of 66 wetlands

	CCA				CA			
Axes:	1	2	3	4	1	2	3	4
Eigenvalues	.522	.207	.142	.139	.569	.350	.290	.260
Species-environment correlations	.968	.899	.897	.891	.951	.325	.734	.503
Cumulative percentage variance:								
of species data	8.5	11.9	14.2	16.5	9.3	15.0	19.7	23.9
of species-environment relation	30.6	42.8	51.1	59.3	29.8	31.9	41.0	44.8

From the direction of the arrows in the species biplot (Fig. 6.3), the strong negative correlation of altitude and temperature, particularly minimum temperature, and the weak correlation of altitude and rainfall deficit and evaporation, are apparent. The main spread of species is clearly visible along the altitude/temperature gradient. Besides differences in altitudinal optima (Table 6.4), species varied greatly in the altitudinal range that they occupied. The CCA analysis provides a measure of environmental tolerance (Table 6.4). Species such as *Cyperus sexangularis* and *Merxmuellera macowanii* had low values, being confined to a small portion of the altitudinal gradient, while species such as *Aristida junciformis*, *Agrostis lachnantha*, *Phalaris arundinacea* and *Carex cognata* had high tolerance values indicating occurrence across a wide altitudinal range. Although *C. cognata* had such a wide altitudinal range, it was absent, along with *C. acutiformis* and *C. austro-africana*, from wetlands with high rainfall deficit values. All three species were entirely absent from all of the seven wetlands with rainfall deficit values exceeding 1000 mm.

Table 6.4 Taxon (Grass [Poaceae]; Sedge [Cyperaceae & Juncaceae]) Photosynthetic pathway, species scores, frequencies, and tolerance values (niche width) and cumulative fit per species (as a fraction of variance of species) for the first and second axes of the CCA analysis of the data from the 66 wetlands, with species ordered according to their positions on the CCA Axis 1.

Species	Taxon & Photo path.	Species scores: Axis 1	Species scores: Axis 2	% frequ.	Tolerance values Axis 1	Tolerance values Axis 2	Cumulative fit Axis 1	Cumulative fit Axis 2
Cyperus sexangularis	Grass C_4	-1.7713	0.0587	3	0.2220	0.4190	12.2%	13.0%
Pycreus polystachyos	Grass C_4	-1.7493	-0.9077	4	0.1183	0.6456		<10%
Bothriochloa insculpta	Grass C_4	-1.6238	-2.2659	2	0.1527	0.1000		<10%
Isolepis prolifera	Sedge C_3	-1.6205	-0.775	2	0.1551	0.5781	7.2%	10.1%
Cyperus dives	Sedge C_4	-1.5825	-0.9332	4	0.2605	0.1893		<10%
Panicum maximum	Grass C_4	-1.5671	-1.4802	6	0.1393	0.5347	9.1%	16.9%
Hyparrhenia cymbaria	Grass C_4	-1.5374	-0.3532	2	0.0951	0.3863		<10%
Chloris gayana	Grass C_4	-1.4878	-1.5039	10	0.2706	0.5355	9.5%	16.2%
Fimbristylis ferruginea	Sedge C_4	-1.4864	0.0433	2	0.4698	0.1919		<10%
Cyperus sphaerospermus	Sedge C_3	-1.4384	-1.3111	8	0.1178	0.6583		<10%
Juncus krausii	Sedge C_3	-1.4215	1.2048	3	0.3440	1.3331	8.6%	13.8%
Digitaria eriantha	Grass C_4	-1.3887	-1.1605	16	0.3106	0.9238	25.9%	35.0%
Cynodon dactylon	Grass C_4	-1.3663	0.5275	7	0.3699	1.3015	19.7%	19.8%
Fimbristylis complanata	Sedge C_4	-1.3403	0.7125	3	0.4511	1.0634	11.1%	13.9%
Cyperus articulatus	Sedge C_4	-1.2998	0.8315	5	0.4491	1.0538	13.9%	16.5%
Kyllinga melanosperma	Sedge C_4	-1.296	-0.9493	15	0.3727	0.8545	37.1%	42.7%
Phragmites mauritianus	Grass C_3	-1.2758	0.6673	10	0.3684	1.0289	25.1%	27.0%
Hyparrhenia hirta	Grass C_4	-1.2241	0.0441	12	0.3504	1.0900	21.0%	21.1%
Mariscus sumatrensis	Sedge C_4	-1.2174	-0.3584	5	0.3368	1.1254	9.8%	11.6%
Cyperus latifolius	Sedge C_4	-1.2118	-0.5839	11	0.3596	0.9044	14.3%	16.6%
Sporobolus pyramidalis	Grass C_4	-1.2001	-0.4375	7	0.4507	1.1801		<10%
Aristida congesta	Grass C_4	-1.1655	2.9695	3	0.4977	1.1062		<10%
Brachiaria eruciformis	Grass C_4	-1.1655	2.9695	3	0.4977	1.1062	12.5%	40.0%
Pycreus mundii	Sedge C_4	-1.1349	-0.0117	10	0.4516	0.9462	19.5%	19.7%
Cyperus longus	Sedge C_4	-1.1264	0,075	12	0.3934	0.9157	22.8%	22.8%
Paspalum urvillei	Grass C_4	-1.0622	-0.4107	14	0.4878	1.0631	25.7%	25.8%
Paspalum scrobiculatum	Grass C_4	-1.0554	1.1525	7	0.5747	1.1408	16.0%	23.9%
Juncus punctorius	Sedge C_3	-1.0461	0.1925	4	0.5316	0.8754		<10%
Fimbristylis dichotoma	Sedge C_4	-1.0201	-0.8058	13	0.5620	0.9527	16.1%	16.8%
Cymbopogon validus	Grass C_4	-0.9843	-0.9489	12	0.4623	0.9953	8.8%	11.7%
Pennisetum macrourum	Grass C_4	-0.9794	-0.3372	10	0.4705	0.8755	10.6%	10.9%
Imperata cylindrica	Grass C_4	-0.9517	0.293	14	0.4247	0.9010	21.2%	22.4%
Setaria sphacelata	Grass C_4	-0.9156	-1.1671	20	0.4024	0.8054	18.1%	33.8%
Miscanthus junceus	Grass C_4	-0.8763	2.3224	4	0.3766	1.1499	8.1%	35.8%
Cyperus esculentus	Sedge C_4	-0.8698	0.6514	7	0.5417	1.3016		<10%
Mariscus solidus	Sedge C_4	-0.8183	-0.2381	9	0.4653	0.8314		<10%
Cyperus fastigiatus	Sedge C_4	-0.7708	0.5737	12	0.5153	1.0179	11.9%	13.0%
Andropogon eucomus	Grass C_4	-0.7533	1.7313	7	0.4796	0.9434	12.5%	40.0%
Hyparrhenia quarrei	Grass C_4	-0.7452	0.0809	8	0.2991	0.7793		<10%
Sporobolus africanus	Grass C_4	-0.7387	0.4777	14	0.6941	1.1555	10.0%	10.2%
Leersia hexandra	Grass C_3	-0.7338	-0.3974	32	0.6521	0.9629	28.3%	31.3%
Eragrostis gummiflua	Grass C_4	-0.6798	4.6436	2	0.0493	0.3104	4.0%	53.9%
Agrostis eriantha	Grass C_3	-0.6551	0.8701	8	0.3900	0.8033		<10%
Typha capensis	TypaceaeC_3	-0.6275	0.4809	17	0.7828	0.9673	12.8%	17.7%
Hemarthria altissima	Grass C_4	-0.6255	0.6169	19	0.5682	0.9547	15.5%	21.6%
Paspalum distichum	Grass C_4	-0.544	0.9059	16	0.9517	0.6544	9.8%	17.3%
Setaria pallide-fusca	Grass C_4	-0.5381	0.989	7	0.4024	0.8054		<10%
Eragrostis curvula	Grass C_4	-0.4787	-0.2572	27	0.8376	0.0424		<10%

Juncus lomatophyllus	Sedge C_3	-0.4687	-1.2924	15	0.7776	0.6070	4.8%	13.3%
Mariscus congestus	Sedge C_4	-0.4474	-0.0197	12	0.7992	1.0999		<10%
Ischaemum fasciculatum	Grass C_4	-0.4362	-0.3575	8	0.9957	0.8096		<10%
Schoenoplectus paludicola	Sedge C_3	-0.4257	-0.6482	6	0.6140	0.9582		<10%
Hyparrhenia rufa	Grass C_4	-0.3629	0.2843	5	0.4850	0.8888		<10%
Pycreus nitidus	Sedge C_4	-0.3501	0.6635	6	0.2806	0.8995		<10%
Phragmites australis	Grass C_3	-0.3012	0.651	20	0.8497	0.9218		<10%
Paspalum dilatatum	Grass C_4	-0.2355	0.4647	7	0.9514	0.6544		<10%
Cyperus denudatus	Sedge C_4	-0.2147	0.5505	8	0.7271	0.9236		<10%
Miscanthus capensis	Grass C_4	-0.2131	-0.7979	19	1.0483	0.7389		<10%
Eragrostis plana	Grass C_4	-0.1351	0.5296	19	0.8304	1.0472		<10%
Schoenoplectus decipiens	Sedge C_3	-0.1214	2.0647	4	0.6808	1.0709		<10%
Arundinella nepalensis	Grass C_4	-0.0862	-0.9451	24	0.8785	0.8872	0.0%	10.4%
Fuirena pubescens	Sedge C_3	-0.0715	-0.1063	27	0.9338	1.0074		<10%
Kyllinga erecta	Sedge C_4	-0.0627	0.1699	13	0.8590	0.9157		<10%
Eragrostis chloromelas	Grass C_4	0.0477	4.183	3	0.7442	0.3898	0.1%	59.3%
Eleocharis limosa	Sedge C_3	0.0477	4.183	3	0.7442	0.3898	0.1%	59.3%
Setaria nigrirostris	Grass C_4	0.1354	3.5583	3	0.8337	0.7427	0.0%	24.5%
Cyperus difformis	Sedge C_3	0.1826	-0.2463	9	0.8527	0.7875		<10%
Pennisetum unisetum	Grass C_4	0.1907	0.9286	5	0.8205	0.8300		<10%
Juncus effusus	Sedge C_3	0.1936	0.1161	19	0.8539	0.7566		<10%
Helictotrichon turgidulum	Grass C_3	0.2097	0.5154	4	0.6249	0.9617		<10%
Phalaris arundinacea	Grass C_3	0.2098	-0.0223	8	1.0260	0.8205		<10%
Carex cognata	Sedge C_3	0.4089	0.5207	18	0.9268	0.7686		<10%
Themeda triandra	Grass C_4	0.4201	1.1385	14	0.9415	1.0279	4.9%	10.6%
Carex acutiformis	Sedge C_3	0.4372	-0.227	27	0.8788	0.8680		<10%
Elionurus muticus	Grass C_4	0.4455	3.6116	2	0.7636	0.1590	0.4%	29.7%
Abildgaardia ovata	Sedge C_3	0.4455	3.6116	2	0.7636	0.1590	0.4%	29.7%
Aristida junciformis	Grass C_4	0.4679	-0.3459	35	1.0699	0.9160	8.8%	12.9%
Eragrostis capensis	Grass C_4	0.4835	1.085	13	0.9283	1.0217	3.0%	10.5%
Agrostis lachnantha	Grass C_3	0.4915	-0.3939	15	1.0123	0.8270		<10%
Rhynchospora brownii	Sedge C_3	0.5823	-0.4024	9	0.6358	1.0789		<10%
Schoenoplectus brachyceras	Sedge C_3	0.5869	1.3821	8	0.5663	0.7703	4.2%	14.3%
Juncus exsertus/oxycarpus	Sedge C_3	0.6269	-0.504	27	1.1089	0.8686		<10%
Scleria welwitschii	Sedge C_3	0.7075	0.9876	7	0.7827	0.7932		<10%
Eragrostis planiculmis	Grass C_4	0.8032	-0.3622	28	0.8278	1.0000	16.3%	16.8%
Tristachya leucothrix	Grass C_4	0.9212	0.3926	7	0.6828	0.8842	9.7%	10.6%
Pycreus unioloides	Sedge C_4	0.9733	1.2415	6	0.6282	0.9601	6.1%	12.6%
Harpochloa falx	Grass C_4	0.9855	0.9806	10	0.7212	0.7386	19.6%	24.1%
Pycreus sp	Sedge C_4	1.0823	0.7195	5	0.2348	0.4669	10.4%	11.2%
Eleocharis dregeana	Sedge C_3	1.0953	-0.0869	28	0.1973	0.9471	22.3%	22.3%
Isolepis fluitans	Sedge C_3	1.1365	-0.3097	18	0.7587	0.7988	19.6%	20.7%
Fingerhuthia sesleriiformis	Grass C_4	1.1686	1.2231	4	0.3439	0.3650		<10%
Carex austro-africana	Sedge C_3	1.1789	-0.6468	11	0.5693	0.6433	12.8%	13.3%
Hyparrhenia dregeana	Grass C_4	1.2917	0.2703	4	0.8585	1.3928		<10%
Ascolepis capensis	Sedge C_4	1.3459	-0.2629	7	0.3171	0.8342	15.9%	16.2%
Isolepis costata	Sedge C_3	1.3643	-1.3186	10	0.7668	0.7159	11.4%	11.7%
Pycreus cooperi	Sedge C_4	1.3812	-0.7601	8	0.3401	0.9095	10.0%	10.4%
Scleria dietelenii	Sedge C_3	1.4199	-0.1044	4	0.1575	0.7010	12.8%	12.8%
Pycreus macranthus	Sedge C_4	1.4365	-0.1249	12	0.5646	1.0265	16.0%	16.7%
Digitaria setifolia	Grass C_4	1.4487	2.5154	2	0.0390	0.3395	7.6%	12.6%
Agrostis barbuligera	Grass C_3	1.5555	-0.5256	3	0.1011	0.7386		<10%
Bulbostylis schoenoides	Sedge C_4	1.5985	-0.1623	11	0.6575	1.0066	19.6%	21.5%
Andropogon appendiculatus	Grass C_4	1.6008	-0.3666	29	0.6926	0.9914	44.1%	44.6%
Merxmuellera macowanii	Grass C_3	1.6381	0.0057	6	0.2061	0.5579	14.9%	15.3%
Poa binata	Grass C_3	1.6727	0.4872	4	0.5651	0.9743		<10%

Diheteropogon filifolius	Grass C_4	1.6766	0.8972	2	0.2036	0.3965	10.2%	10.2%
Scirpus ficinioides	Sedge C_3	1.7387	0.0807	4	0.1575	0.6816	10.2%	11.4%
Pennisetum sphacelatum	Grass C_4	1.7431	-0.3258	2	0.2517	0.9527		<10%
Juncus dregeanus	Sedge C_3	1.7437	-0.6208	10	0.3013	0.6090	22.0%	22.1%
Schoenoxiphium rufum	Sedge C_3	1.7479	-0.7135	4	0.2294	0.8680	8.7%	11.7%
Festuca costata	Grass C_3	1.7521	0.2244	4	0.1572	0.7218	10.0%	10.2%
Kyllinga pauciflora	Sedge C_4	1.802	0.1254	4	0.2456	0.5366	12.9%	13.0%
Carpha filifolia	Sedge C_3	1.812	0.742	3	0.0765	0.2539	11.3%	11.6%
Festuca caprina	Grass C_3	1.8147	-0.8772	10	0.3028	0.6998	20.9%	21.7%
Bromus inermis	Grass C_3	1.8221	-0.6871	4	0.5631	0.6754		<10%
Aristida monticola	Grass C_4	1.9595	-0.5099	2	0.1788	0.6015		<10%
Koeleria capensis	Grass C_3	1.9994	-0.802	13	0.3519	0.6047	22.4%	24.2%
Pennisetum thunbergii	Grass C_4	2.0031	-1.3595	11	0.3533	0.4385	25.4%	27.3%

Although there were a few species (e.g. *Aristida junciformis*) with wide altitudinal ranges, there was a high turn-over of species from an altitude of 550 m to 2050 m. In permanent/semi-permanently wet areas there was an appreciable increase in the number of dominant species and greater architectural diversity with decreasing altitude. At altitudes >1 700 m the main dominant species was *Carex acutiformis* (C_3) or, in depressions, *Eleocharis dregeana* (both species seldom reaching heights of more than 1.5 m and 0.8 m respectively). *Carex* belongs to the subfamily Caricoideae, which is considered to have acquired thermal adaptations to temperate and cold regions (Ueno and Takeda, 1992). Emerging shoots of *C. acutiformis* were observed in the study area during winter, and similar observations were made by Gorham and Somers (1973) in a study of *Carex* in Canada.

At altitudes of 1100 m to 1700 m, besides *Carex* species, *P. australis* (C_3), *Cyperus fastigiatus* (C_4), and *Typha capensis* (C_3) dominated extensive areas. These three species generally reach heights of greater than 4 m, 1.5 m and 1.8 m respectively. At 800 m to 1 100 m where, although *Carex* species were less extensive, all of the dominant species encountered in the preceding altitudinal zone were present with the addition of *Cyperus latifolius* (a C_4 species reaching heights of 2 m). At <800 m, *Carex* species were not dominant and *Cyperus dives* (C_4) was found as an additional dominant species.

Wetland areas found to be markedly hummocked were predominantly at altitudes >1 400 m. The inherently tussocky nature of some of the plant species and the activities of earthworms, observed to be abundant in many of the hummocks, appear to contribute to this micro-topographical feature. Climatic factors may also be directly involved in the origin of the hummocks through local displacement of surface soil material resulting from seasonal frost penetration, as shown by Grab (1994) to occur in certain wetlands in Lesotho. Such phenomena have, however, only been described at altitudes >2 800 m, where air temperatures are lower and the number of frost days in a year greater than in the coldest sites in the study area.

Seasonally and temporarily wet areas with vegetation heights less than 1 m were seldom dominated by a single species. Although these areas remained physiognomically similar across the altitudinal range sampled, there was a turn-over of commonly occurring species from high to low altitudes. In the seasonally wet areas *Scleria* spp., *Rhynchospora brownii* (both C_3) and *Kyllinga erecta* (C_4) were replaced by species in the sub-genus *Cyperus* (C_4), *Fimbristylis* spp. and *Kyllinga melanosperma* (both C_4) with decreasing altitude. *Fuirena pubescens* (C_4), which had a high first axis tolerance value, was the most widely distributed species common to these areas.

In the temporarily wet areas *Festuca caprina* and *Koeleria capensis* (both C_3) were restricted to altitudes >1 700 m, *Andropogon appendiculatus* extended to 1 100 m, and *Digitaria eriantha* and *Chloris gayana* (both C_4) were largely restricted to altitudes <1 100 m.. Two species which were found to dominate certain seasonally wet areas, *Mariscus solidus* and *Cyperus sexangularis* (both C_4) were restricted to altitudes less than 1200 m and 900 m respectively and tall *Hyparrhenia* spp. (C_4), which dominated certain temporarily wet areas, were restricted to altitudes <1 700 m.

While landform setting was found to be less important than altitude in affecting overall species composition, certain species showed strong affinities with particular landform settings and geomorphological features. *Cyperus fastigiatus* was associated with valley bottom flats having mid to high order streams. Within its altitudinal range it was absent from all wetlands isolated from the stream network or with a stream order of less than three and was present in over 60% of those wetlands with a stream order greater than 3. It was commonly found in non-channelled portions and particularly in oxbow depressions and margins of slow flowing streams. In contrast, *Eleocharis dregeana* appeared to be strongly associated with depressions and occurred in all depressions described, most of which were isolated from the drainage network. Similarly, in an investigation of the wetlands of the Drakensberg (Dely *et al.*, 1996) of the 13 depressions described, the only ones lacking *E. dregeana* were the shallow temporarily wet depressions, lacking permanently or seasonally wet areas.

At altitudes <800 m, where topography is dissected and rainfall generally lower than at higher altitudes, extensive non-channelled and floodplain wetlands were considerably less common than at altitudes of 800 m to 1800 m, where topography is less dissected and rainfall generally higher. At the lower altitudes, in particular, wetlands are largely restricted to narrow areas within and immediately adjacent to stream channels and, to a lesser extent, to small areas (usually < 1 ha) on seepage slopes. This would explain why the channelled setting is associated with lower altitudes (see Fig. 6.3).

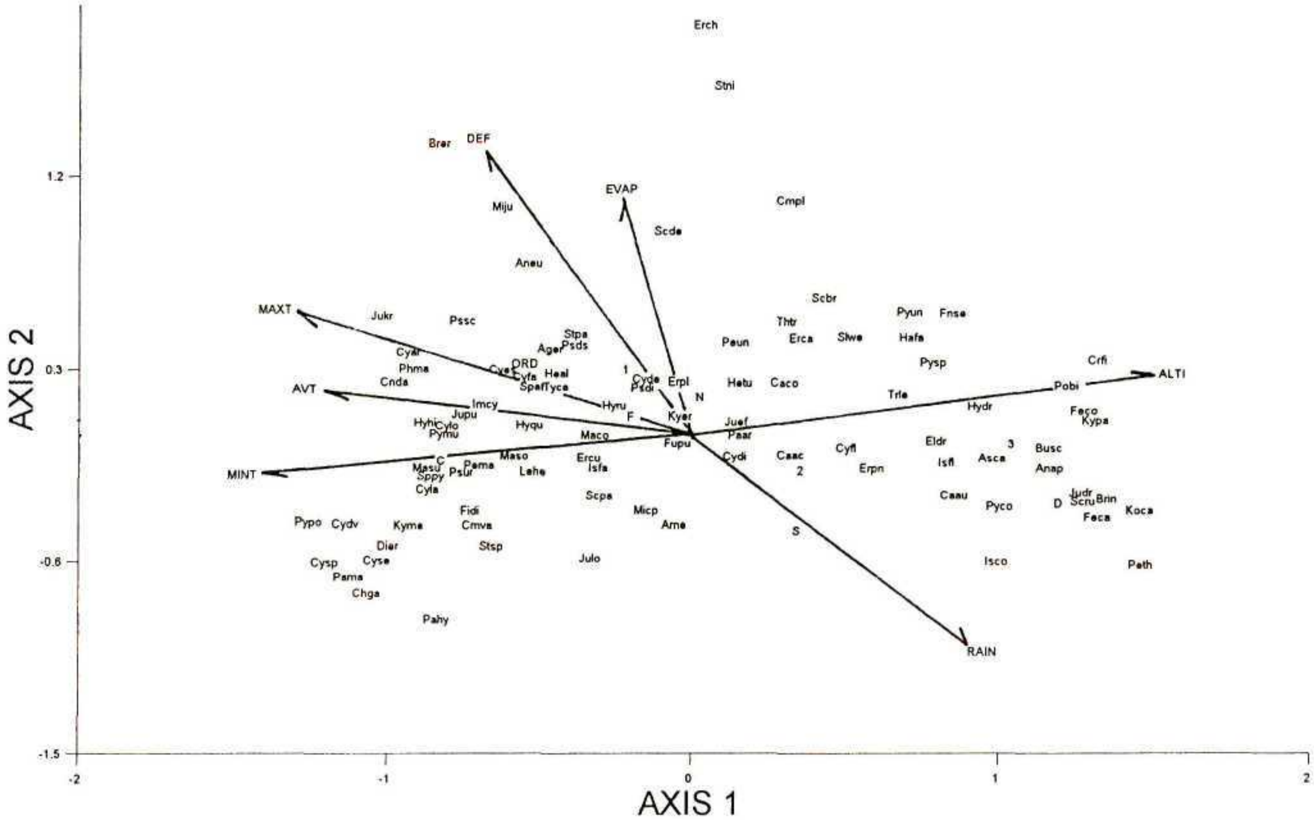


Fig. 6.3 CCA ordination diagram of 66 wetland sites

KEY: Ager, *Agrostis eriantha*; Aneu, *Andropogon eucomus*; Anap, *Andropogon appendiculatus*; Arne, *Arundinella nepalensis*; Asca, *Ascolepis capensis*; Brin, *Bromus inermis*; Busc, *Bulbostylis schoenoides*; Caau, *Carex austro-africana*; Caco, *Carex cognata*; Caac, *Carex acutiformis*; Chga, *Chloris gayana*; Cmva, *Cymbopogon validus*; Cyda, *Cynodon dactylon*; Cyar, *Cyperus articulatus* Cyes, *Cyperus esculentus*; Cyfa, *Cyperus fastigiatus*; Cyfl, *Cyperus flavescens*, Cydi, *Cyperus difformis*; Cyde, *Cyperus denudatus*; Cylo, *Cyperus longus*; Cyla, *Cyperus latifolius*; Cydv, *Cyperus dives*; Cyse, *Cyperus sexangularis*; Cysp, *Cyperus sphaerospermus*; Dier, *Digitaria eriantha*; Eldr, *Eleocharis dregeana*; Ercu, *Eragrostis curvula*; Erpl, *Eragrostis plana*; Erpn, *Eragrostis planiculmis*; Erca, *Eragrostis capensis*; Feco, *Festuca costata*; Feca, *Festuca caprina*; Fidi, *Fimbristylis dichotoma*; Fnse, *Fingerhuthia sesleriiformis*; Fupu *Fuirena pubescens*; Hafa, *Harpochloa falx*; Hetu, *Helictotrichon turgidulum*; Heal, *Hemarthria altissima*; Hydr, *Hyparrhenia dregeana*; Hyhi, *Hyparrhenia hirta*; Hyru, *Hyparrhenia rufa*; Hyqu, *Hyparrhenia quarrei*; Imcy, *Imperata cylindrica*; Isfa, *Ischaemum fasciculatum*; Isfl, *Isolepis fluitans*; Isco, *Isolepis costata*; Judr, *Juncus dregeanus*; Jueff, *Juncus effusus*; Julo, *Juncus lomatophyllus*; Jupu, *Juncus punctorius*; Koca, *Koeleria capensis*; Kyme, *Kyllinga melanosperma*; Kypa, *Kyllinga pauciflora*; Kyer, *Kyllinga erecta*; Lehe, *Leersia hexandra*; *Mariscus sumatrensis*; Maso, *Mariscus solidus*; Maco, *Mariscus congestus*; Mema, *Merxmuellera macowanii*; Miju, *Miscanthus junceus*; Mica, *Miscanthus capensis*; Pama, *Panicum maximum*; Pssc, *Paspalum scrobiculatum*; Psdi, *Paspalum dilatatum*; Psur, *Paspalum urvillei*; Psdi, *Paspalum distichum*; Pema, *Pennisetum macrourum*; Peun, *Pennisetum unisetum*; Peth, *Pennisetum thunbergii*; Paar, *Phalaris arundinacea*; Phma, *Phragmites mauritianus*; Pobi, *Poa binata*; Pyun, *Pycreus unioloides*; Pypo, *Pycreus polystachyos*; Pyni Pyco, *Pycreus cooperi*; Pysp, *Pycreus* sp; Pymu, *Pycreus mundii*; Scbr, *Schoenoplectus brachyceras*; Scpa, *Schoenoplectus paludicola*; Scde, *Schoenoplectus decipiens*; Scru, *Schoenoxiphium rufum*; Scfi, *Scirpus ficinioides*; Slwe, *Scleria welwitschii*; Stsp, *Setaria sphacelata*; Stpa, *Setaria pallide-fusca*; Sppy, *Sporobolus pyramidalis*; Spaf, *Sporobolus africanus*; Thtr, *Themeda triandra*; Trle, *Tristachya leucothrix*; *Tyca, Typha capensis*; 1: *Phragmites australis*; *Pycreus nitidus*; 2: *Agrostis lachnantha*; *Aristida junciformis*; *Juncus exsertus/oxycarpus*; *Rhynchospora brownii*; 3: *Pycreus macranthus*; *Scleria dregeana*; F, floodplain (channelled flat); D, depression; N, non-channelled flat; S, slope; ALTI, altitude; STRM, stream order; RAIN, mean annual rainfall; EVAP, potential evapotranspiration; MAXT, average daily maximum temperatures; MINT, average daily minimum temperature; AVT, overall average daily temperature; DEF, average annual water deficit.

In examining species composition in relation to broad geographical areas, most of the species recorded were shared by the Pietermaritzburg and Vryheid sites, with only a few species having restricted distributions. The most obvious difference between the Pietermaritzburg and the Vryheid sites was the replacement of *Miscanthus capensis* by *M. junceus* (both largely absent from high altitude sites).

6.4.3 Distribution of photosynthetic pathways in relation to degree of wetness and altitude

The interaction of photosynthetic type and degree of wetness in determining percentage vegetation cover was found to be significant ($P<0.001$) in all of the six wetlands. In the case of all four functional types in all six wetlands, except for the C_3 grasses in the Mgeni vlei, variances of means of relative cover among wetness classes were significantly ($P<0.05$) greater than expected on the basis of variance of cover within wetness classes (Table 6.5). In all of the six wetlands the mean relative cover of C_4 grasses was significantly higher in the non-wetland and temporary classes than in the wetter (i.e. seasonal and permanent/semi-permanent) classes. In the three higher altitude wetlands mean relative cover of C_4 grasses was significantly lower in the temporary class than in the non-wetland class but no significant differences were detected between these classes in the lower altitude wetlands.

In the highest altitude wetland there was no significant difference in the mean relative cover of C_3 grasses between any of the wetness classes, and in the next highest wetland only the wettest class and the non-wetland class were significantly different. In all of the remaining four wetlands the mean relative cover of the permanently wet class was significantly greater than at least the temporary and non-wetland classes. The low C_3 grass cover in the wetter zones at high altitudes compared with lower altitudes can be attributed to the fact that the predominant C_3 grass species associated with the wetter zones, *P. australis* and *L. hexandra*, are entirely absent from all wetlands >1 800 m.

The mean relative cover of C_4 sedges in the permanently wet class was generally not significantly different or, in the case of two of the wetlands, was lower than the seasonal sites. A similar trend was found for C_3 sedges at the three lower altitude wetlands, with no significant differences detected between the permanent and seasonal classes. However, in all of the three higher altitude wetlands the relative cover of C_3 sedges in the permanently wet class was significantly higher than that of the seasonal class. In the case of both C_3 and C_4 sedges, no significant differences were generally detected between the relative cover of the temporary and the non-wetland classes (see Table 6.5).

Table 6.5 Comparison of mean (±SE) percentage cover of the four functional groups C_4 grasses, C_3 grasses, C_4 sedges, C_3 sedges within sampling plots grouped into the four wetness classes, permanent/semi-permanent, seasonal, temporary and non-wetland, for the six wetland sites. Significant differences are indicated by the different letters (P<0.05)

	Degree of wetness			
	Permanent/ semi-permanent	Seasonal	Temporary	Non-wetland
Mongolwane (550 m)	(n=13)	(n=43)	(n=21)	(n=15)
C_4 grasses	1.7 ± 4.70a	21.0 ± 32.99a	79.6 ± 22.73b	94.3 ± 21.47b
C_3 grasses	39.6 ± 41.88a	13.2 ± 18.05b	10.0 ± 17.33b	1.1 ± 4.30b
C_4 sedges	49.2 ± 41.35b	57.6 ± 38.07b	10.4 ± 13.44a	4.6 ± 17.18a
C_3 sedges	9.5 ± 04.70a	8.2 ± 32.99ab	0.0 ± 0b	0.0 ± 0b
Boschoffsvlei (1150 m)	(n=8)	(n=28)	(n=50)	(n=23)
C_4 grasses	0.2 ± 0.58a	47.6 ± 36.62b	91.9 ± 18.51 c	92.6 ± 15.78c
C_3 grasses	85.0 ± 24.20a	22.8 ± 23.04b	5.4 ± 13.87 c	6.0 ± 15.52 c
C_4 sedges	1.7 ± 2.07a	6.2 ± 15.23a	2.3 ± 8.43 a	1.4 ± 5.01 a
C_3 sedges	13.1±24.34ab	23.4 ± 33.06b	0.4 ± 2.24 a	0.0 ± 0 a
Blood River (1250m)	(n=30)	(n=51)	(n=51)	(n=18)
C_4 grasses	6.6 ± 16.94a	43.4 ± 31.49b	91.7 ± 17.69c	94.8 ± 11.81c
C_3 grasses	68.4 ± 33.02a	22.7 ± 25.86ba	4.6 ± 16.26b	2.5 ± 7.26b
C_4 sedges	22.5 ± 28.13a	25.9 ± 23.12a	2.5 ± 6.22b	1.1 ± 2.15b
C_3 sedges	2.5 ± 7.67a	8.0 ± 15.01a	1.2 ± 3.97a	1.6 ± 6.11a
Ntabamhlope (1480m)	(n=27)	(n=35)	(n=21)	(n=16)
C_4 grasses	9.0 ± 16.56a	36.8 ± 23.40b	62.6 ± 33.63c	91.3 ± 33.24d
C_3 grasses	47.7 ± 27.70a	32.1 ± 23.48a	15.2 ± 26.47b	5.9 ± 10.45b
C_4 sedges	6.7 ± 8.97a	21.2 ± 24.82b	8.9 ± 12.11ab	1.2 ± 8.72a
C_3 sedges	36.6 ± 31.84a	9.9 ± 15.78b	13.3 ± 22.75b	1.6 ± 6.18b
Wakkerstroom (1750m)	(n=52)	(n=21)	(n=19)	(n=14)
C_4 grasses	2.4 ± 8.47a	37.5 ± 36.129b	63.5 ± 36.20c	90.1 ± 11.54d
C_3 grasses	23.1 ± 19.53a	12.2 ± 15.07ab	14.6 ± 19.77ab	8.5 ± 11.26b
C_4 sedges	16.2 ± 19.75a	14.6 ± 16.50a	9.6 ± 14.12ab	0.4 ± 1.17b
C_3 sedges	58.3 ± 28.36a	35.7 ± 37.64b	12.3 ± 19.31bc	1.0 ± 2.00c
Mgeni vlei (1830m)	(n=12)	(n=13)	(n=18)	(n=14)
C_4 grasses	12.6 ± 18.18a	19.8 ± 25.81a	61.6 ± 35.42b	88.4 ± 12.14c
C_3 grasses	0.7 ± 1.49a	3.3 ± 5.93a	9.0 ± 17.84a	10.7 ± 11.86a
C_4 sedges	11.1 ± 17.76a	43.1 ± 27.64b	17.4 ± 20.85c	0.4 ± 1.06a
C_3 sedges	75.6 ± 36.49a	33.8 ± 25.89b	12.0 ± 14.96c	0.5 ± 1.32c

A significant relationship between proportional contribution to the overall number of graminoid species per wetland and altitude was found with the C_4 grass ($P<0.01$), C_3 grass ($P<0.01$), C_4 sedge ($P<0.001$) and C_3 sedge ($P<0.001$) functional types groups; the relationship was negative for the C_4 groups and positive for the C_3 groups (Fig. 6.4). There was a concentration of C_4 species on the low altitude end and C_3 species on the high altitude end of CCA ordination Axis 1, which was strongly correlated with altitude (Table 6.4).

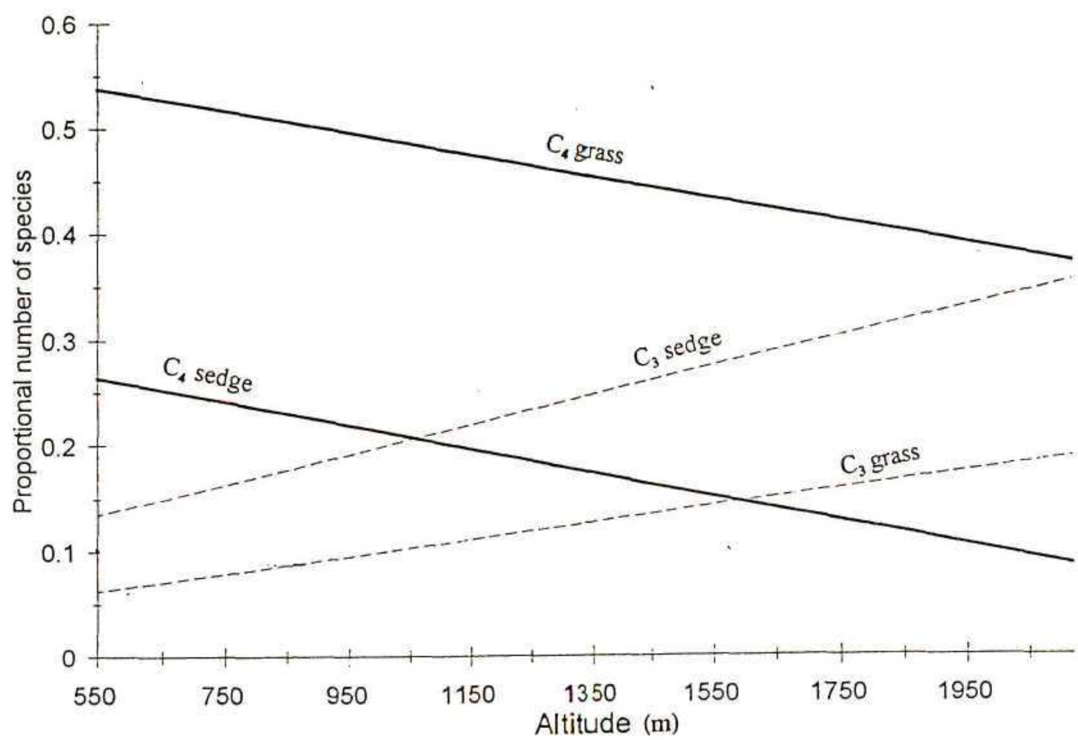


Fig. 6.4 The relationship between proportional contribution to the overall number of graminoid species per wetland and altitude for the four functional types: C_4 grass (Y= -0.00011(Altitude [m]) + 0.596), C_3 grass (Y= 0.00008(Altitude) + 0.019), C_4 sedge (Y= -0.00011(Altitude) + 0.327) and C_3 sedge (Y= 0.00014 (Altitude) + 0.059).

The C_4 pathway is a metabolic adaptation which greatly assists plant survival under water stressed conditions (Teeri and Stowe, 1976; Ellis *et al.*, 1980; Pearcy and Ehleringer, 1984). C_4 grasses predominate over C_3 grasses in habitats characterized by high levels of irradiance, high daytime temperatures and low levels of water availability. In water stressed environments, C_3 species are largely confined to localized habitats with minimal water stress (e.g. permanently saturated areas) and with decreasing ambient temperatures and decreasing aridity, C_4 species decrease in abundance relative to C_3 species. The main environmental variable limiting C_4 plants appears to be low temperature during the growing season (Teeri and Stowe,1976; Ellis *et al.*, 1980). At all altitudes examined, C_4 grass cover was significantly greater in the least wet zone of the wetland (which would be subject to the greatest water stress) and the ratio of C_3 to C_4 grass species increased with increasing altitude (and associated decrease in temperature and increase in rainfall) which accords with the above literature.

Sedge species showed the same general trend of an increasing ratio of C_3 to C_4 species with increasing altitude. At lower altitudes, however, sedges differed fundamentally from grasses in that C_4 species occurred extensively in the wettest zone. This resulted from the high occurrence in this zone of an exclusively C_4 subgenus, *Cyperus* which includes *C.dives*, *C. fastigiatus* and *C. latifolius*. When considering the physiological characteristics of C_4 plants it would be expected that they would dominate habitats with low water availability and not habitats where water is freely available. Thus, it appears that the main adaptive value of the C_4 photosynthetic pathway to these particular species lies in something other than enhanced water-use efficiency. Little information is available on the ecophysiological characteristics of C_4 plants adapted to wet conditions except for *Cyperus papyrus* (Jones, 1987; Jones, 1988) and *C. latifolius* (Jones, 1988). Jones (1988) suggests that the adaptive advantage of the C_4 pathway in these species would be higher nitrogen-use efficiency. Christie and Detling (1982) found the nitrogen-use efficiency of C_4 plants was higher than C_3 plants under high temperatures but the reverse was true under low temperature conditions.

6.4.4 Species richness and evenness

Of the four models commonly used to describe species-area relationships (Connor and McCoy, 1979), the species-logarea model gave the best fit for the data set (Fig. 6.5) as the distribution of wetland size was found to be skewed. A relationship ($P<0.001$) was found between the total number of graminoid species recorded in a wetland and the logarithm of wetland size, with 68% of the variance accounted for. In a multiple regression of species richness with log of wetland size, stream order, altitude, average annual temperature and rainfall, the latter four variables accounted for only a further 3.7% of the variance.

While this study shows that larger wetlands tend to contain more landform types and habitats than small wetlands, it is not possible to comment on the relative importance of different theories in accounting for the particular species-area relationship. Such theories include the habitat-diversity hypothesis, whereby, as an area increases, new habitats with associated species are included, and the equilibrium theory, which is a function of immigration and extinction (see Connor and McCoy, 1979).

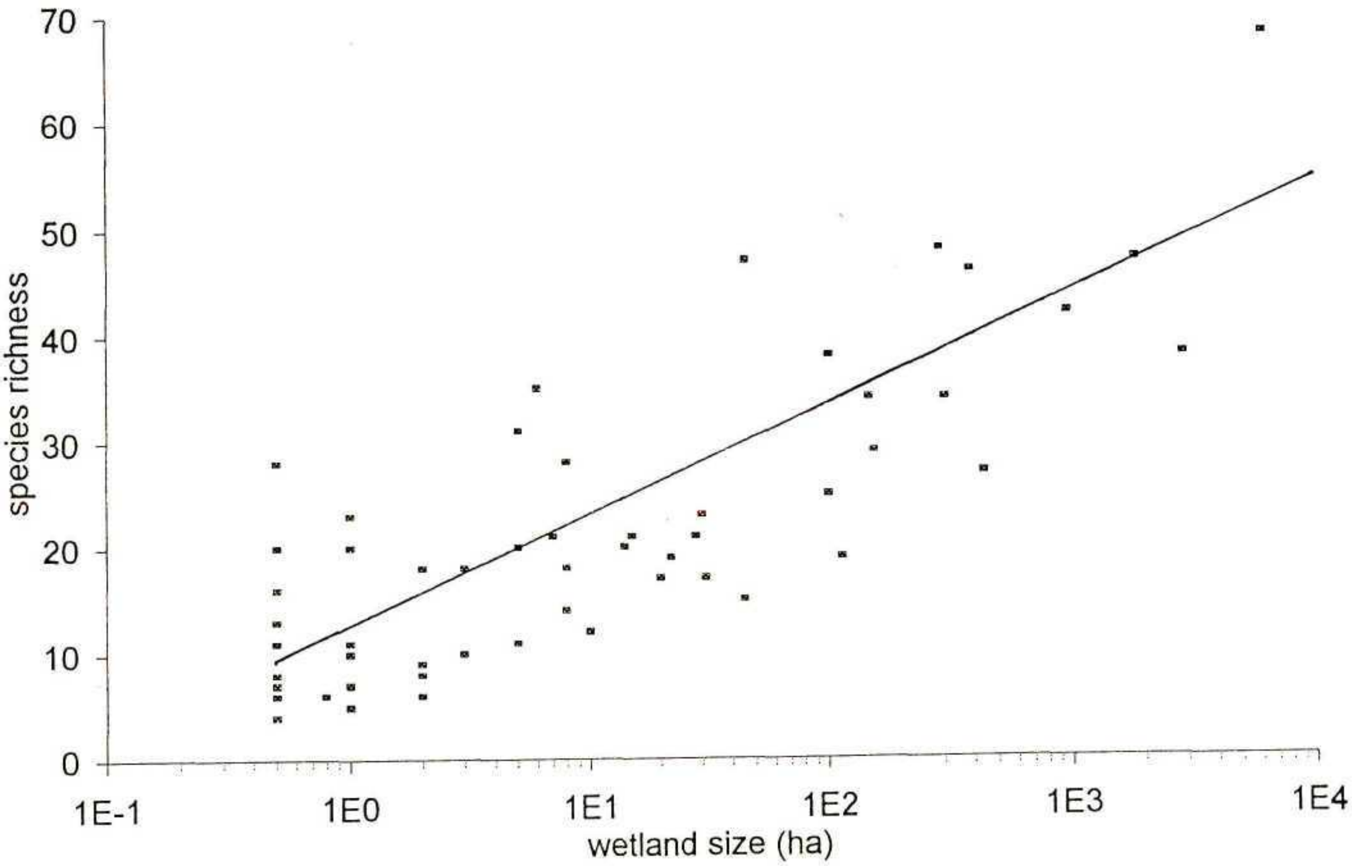


Fig. 6.5 Relationship of graminoid species richness with wetland size. Y = (logwetland size)4.381 + 11.01.

In the investigation of species richness (at the level of individual sampling plots and of the overall wetness zone) and evenness (in the overall wetness zone) in relation to degree of wetness, all had a lower species richness ($P<0.01$) in the permanent/semi-permanently wet zone compared with the seasonal and temporarily wet zone. However, there was no difference ($P>0.05$) between seasonally and temporarily wet areas (Table 6.6). An important factor contributing to the lower species richness of the wettest areas is likely to be the prolonged anaerobic conditions which exclude all but those species most tolerant of such conditions. Competition from the tall, vigorously growing clonal species with a high standing crop which are associated with these areas may also be a contributing factor to reduced richness and evenness. This negative relationship between high standing crops and species richness in wetlands has been widely demonstrated (Wheeler and Giller, 1982; Vermeer and Bredense, 1983; Day *et al.*, 1988; Moore *et al.*, 1989). The similar average species richness of the seasonally and temporarily wet areas suggests that seasonal areas are not close enough to the wettest end of the wetness gradient, with its associated prolonged anaerobic conditions and high standing crops, to significantly depress species richness.

Table 6.6 Summary, for the six pooled wetlands, of the mean ±SE of graminoid species richness in sampling plots and in the overall wetness zones and species evenness (J´) for the overall wetness zones

Degree of wetness:	n	Richness, plots	Richness, overall zone	Evenness, overall zone
Permanent/semi-permanent	6	3.85 ±0.619	16.5 ±6.83	0.63 ±0.046
Seasonal	6	5.53 ±1.503	34.0 ±10.53	0.73 ±0.063
Temporary	6	5.43 ±0.817	31.3 ±3.24	0.73 ±0.044

Although the species richness of seasonally and temporarily wet areas were higher than permanently wet areas, the species richness of wetland areas in general have been shown to be lower than adjacent non-wetland grasslands (see Kooij, 1990; Eckhardt *et al.*, 1993; Eckhardt *et al.*, 1996). Nonetheless, the contribution of wetlands to species diversity at a landscape scale lies in their distinctiveness from other habitats. For this study, plant species associated with permanent to seasonally wet areas were found to be largely confined to wetland areas.

6.5 Conclusion

Degree of wetness was the most important of the measured environmental variables accounting for vegetation pattern within an individual wetland and there was a high level of turn-over of species along the wetness gradient. This is in agreement with the general findings of the literature (e.g. Downing, 1966; Davis *et al.*, 1996; Runhaar *et al.*, 1997). Other measured factors, including soil texture (which was positively correlated with wetness) and landform setting, were found to be less important, but nevertheless contributed to explaining variation in species composition. Landform setting was described at a very coarse level, and in order to comment more fully on this descriptor it would need to be described in more detail, using optical survey techniques for example.

Temporarily wet areas were dominated by Poaceae (predominantly C_4), most seasonally wet areas were dominated by Cyperaceae and/or Poaceae, and permanent/semi-permanently wet sites were dominated either by Cyperaceae, *Typha capensis, P. australis* or *L. hexandra*, the latter two species being C_3 grasses. Species with a C_3 pathway were generally most frequent at the wetter extreme and C_4 species at the drier extreme of the wetness gradient. However the subgenus *Cyperus,* which is C_4, was most abundant in the seasonally and permanently wet areas, and it appears that for this subgenus that the C_4 pathway is an adaptation for enhanced nitrogen-use efficiency. Where species were found in more than one wetland, their distribution in relation to wetness class was generally consistent across wetlands. A notable exception, however, was *Leersia hexandra*, whose distribution appeared to be strongly influenced by disturbance.

Altitude (through its influence on climate) was the most important factor accounting for vegetation pattern among the 66 wetlands, which is consistent with the widely demonstrated importance of climatic controls on vegetation patterns (e.g. Halsley *et al.,* 1997). At high altitudes C_3 species were most frequent and at low altitudes C_4 species. Few other studies, certainly in Africa, have examined photosynthetic pathways in relation to climate and local hydrological conditions, and it is recommended that this be investigated further owing to the functional significance of these gradients in relation to wetland structure and functioning and to factors such as global climate change.

In the wetlands investigated: alpha diversity varied from low in permanent/semi-permanently wet areas to higher levels in seasonally and temporarily wet areas, and beta diversity was high in that there was a high turn-over of species within individual wetlands, primarily resulting from water regime differences.

The results of this study confirm that degree of wetness, the central descriptor employed by WETLAND-USE for characterizing wetland state and likely response to land-use pressure, is strongly related to described structural and functional vegetation features of wetlands. This confirms that wetness is an essential gradient to consider when assessing the environmental impacts of a particular disturbance or management regime. This chapter has yielded useful information on the relation of common individual species with degree of wetness, which was incorporated into the revised WETLAND-USE system. The results of this study also indicate that if representative examples of the different types of wetlands are to be identified and conserved then protocols should be adopted which ensure that: (1) the full altitudinal range is represented because of the distinctiveness of wetlands at different altitudes; and (2) different geographical locations are also represented. The following chapter will draw on the results of this chapter, together with additional literature, in the development of protocols for accounting for cumulative impacts on wetlands, particularly on biodiversity values, an important deficiency in WETLAND-USE.

CHAPTER 7
ACCOUNTING FOR CUMULATIVE IMPACTS ON WETLANDS

7.1 Introduction

The occurrence and maintenance of wetlands, and many of the wetland functions valued by society (e.g. water quality enhancement) reflect large-scale and long-term characteristics of catchments, landscapes, and regions (Bedford and Preston, 1988; O'Brien, 1988; Bedford, 1996). The values provided by a particular wetland result not only from the intrinsic nature of the wetland (e.g. its size and slope) but also from its relation to other wetlands (Breen, 1991), ecosystems and land-use types (Bedford and Preston, 1988). Thus, the impacts on two wetlands may be equivalent when each is considered singly, but, depending on their respective landscape contexts, may be very different when considered from the point of view of cumulative impacts at the landscape level. In order to account for cumulative impacts it is therefore necessary to describe wetlands within these larger contexts (see Table 7.1).

Table 7.1 Different scales at which impact assessment might be conducted, and characteristics determining their spatial boundaries (after Forman and Gordon 1986)

Scale	**Characteristics determining spatial boundaries**
Individual wetland	A single site defined by the boundaries of the wetland itself
Catchment or basin	The area drained by a river or stream and its tributaries
Landscape	Spatially repetitive cluster of interacting ecosystems Similar geomorphology Similar set of disturbance regimes May contain one or more catchments
Region	Area determined by a complex of climatic, physiographic, biological, economic, social and cultural characteristics May contain one or more landscapes

"Cumulative impact" is the incremental effect of an impact added to other past, present, and reasonably foreseeable future impacts. It has been an area of increasing interest with the continuing loss and degradation of wetlands (Johnston, 1994). A wetland area is considered to be "lost" if it has been degraded or transformed to the point that it has lost most of its indirect values as when severely eroded or completely drained and cultivated. While cumulative impacts can occur within individual wetlands, the concept of cumulative impacts is generally used when there are many impacts to multiple wetlands

(Johnston, 1994). The purpose of cumulative impact assessment is to evaluate the physical, chemical and biological changes that accumulate over space or time as a result of human-generated actions. There are several ways in which effects accumulate (Beanlands *et al.*, 1986):

1. time-crowded perturbations, in which disturbances are so close in time that the system cannot recover in the time between;
2. space-crowded perturbations, in which disturbances are so closely spaced that their effects are not dissipated in the distance between;
3. synergisms, the interaction of disturbances to produce effects qualitatively and quantitatively different from the individual disturbances;
4. nibbling, disturbances that produce effects by small incremental changes; and
5. indirect effects, in which disturbances produce effects remote in time or space from the original disturbance.

It is of little value to instruct environmental workers and regulators to consider cumulative effects of wetland loss on wetland function without their having the necessary tools/protocols to do so. Although the concept of cumulative impact has strong intuitive appeal and has influenced U.S. federal legislation as early as the 1970's, its effect on decision-making has, however, been limited by a lack of explicit operational formulation (Preston and Bedford, 1988). In South Africa, protocols to assist in describing the context of wetlands in the landscape are lacking. The prototype WETLAND-USE system employs a simple rule: the higher the existing loss of wetland area in the landscape the greater will be the cumulative impact if further loss is incurred. The rule does not, however, consider different spatial scales and patterns of wetland loss, which may have important implications for the level of cumulative impact. Clearly, there is a need to examine more fully how landscape-level considerations for wetlands can be incorporated into decision-making in South Africa, and specifically into the revised WETLAND-USE system.

The objectives of this investigation, which is largely literature based, are the following.

1. Examine the theoretical frameworks used for describing cumulative effects on wetlands and empirical data pertaining to the topic.

3. Recommend protocols for considering cumulative effects on wetlands to be incorporated into WETLAND-USE, accounting for the level of data and resources available in South Africa.

2. Examine the extent to which conservation initiatives in KwaZulu-Natal, South Africa (e.g. land acquisition for protection and designation of priority wetlands) account for cumulative effects.

7.2 Cumulative loss of wetland area at different spatial scales

One of the most commonly measured cumulative effects is the loss of wetland area. In the U.S. considerable resources invested in measuring this have showed that in the period from the 1780's to the 1980's the total wetland area had decreased by 53%, with greatest losses in the south, Midwest and California (Johnston, 1994). In the U.S., wetland loss statistics have served as justification for permit denials. The sources of impact that cause cumulative wetland area loss and the particular types of wetlands lost may also be described. For example, in the U.S. from the 1950's to the 1970's, agricultural development was the major cause of palustrine wetland loss (Johnston, 1994). In South Africa, information on wetland loss exists for some areas (see DEAT, 1998c) but this information is fragmented and has not been consolidated.

Within a catchment, riparian wetlands are all linked by the drainage network and together could be described as a functional unit, with impacts on upstream wetlands potentially impacting downstream wetlands. Nature conservation departments, which are increasingly looking at broad-scale processes rather than only at single species, have also recognized the importance of considering catchments. In South Africa it is recognized that management of water should be within a catchment area and it is therefore accepted that an integrated catchment management (ICM) approach will be adopted for the country (DWAF, 1996; 1998). Wetland inventories have been undertaken in only a few isolated South African catchments, notably the Mfolozi (Begg, 1988) and Mkomazi (EnviroMap, 1996) catchments and the upper Mgeni catchment (see Chapter 8). The wetland losses from these catchments are 58%, 52%, and 66% respectively. Although the extent of loss is high in all of these, the upper Mgeni catchment, which has the highest level of agricultural development, has the highest wetland loss.

Regions can be described across a range of scales and using a range of biophysical and social factors. Ecoregions have been defined at several hierarchical levels for the U.S. on the basis of physical, chemical and biological criteria (Omernik and Griffith, 1991). Ecoregions provide a natural complement to catchments as a framework for research and planning, and the two should be used in combination to adequately explore spatial patterns and management options (Bryce and Clarke, 1996). A catchment framework is the appropriate approach for investigating factors such as pollutant loading and nutrient cycling, which take place largely within a catchment. However, spatial differences in landscape characteristics, and biota are often not portioned by catchment divides (Omernik and Griffith, 1991). Particularly in areas of some relief, catchments straddle tremendous variability, making them too heterogenous to explain adequately resource patterns. For example, a small high altitude stream and its associated wetlands has much more in common with streams in neighbouring catchments at comparable altitudes than with small streams at lower elevation within the same catchment. Chemical and physical habitat measures and even fish distributions have been shown to be better explained by an ecoregion framework than a catchment framework (Hughes *et al.*, 1987; Omernik and Griffith, 1991).

Through its effect on climate, altitude has an important influence on the nature of wetlands. In recognizing this, Begg (1986) proposed a provisional method of differentiating between types of wetlands in KwaZulu-Natal, using altitude as a determinant. This is supported by the findings in Chapter 6 which showed that altitude was the most important factor accounting for floristic differences among wetlands from 550 m to 2050 m, with an almost complete turn-over of plant species along this gradient. If wetland loss is concentrated within a particular ecoregion then the assemblages of species associated with that region would be subject to disproportionately high loss. Thus, in order to secure representative examples of the range of wetland types in a given geographical area the assumption is made that wetlands should be well represented across all of the regions or altitudinal zones.

In the Mfolozi and Mkhomazi catchments loss is not uniform across altitudinal zones (Figs. 7.1 and 7.2). In both of these catchments, higher altitudes had the lowest loss. This low level of wetland loss at higher altitudes was confirmed by an inventory of the Drakensberg, which included the uppermost portions of several of the major catchments in the Province (Dely *et al.*, 1995). This showed that artificial drainage and other forms of anthropogenic modification were almost entirely lacking in the wetlands described at high altitudes.

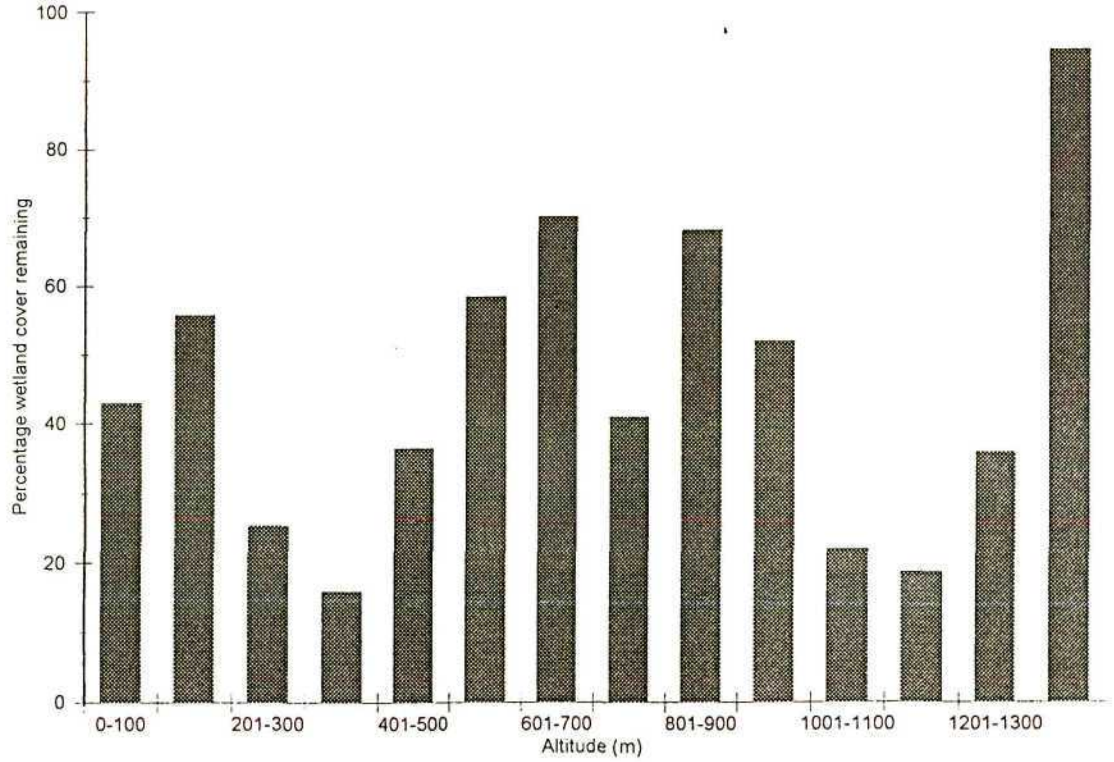


Fig. 7.1 Percentage of wetland area remaining in the Mfolozi catchment in relation to altitude (data from Begg, 1988).

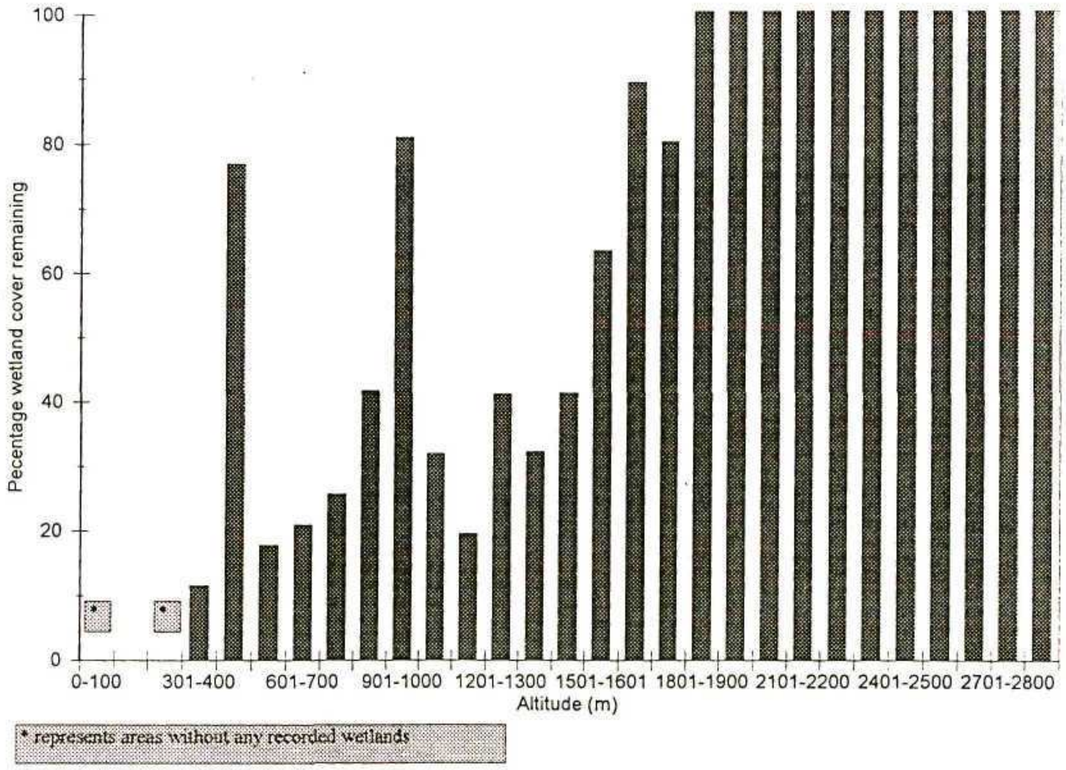


Fig. 7.2 Percentage of wetland area remaining in the Mkomazi catchment in relation to altitude (data from EnviroMap, 1988).

7.3 Cumulative loss of wetland area and its relation to wetland function

Loss of wetland area results in a corresponding loss of wetland functions. Several different theoretical relationships describing the relationship between function and area have been proposed by Preston and Bedford (1988) and Johnston (1994) (Fig. 7.3). Relationship 1 is linear, with each additional unit area of wetland lost having the same relative effect as every other unit lost. In Relationship 2, initial area losses have the largest effect on function, after which additional losses have less of an effect, while, in Relationship 3, initial losses have a relatively small effect relative to later losses. In Relationship 4, the greatest impacts of wetland loss occur in the mid-range of wetland loss.

Few empirical studies examining wetland function-area relationships exist. Jones *et al.* (1976) evaluating the effect of wetlands in 34 Iowa catchments, showed a significant linear relationship between proportion of wetlands in the catchment and nitrate concentrations in the streams (i.e. Relationship 1). Validated floodflow models such as that of Novitzki (1979) have shown that floodflow is decreased by having some wetlands in a catchment, but a catchment having a large proportion of wetlands does not reduce floodflow much more than one with an intermediate proportion of wetlands (i.e. Relationship 3 holds, assuming an initial high proportion of wetlands, ie. ca. 30 % of the area of the catchment).

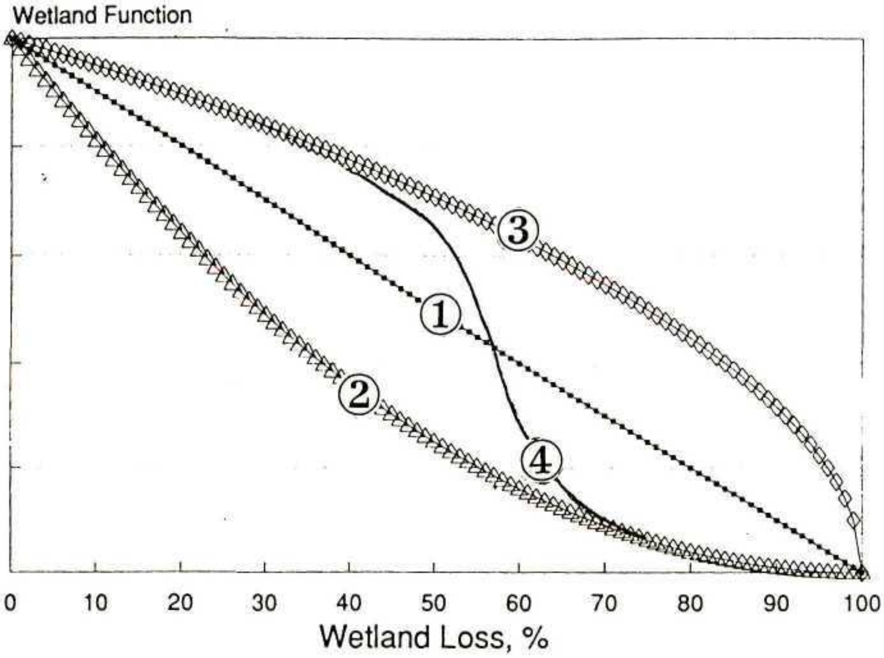


Fig. 7.3 Possible relationships between loss of wetland area and loss of wetland function (adapted from Johnston, 1994).

As the spatial extent of wetland or any other system is reduced, the size of populations of organisms dependent on the systems will, in general, decline accordingly. The vulnerability of species to extinction would obviously depend in part on the magnitude of this reduction, with the persistence of populations depending on their being large enough to withstand the risks of extinction (Soule, 1987). The most rapid extinctions are likely in species that depend entirely on native vegetation, those that require large territories, and those that exist at low densities (Saunders *et al.*, 1991).

In addition to total loss of wetland area, a decrease in the size of individual wetlands may have an important impact on wetland-dependent species for which wetland size is an important determinant of habitat suitability (as a result of their large home range requirements). Robins *et al.* (1989) showed that several wetland-dependent bird species in the Middle Atlantic states, U.S. require areas of wetland and adjacent native vegetation of > 100 ha. In an investigation of breeding occurrence of 13 bird species in 212 reed beds, Schiess (1989, as cited by Tscharntke, 1992) found that although most species required patches of at least 2 ha, the minimum patch size varied greatly among species, even among closely related species. The reed warbler (*Acrocephalus scirpaceus*) was found to breed in all reed patches >1 600 m^2, while the great reed warbler (*Acrocephalus arundinis*) was found regularly in reed patches >21 000 m^2. There is also tremendous variation in minimum habitat patch size requirements among wetland-dependent bird species in South Africa (Table 7.2).

Table 7.2 Minimum suitable habitat patch size of South African wetland-dependent bird species

Species	**Minimum patch size (ha)**	**References**
RALLIDAE		
Sarothrura rufa Red-chested Flufftail	0.1 ha	(Taylor, 1994)
Rallus caerulescens African Rail	0.25 ha	(Taylor, 1994; 1997a)
Amaurornis flavirostris Black Crake	0.3 ha	(Taylor, 1994; 1997a)
Aenigmatolimnas marginalis Striped Crake	No data; probably <0.5 ha	(Taylor, 1998. *Pers. obs.*)
Porphyrio porphyrio Purple Swamphen	2.5 ha	(Taylor, 1997a).
P. alleni Allen's (Lesser) Gallinule	0.3-1 ha	(Taylor, 1997a;Taylor *Pers. obs.*)
Gallinula chloropus Common Moorhen	≥ 0.5 ha adjacent open water required	(Taylor & van Perlo, 1998; Taylor *Pers. obs.*)
G. angulata Lesser Moorhen	0.3-1 ha	(Taylor, 1997a; Taylor, *Pers. obs.*)
Fulica cristata Red-knobbed Coot	< 1 ha open water with fringing emergents required	(Taylor & van Perlo, 1998)
OTHER NON-PASSERINES		
Ardea purpurea Purple Heron	1-2 ha	(Taylor & Harrison, 1997)
Ixobrychus minutus payesii Little Bittern	0.1-2.5 ha	(Taylor & Harrison, 1997).
Circus ranivorus African Marsh Harrier	1-2 ha	(Taylor & Harrison, 1997).
Bugeranus carunculatus Wattled Crane	2-3 ha 15-30 ha of adjacent natural grassland required	(McCann, 1998. *Pers. obs.)*
Balearica regulorum Crowned Crane	1-2ha 10-15 ha of adjacent natural grassland or grassland and agricultural land required	(McCann, 1998. *Pers. obs.)*
Rostratula benghalensis Painted Snipe	0.2-4 ha	(Taylor 1997a; Taylor, 1998. *Pers. obs.*).
Tyto capensis Grass Owl	1-2 ha	(Steyn, 1982)
PASSERINES		
Bradypterus baboecala African Sedge.	<1 ha	(Taylor, 1998. *Pers. obs.*)
Acrocephalus spp.	No data on species endemic to Africa	
Cisticola tinniens Levaillant's Cisticola.	0.01-0.1 ha	(Taylor, 1998. *Pers. obs.*)

Taxon names conform to Brown *et al.* (1982) and Urban *et al.* (1986).

7.4 The spatial configuration of wetlands and its relation to wetland function

In accordance with the basic theory of landscape ecology that the spatial arrangement of ecosystem components influences the processes within these systems, it is assumed that the spatial configuration of wetlands in the landscape is likely to have an important influence on particular functions (Greiner and Hershner, 1998). The functions considered in this discussion are grouped into water quality enhancement, flood attenuation and life-support (habitat) (Preston and Bedford, 1988).

Theoretical evidence in support of the importance of landscape considerations for catchment water quality enhancement is given by Brinson (1993). He contends that management programs for wetlands oriented to protect water quality ought to re-examine the use of surface area alone and also consider length of intact riparian wetland, which is a better index of potential for enhancing water quality than area. Thus, he points out that applying a fixed area of riparian wetland disturbance will affect a much greater length of stream in low order streams than in high order streams, as wetlands tend to be much narrower in low order streams.

Empirical evidence presented by Kratz *et al.* (1991) and Detenbeck *et al.* (1993) indicate that the location of wetlands within a catchment has an important effect on the cumulative effect that wetlands have on overall catchment water quality. Detenbeck *et al.* (1993) suggest that for non-point source loadings, wetlands lower in the catchment protect water quality most efficiently, and consequently loss of a given wetland area in this part of the catchment is likely to have a greater impact on catchment water quality than loss of an equivalent area high in the catchment. Greiner and Hesher (1998), however, showed that tidal and nontidal wetlands in the Mattaponi River catchment retained total phosphorus at approximately the same rates regardless of catchment position and surrounding landscape. These results suggest that the position of a wetland in the landscape did not have an important influence on the internal ecosystem processes of a wetland examined. Nonetheless, Greiner and Hesher (1998) still provide recommendations as to where wetland restoration efforts should be focused in order to minimize cumulative impacts, based largely on the context of the wetland (see Section 7.5). The concept of water quality encompasses many elements (e.g. phosphorus, nitrogen and heavy metals) with a multitude of catchment and wetland characteristics affecting the retention of these elements. It is understandable therefore that there is a lack of predictive models for determining the cumulative effect of wetlands on water quality.

The effect of wetlands on floodflows is less complex than the effect on water quality, and the location of wetland loss in the catchment has an important effect on the contribution of wetlands to flood attenuation. Ogawa and Male (1986) using a simulation model approach showed that the increase in floodpeaks resulting from loss of wetland area from high order streams (i.e. stream order >3) extended considerably further downstream than that resulting from loss of the same wetland surface area from low order streams.

The relationship between wetland spatial configuration and the life-support function of wetlands is very complex owing to the multitude of species and levels of biological organization supported by wetlands. Landscape ecology and metapopulation theory provide useful frameworks for investigation (see Section 3.2.2). As indicated in Section 3.2.2, long-term persistence of metapopulations of wetland organisms is dependent in part on the dispersal of individuals among wetland patches and the re-colonization of newly created or recently vacated patches (Gibbs, 1993). Wetlands are generally found in discrete patches within a matrix of non-wetland area. Thus, many wetland-dependent species, particularly those with low dispersal capabilities are effectively described using metapopulation theory, which views a population as a set of spatially separated sub-populations that are linked by dispersal (Gibbs, 1993). Any factors decreasing the probability of successful dispersal and patch re-colonization may lead to a smaller proportion of patches having extant populations at any given time, and ultimately to the greater likelihood of metapopulation extinction over time (Gilpin and Hanski, 1991). Because the distance between wetlands is inversely proportional to the density of wetlands, loss of wetlands increases the dispersal distance. This, in turn, decreases the likelihood of successful dispersal in the face of risks such as predation. Studies by Gibbs (1993) and Semlitsch and Bodie (1998) suggest that small wetlands play a greater role in the dynamics of metapopulations of certain taxa of wetland animals than the modest area comprised of small wetlands might imply, and that small wetlands play an important role in reducing isolation among wetland patches.

Besides factors which increase the level of isolation of existing separate wetlands, long expansive wetlands, such as southern bottomland hardwoods of the U.S., may be cut into fragments by intervening urban and agricultural area. The documented loss of connectivity of southern bottomland hardwoods is considered to have diminished the function of southern bottomland hardwoods as conduits for animal movement (Johnston, 1994). Fragmentation of forests has the additional negative effect of induced edges in allowing common generalist species to penetrate into these natural areas at the expense of the specialist species (Whitcome *et al.*, 1976; Gates and Gysel, 1978).

It is difficult to isolate specific effects from empirical studies as there are often confounding effects (e.g. there is seldom fragmentation without some level of habitat loss) (see Burgess, 1988). Empirical evidence of the negative effect of reduced connectivity *per se* of wetlands on wetland-dependent biota is very limited, particularly for plants. Møller and Rørdam (1985) showed that ponds hold significantly more species per unit area where ponds are closer. Ouborg (1992) found that although isolation was relatively unimportant in explaining total species variation, in some species such as *Eryngium campestre* and *Medicago falcata*, both extinction and colonization were influenced by isolation, suggesting that populations of these species had metapopulation structure. In the face of a lack of empirical data on the effects of isolation among wetland patches on populations of wetland organisms, the likely effects can be inferred from information on population dynamics and interspecific interactions. For example, flush-crash cycles of the *Phragmites australis* stem-boring moth *Archanara geminipuncta* populations in the Netherlands and Germany showed regionally concurrent, local extinctions despite originally large populations (>180 00 adults) (Tscharntke, 1992). These results emphasise the importance of numerous, more or less closely coherent reed patches allowing recolonization from neighbouring populations and promoting metapopulation dynamics for this particular species. *Archanara geminipuncta* is a keystone species in that the larvae kill the growing shoot, causing side shoots to grow, on which several species such as the midge *Lasioptera arundinis* depend (Tscharntke, 1992). Thus, persistence of several species in the study area are dependent on the status of the *Archanara geminipuncta* meta-population.

7.5 The wetland context and its relation to wetland function

Wetlands occur as patches in an intervening landscape matrix, with exchanges of material, information and energy in both directions between wetland and matrix. It can be assumed therefore that the functioning of a wetland will be influenced by the nature of the surrounding matrix, including anthropogenic modifications to this matrix. Thus, the value of a wetland for performing a particular function may be reduced by activities beyond its boundaries. For example, Richter and Azous (1995) found amphibian species richness in individual wetlands in the Puget Sound Basin to be negatively affected by the level of urbanization of the surrounding catchment, which was shown to alter the timing of runoff into the wetland.

In South Africa, where evaporation is generally well in excess of precipitation, a significant proportion of the water supply of most wetlands is from the surrounding catchment. In Ntabamhlope vlei, for example, it was estimated that water from the surrounding catchment (primarily surface water) contributed 61% of the annual input volume to the wetland (Donkin, 1994). These wetlands are consequently susceptible to off-site impacts on the quality and quantity of their water supplies. With the projected increase in water demand in South Africa, off-site impacts are likely to become increasingly prevalent.

Aside from any possible impacts on inflow of water and other materials to the wetland, a decrease in the extent of natural habitat in the surrounding matrix generally diminishes the habitat function of the wetlands by: (1) increasing the level of isolation among wetlands; and (2) reducing the overall quality of habitat complexes for species requiring wetland and adjacent habitats. The situation is analogous to the value of a property in a declining neighbourhood - no matter how well the property is maintained, it will loose value along with the general neighbourhood. For several wetland-dependent species that require both wetland and adjacent non-wetland habitat, a component of the habitat value of wetland systems derives from their location adjacent to other non-wetland systems (Brown *et al.* 1990). Wattled crane, for example, which nest and feed in wetlands, also feed extensively in adjacent non-wetland grasslands (McCann K, 1998, *Pers. comm.*, Eskom/EWT National Crane Conservation Project, Mooi River), and transformation of these grasslands would reduce the value of the adjacent wetland as a breeding site even if the wetland itself was not altered.

Further negative effects of changes in the intervening matrix may be the increased sources of alien plant invasion and increased predation. Forestry plantations, for example, have been shown to increase the level of alien plant infestation into remnants of native vegetation (Armstrong and Hensbergen, 1996). Brown *et al.* (1987) cite several studies documenting the negative effects of predation from domestic cats and dogs on wetlands adjacent to urban areas, and Wilcove and May (1986) found that avian nest predation rates in woodlots surrounded by suburbs were higher than woodlots surrounded by agricultural land. The mammal and bird species most susceptible to predation are ground feeding and breeding, which represent many of the wetland-dependent bird species such as rallids.

A change in the context of a particular wetland is unlikely to affect all of the benefits it provides to the same degree or even in the same direction. For example, where increased human activity in the wetland's catchment tends to reduce the value of that wetland for supporting biodiversity, it often increases its value for enhancing catchment water quality in that the wetland is afforded increased opportunity for enhancing water quality. The benefits that are ultimately yielded will, however, obviously also depend on the effectiveness of the wetland in assimilating the pollutants that it receives.

7.6 Cumulative effects within wetlands

The focus of this investigation is on cumulative impacts taking place at broad spatial scales (i.e. at the catchment, landscape and regional scales). Effects can also accumulate at more localized scales (i.e. at the level of an individual wetland). While this is largely beyond the scope of this investigation, two issues are addressed: representation of particular patches and the influence of the spatial scale of observation on the level of cumulative impact detected.

Individual wetlands are seldom homogenous, and several gradients and recognizable patches occur within a wetland. Chapter 6 demonstrated that particular species were consistently associated with particular patches defined on the basis of degree of wetness. Of the three wetness zones recognized (namely permanent, seasonal and temporary) nearly all graminoid species were confined to two or one of these zones. Several species (e.g. *Eragrostis planiculmis*, *Fuirena pubescens*, and *Pycreus macranthus*) were confined to the temporary and seasonal zones, and were largely absent from both the permanent zone and from areas outside of wetlands. These species would clearly be disproportionately affected by preferential loss of the less wet zones within the wetland as would occur with fringe cultivation (see Section 9.5). Processes associated with particular patches would also probably be disproportionately affected, which would have implications for overall wetland functioning. This emphasises that simply looking at wetland *area* loss per se may mask the effect of loss of particular patch types.

In most cases a "wetland" as an individual unit is a human construct. Although endorheic wetlands which are not associated with the current drainage network occur as more or less discrete units, often circular or kidney shaped (see Chapter 5), riparian wetland areas are characteristically linear shaped and may extend for a considerable distance as a narrow fringe along the drainage system. Where the wetland area widens, such a portion may be demarcated as a "wetland" but it is often arbitrary as to where one "wetland" ends and another "wetland" begins. In Fig. 7.4, for example, wetland A and B may either be considered as separate "wetlands" or a single "wetland". Assuming that wetland A was totally untransformed and wetland B was totally transformed, if wetland A and B are considered together as a single wetland then transformation of a small area of wetland A may be considered to have a high incremental impact. If, however, wetland A was considered as a separate wetland then transformation of a small area of an otherwise untransformed wetland would likely have a low incremental impact when considered at the level of a "wetland". This emphasises the fact that the cumulative impact measured is strongly a function of the spatial scale of observation. For this reason it is considered preferable to consider incremental impacts at broad spatial scales. Nevertheless, while accepting the potential arbitrariness of individual wetland designation, from a management point of view at the level of a single owner or Tribal Ward, it is often advantageous to also consider cumulative impact within individual wetlands (see Chapter 9). For the purposes of setting local management goals concerning cumulative effects, the more local the level that this is done the more tangible this is likely to be to the wetland owners/users. For example, a farmer intending to transform 25% of his/her wetland is more likely to accept the fact that this is unacceptable considering that >50% of his/her wetland is already transformed than if it was unacceptable because >50% of the wetland area in the eco-region, for which he/she may have no affinity, had already been transformed.

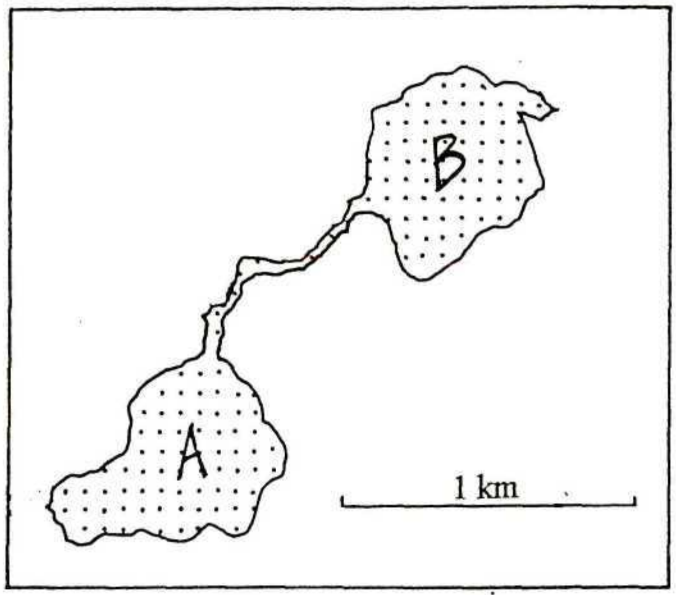


Fig. 7.4 Spatial distribution of two hypothetical wetland areas.

7.7 Rules of thumb for accounting for cumulative effects

"Rules of thumb" (given in underlined text) for accounting for cumulative effects were developed based on the theoretical and empirical material reviewed in this investigation (Fig 7.5). This was done so in light of the resource- and data-poor situation in which cumulative impacts will need to be made in South Africa in the foreseeable future.

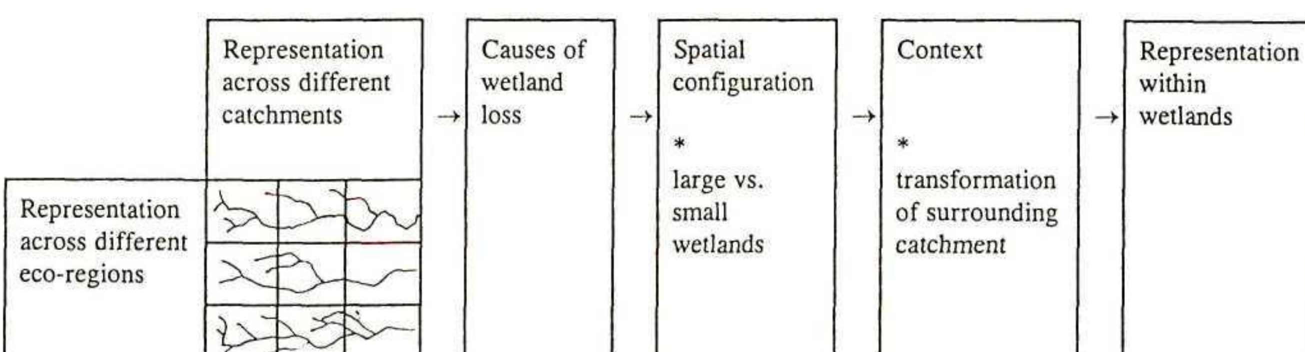


Fig. 7.5 Synoptic diagram of the steps to follow in applying the rules of thumb for accounting for cumulative impacts to wetlands.

Representation across different catchments

The greatest loss of wetlands tends to take place in areas subject to high levels of transformation (e.g. through agriculture, forestry or urban development). The results reported in this study from individual catchments show that the level of loss varies greatly among catchments. While it is considered undesirable to "write-off" particular catchments that are extremely developed, it will be unrealistic to maintain the percentage loss of wetlands at a similar level in all catchments, as development will continue to be concentrated in particular catchments. From the preceding sections it is clear that there is very little empirical basis on which to identify sub-minimum standards. Several interacting factors will need to be considered and the choice of which combination of functions to use is a subjective one, requiring stakeholder input. Nevertheless, it is considered useful to set guidelines for sub-minimum levels of loss, and it is recommended provisionally that at least 50% of a catchment's wetlands should be maintained. These limits should apply to the overall catchment and for sub-catchments down to the level of quaternary sub-catchments, which provide the basis for sub-division of catchments for integrated catchment planning and management (see DWAF, 1994).

Representation across different ecoregions

In order to ensure representation of biodiversity it is recommended that: a province be divided into ecoregions, where physical wetland determinants are reasonably uniform, resulting in similar suites of wetlands; wetland loss be assessed across all ecoregions; ecoregions with high loss be identified; and wetlands with low on-site and off-site impacts be secured within all ecoregions.

Although at present, no nationally accepted wetland ecoregion system exists, Cowan (1995a) proposed a wetland region system for South Africa, comprising 26 classes. The usefulness of this, or any other system, for representing the diversity of wetland types has not been formally investigated. However, the results reported in Chapter 6 examined in relation to this system provide a useful preliminary indication, for one of the classes. Almost all of the 66 wetlands included in the study reported in Chapter 6 fall within one of the regions of the Cowan (1995a) system, namely Region SEd. This region spans an altitudinal range of over 1000 m, and as shown in Chapter 6 there is a high turn-over of plant species and marked differences in the relative extent of functional groups defined on the basis of photosynthetic pathways, and consequent high heterogeneity, across this range. These results obtained for Region SEd therefore indicate that the classes of the wetland regions of South Africa (Cowan, 1995a) encompass too much heterogeneity, and are consequently too broad, to serve as a tool for ensuring the representation of the diversity of wetland types in South Africa. For example, if considered at the level of the overall country, even if wetlands were well represented in Region SEd, if these were concentrated in the upper altitude areas of the region then the suite/s of wetland types associated with the lower altitude areas of the region may be very poorly represented. It is proposed that comprehensive testing across the country is required of the variability encompassed within the classes of the different potential systems (e.g.Veld Types of Acocks [1953]; Low and Rabelo [1996]; Cowan, [1995a]). This testing would be integral to a national inventory and classification of wetlands.

While an ecoregion system is being developed, use should be made of (1) altitudinal zones, based on the influence of altitude on plant species composition demonstrated in Chapter 6, or (2) Acocks (1953) Veld Types, which are commonly used for conservation planning (see Scott-Shaw *et al.* 1996) ecoregions. Even recent inventories (e.g. EnviroMap, 1996) have not reported wetland loss in terms of any regional system, and any further inventories should at least report wetland loss within broad altitudinal bands.

The extent of wetland loss in relation to causes of loss

The extent of wetland loss should be reported according the specific causes of wetland loss (e.g. dams, cultivation of crops, erosion). Such information is extremely valuable in helping to focus policy, planning and regulation (if required) on those land-uses which are causing the greatest loss.

Context of the wetland

It is impossible to give an overall general rule of thumb for accounting for the context of the wetland. From a habitat point of view, if conservation effort is to be focused on those wetlands where greatest returns for effort are likely to be achieved then conservation/restoration efforts should generally be directed to wetlands with catchments which have not been greatly modified by anthropogenic effects. In other words, wetlands which are not being compromised by off-site impacts should be chosen. Conversely, if greatest returns for effort are to be achieved from a water quality enhancement point of view (which may however also indirectly impact upon downstream habitats) then efforts should be directed to those wetlands with human activities in their catchments, resulting in greater opportunity for enhancing water quality. Whichever factors are being used, it is clear that the utility of inventories would be enhanced by describing wetlands from an on-site and off-site impact point of view.

Spatial configuration

There should be representation across different wetland size classes. If the objective is simply to conserve as much wetland area as possible then it certainly would be simpler and more cost effective to focus on the larger wetlands. However, based on theoretical and empirical grounds, no basis was found to support this. A focus on large wetlands would lead to higher levels of isolation, as small wetlands are lost, and the under-representation of certain wetland types which do not occur as large areas. Also, as indicated, in KwaZulu-Natal, large wetlands (i.e those >100 ha) are confined almost entirely to 900 m - 1800 m altitudes and the coastal belt (<100 m) and are noticeably absent in the altitudinal range 100 -900 m. Furthermore, a focus on large wetlands is also likely to be less effective in maintaining the water quality enhancement function of wetlands (see Brinson, 1993) owing to the importance of maintaining the length of intact riparian wetland (see Brinson, 1993).

Representation within wetlands

Within individual wetlands there should be representation across patches defined in terms of wetness zones and landforms. Particular attention should be given to the wettest zone because commonly applied disturbances (tillage and cultivation of crops) more readily affect its function (largely because they require greater modification of the hydrological regime and consequent effects on biogeochemical processes) than the less wet zones. However, at the same time this should not be at the expense of representation of the other less wet zones (see Section 9.5). It should be noted, however, that in a wetland area that has already been developed it is often impossible to determine the zone/s that were developed, particularly if a wetland has been extensively transformed. This would therefore make it impossible to determine the extent of representation within such wetlands, as was found in the survey conducted in Chapter 8.

Patches are interlinked to varying degrees. Modification of certain patches will have a greater impact on other patches, notably because of their key influence on the hydrological regime of other patches. For example, those areas of the wetland where diffuse flow concentrates into channelled flow will need to be accounted for to avoid head-ward gully erosion (see Chapter 5).

7.8 Examination of conservation initiatives in relation to considerations of cumulative impacts on wetlands

In examining the extent to which landscape considerations have been included in prioritizing/securing wetlands (through identification as a sensitive or priority site or through formal protection), the focus was on KwaZulu-Natal as it is the province richest in wetlands and which has had the greatest investment in the development of inventories and policy (see Begg, 1990). The specific type of cumulative impact examined is the accumulation of incremental losses (i.e. nibbling).

Priority wetlands of KwaZulu-Natal have been identified by Begg (1989) and he defines these as "wetlands that have a high priority for attention as far as management and policy formulation is concerned". The motivation behind the priority wetland project undertaken by Begg (1989) is that the depletion of KwaZulu-Natal's wetlands should not continue unabated, and in preference to conducting detailed inventories of wetlands throughout each catchment, attention should first be given to safeguarding the functions and values of KwaZulu-Natal's most important wetlands (Begg, 1989). The criteria used resulted in those wetlands being chosen which are large (i.e. priority wetlands are almost all > 100 ha) and with low on-site impacts. The KwaZulu-Natal Conservation Services maintains an Environmental Atlas, which shows environmentally important features, including wetlands. The atlas, which is used extensively for impact assessments and regional planning, has no specific criteria for inclusion of wetlands in the atlas. Approximately 6% of the area of the province is formally conserved, with some of the formally conserved areas being proclaimed specifically in order to secure a particular wetland.

The priority wetlands identified by Begg (1989) are represented only within certain altitudinal zones (Fig. 7.6). Besides the fact that all the priority wetlands represented below 100 m are restricted to the Mocambique coastal plain, no priority wetlands are represented between 100 m and 900 m, and higher than 1900 m. Only a single wetland is represented between 900 m and 1 100 m. The remaining 17 wetlands fall between 1 100 m and 1 900 m. The distribution of wetlands identified in the Environmental Atlas (Fig. 7.7) shows a similar trend to that of the priority wetlands, with most of the wetlands represented either below 100 m or above 900 m and only 6% of the wetlands in the atlas represented in the 100 m to 900 m altitudinal zone. There is also a lower representation of formally conserved wetlands between 100 m and 900 m than on either side of this altitudinal zone. Nature reserves declared because of the presence of wetlands, including the Mgeni vlei, "The Swamp", Stillerust and Mvoti vlei all lie at altitudes greater than 900 m, and several of the extensive wetlands of the Mocambique coastal plain (<100 m) fall within formally conserved land. A large proportion of the overall land area at altitudes > 1 900 m falls within the formally conserved Drakensberg Park and the vast majority of the wetlands in this area are in good condition (Dely *et al.*, 1995). Thus, although none of these wetlands have been identified as priority wetlands or appear as specific features in the Sensitivity Atlas, most are formally conserved.

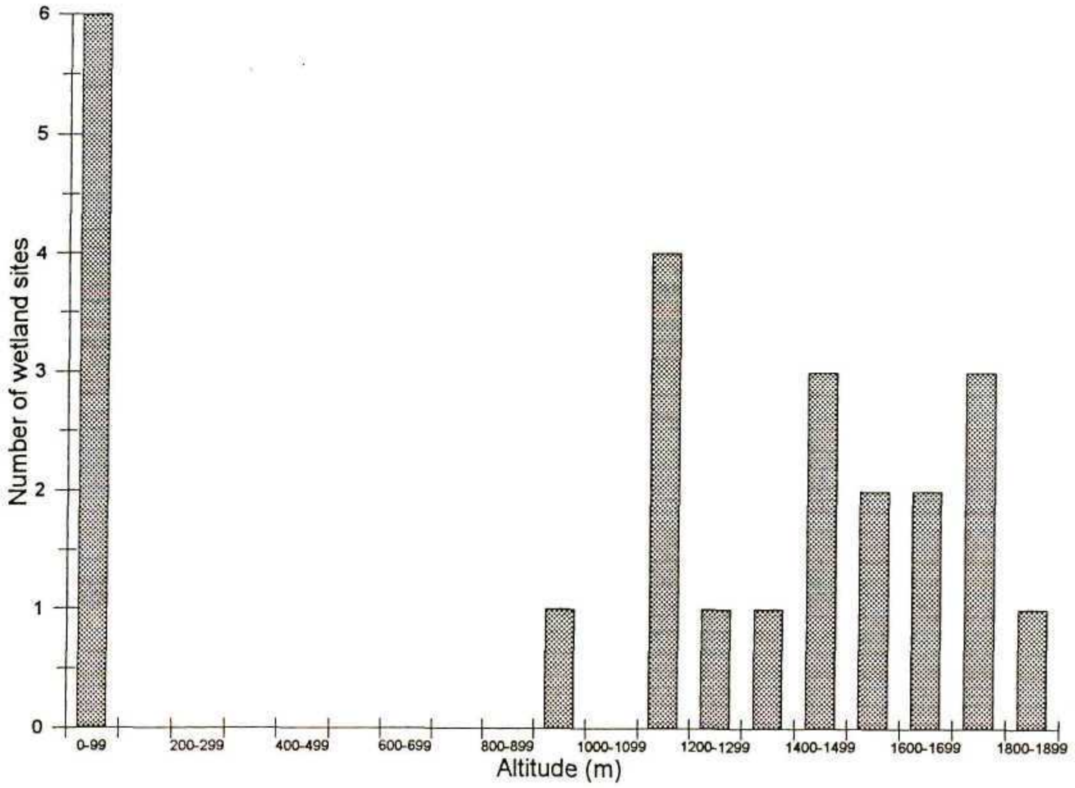


Fig. 7.6 Frequency distribution of priority wetlands for KwaZulu-Natal, in relation to altitude.

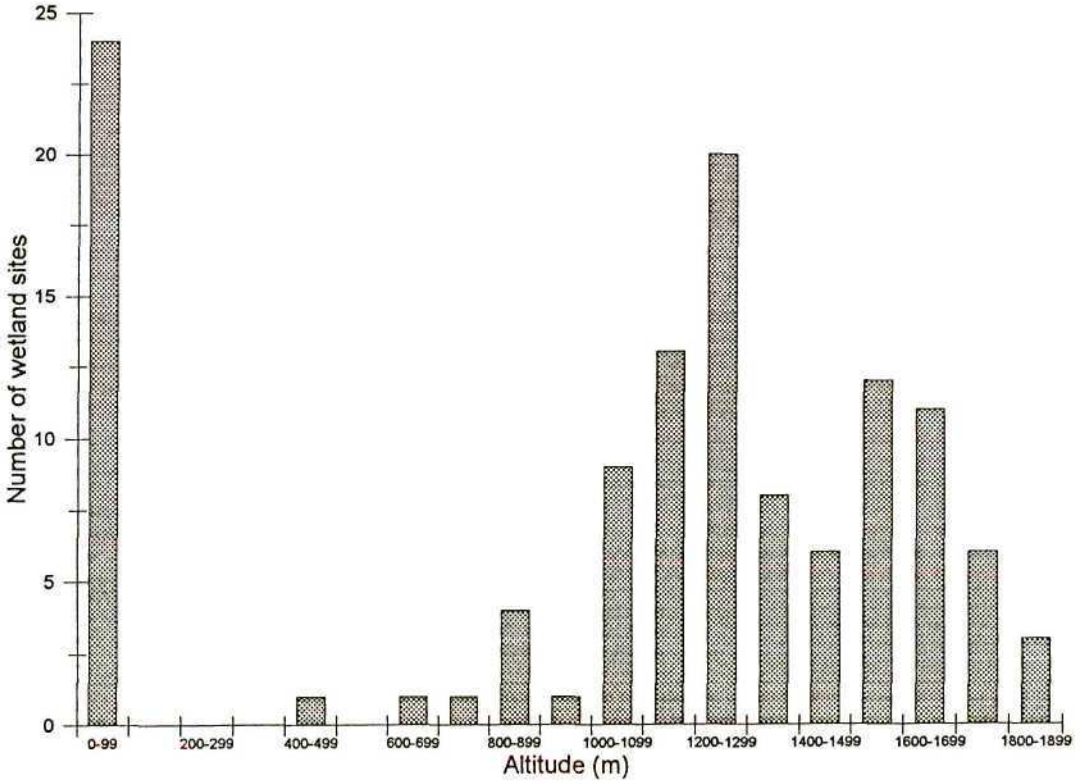


Fig. 7.7 Frequency distribution of wetlands identified in the environmental atlas for KwaZulu-Natal, in relation to altitude.

It is important to note that those altitudinal zones having the greatest percentage loss of wetlands, based on the catchment results reported in Section 7.2, are also lacking wetlands designated as priority or sensitive. On the assumption that designated wetlands are more likely to be conserved than those which are not, as wetlands continue to be afforded lower conservation attention in areas of high loss, the disparity between altitudinal zones in terms of proportional loss is likely to be strengthened. It is therefore recommend that wetlands be urgently secured in the 100m to 900m zone in order to ensure the representation of the diversity of wetland types in the province. It is also recommended that the representation of wetlands according to ecoregions be examined in other provinces.

7.9 Discussion

Exchanges of material, information and energy take place among wetlands and between wetlands and the surrounding landscape matrix. Owing to these exchanges, which are largely mediated through the movement of water and organisms, impacts on one wetland can affect other wetlands and the functioning of the overall landscape. Impacts which may appear minor when considered singly may have a much greater impact when considered collectively over time and space. Through empirical and theoretical evidence, this chapter has demonstrated how many impacts to multiple wetlands may accumulate across catchments, landscapes and regions.

Assessment of cumulative impacts is complicated by the fact that assessments can be undertaken to encompass many different, user defined: (1) spatial and temporal scales; (2) functions/benefits yielded by the wetlands; and (3) attributes used to characterize these functions. Owing to the complexity and multidimensionality of the problem, together with a paucity of data in South Africa, it will be necessary for the foreseeable future, at least, to rely on rules of thumb. Because of the importance of water for mediating exchanges, it is logical to use a catchment-based framework. However, it is useful to complement this with an ecoregion framework, which allows predictions to be made on the assumption that sites within a relatively homogenous area will have broadly similar structure and will respond similarly to a specific type of management. In addition, frameworks for considering: (1) causes of losses (2) context and (3) spatial configuration should be included, as these factors may have an important influence on wetland function at broad spatial scales.

In applying the rules of thumb to answer the question of "where are the priority areas where conservation resources should be focused spatially for maintaining the habitat function of wetlands?" it can be seen that the relationship between the occurrence of transformation-oriented land cover and the priority assigned to wetlands is strongly dependent on the chosen spatial scale. At the broad scale of ecoregions (i.e. where climate is spatially variable across ecoregions) ecoregions with greater spatial extent of transformation oriented land-cover (e.g. cultivated land) in the matrix and particularly in the wetland would be assigned higher priorities. At a localized scale where the climate is fairly uniform then the reverse is true: areas with low levels of modification would receive high priority as they are more likely to contain wetlands in reasonable condition with high levels of connectivity with other natural areas. Different results are likely to be obtained than if wetlands are being chosen in order to maximize the effect they have in enhancing water quality. The priority areas for these wetlands would most likely be transformed matrix areas that provide opportunity for enhancing water quality. The theoretical and empirical evidence reviewed in this investigation thus clearly shows that it will be impossible to define a general area-function relationship. Even a single function (e.g. nitrogen trapping) relationship is dependent on a range of interacting site-specific factors.

The WETLAND-USE prototype considers loss only in the surrounding area and does not have an overall catchment or ecoregion perspective. It also does not consider cumulative losses within individual wetlands. Thus, the system was refined to make these considerations. Nevertheless the empirical and theoretical examination of cumulative impacts shows that WETLAND-USE is still constrained in its consideration of cumulative impacts by its generic rule-based format and the fact that it is not spatially explicit. It was designed as a framework for individual wetlands and not for describing broad-scale cumulative impacts. However, it requires the collection of information on the catchment upstream of the wetland and water use and floodable property downstream of the wetland which, to a degree, places the wetland in a catchment context. It also includes cumulative impact consideration based on available information collated for quaternary catchments and Veld Types, and is able to interface with more spatially explicit systems.

This investigation also indicates that cumulative impacts are best addressed as part of regional planning efforts (e.g. integrated catchment management plans, see DWAF, 1996). This is a proactive approach that allows a comprehensive examination of all the relevant impacts at an appropriate scale, for which the synoptic approach (Leibowitz *et al.*, 1992; Abbruzzese and Leibowitz, 1997) is particularly well suited. In order for its implementation, an agreed-upon framework for wetland considerations in catchment management will be required with effective links to individual assessments (as conducted by systems such as WETLAND-USE) and supporting legal mechanisms. Without such a framework, which is clearly beyond the scope of WETLAND-USE, systems for carrying out assessments on a site-by-site basis will be severely constrained in the extent to which they can account for cumulative effects and have these considerations incorporated into decision making. The synoptic assessment procedure, which is a pro-active, anticipatory approach to wetland regulation, provides a useful reference in the development of a framework for South Africa. This approach was developed based on the argument of Bedford and Preston (1988) and Abbruzzese and Leibowitz (1997) that a conceptual and qualitative understanding of cumulative impacts, based on comparative risk and predictions having low resolution, is a legitimate assessment approach that can improve regulatory decisions during the interim until additional research allows more rigorous assessments. The procedure yields a broad perspective rather than a detailed analysis, providing a complement to the traditional reactive, project-by-project approach. In the following chapter, the protocols for accounting for cumulative impacts developed in this chapter were applied, together with WETLAND-USE, to the upper Mgeni catchment as a pilot study designed to gain an enhanced understanding of the practical application of cumulative impact considerations.

CHAPTER 8

INTEGRATING INFORMATION ON WETLANDS AND THEIR CUMULATIVE LOSS WITH MANAGEMENT OF THE UPPER MGENI CATCHMENT, SOUTH AFRICA

8.1 Background and objectives of the study

This Chapter, which has continued with the same motivation and theme as Chapter 7, describes how WETLAND-USE and the cumulative impact protocols developed in Chapter 7 were used for describing the state of wetlands in a catchment and landscape context, and ultimately for assisting in integrating wetland management planning decisions across various spatial and organizational scales. This was done through a pilot initiative in the upper Mgeni River catchment termed the Wetland Information Network (WIN). The upper Mgeni catchment was chosen as the Mgeni catchment is one of the most developed catchments in South Africa, presently supplying water to 3.5 million people (Ninham Shand, 1996). The overall vision of the WIN Initiative was "a range of stakeholders, including extension workers, planners, EIA practitioners, managers, local communities and environmental education groups contributing and accessing information on the current state of wetlands in the upper Mgeni and Mooi River catchments; and using the information for planning, training, education, and making informed management and rehabilitation decisions".

The objectives of this chapter, which reports on the activities and results of the WIN Initiative, are the following.

1. Describe, in the context of ICM (Integrated Catchment Management), the approach taken by the the WIN Initiative.

2. Describe how WETLAND-USE, and the rules of thumb developed in Chapter 7, were applied for accounting for cumulative effects on wetlands in the upper Mgeni catchment.

3. Describe the extent to which the initiative contributed to vertical and horizontal integration[7] and how the initiative related to the pressure-state-perceptions-policy framework described in Chapter 3.

4. Based on the above findings, comment on the usefulness and limitations of WETLAND-USE for accounting for cumulative impacts.

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[7] In a hierarchical system, vertical integration refers to integration across different levels of the hierarchy (e.g. from those levels concerned with broad spatial areas to those concerned with localized areas) and horizontal integration is that across different classes (e.g. organizations with different functions) at a similar level in the hierarchy.

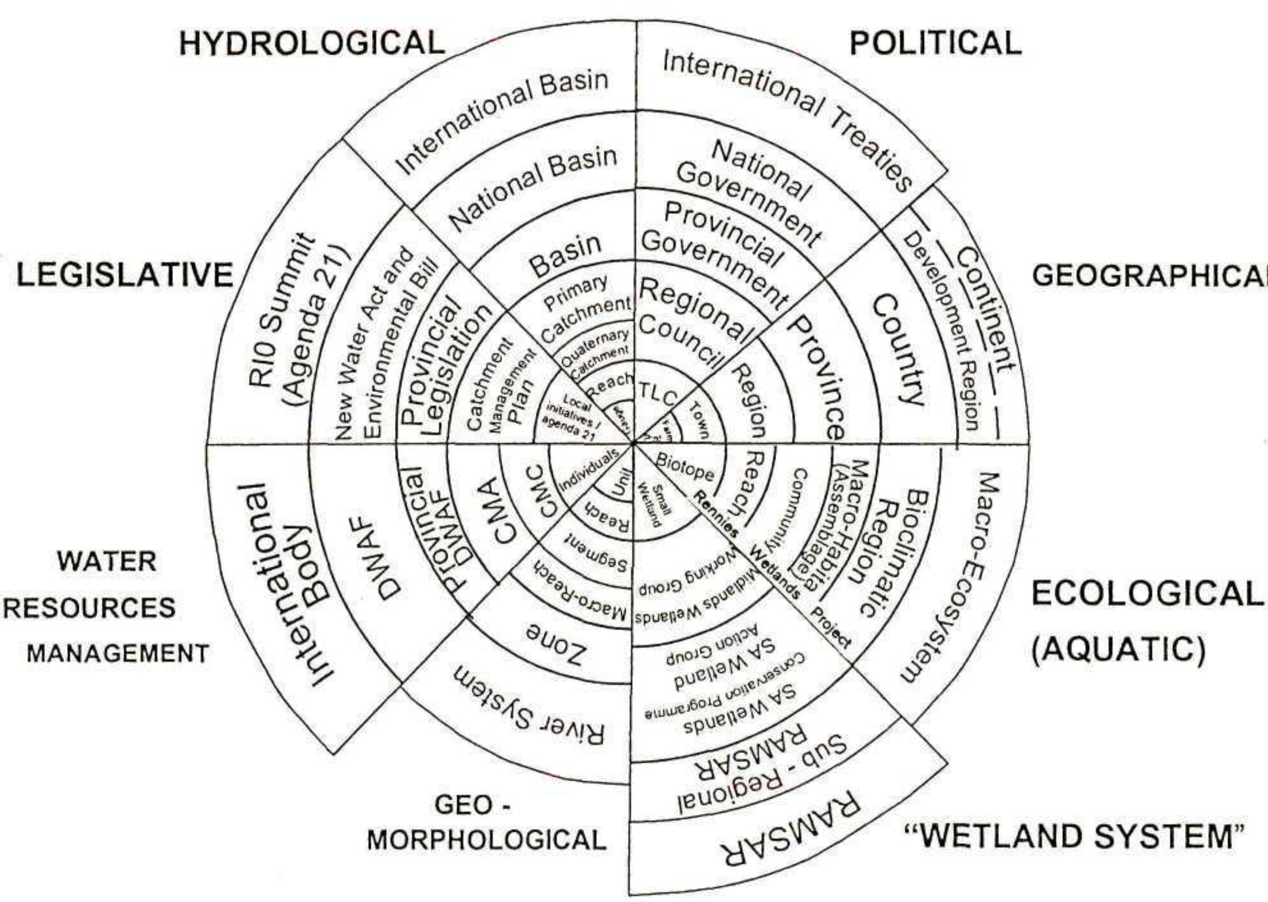
In the Mgeni catchment, as in many other catchments in South Africa, water demand is fast approaching the limits of water availability, and water quality is deteriorating. The need to manage the water resources in the catchment holistically and sustainably has led to the development of an Mgeni Catchment Management Plan for the management of water resources in the catchment (DWAF and Umgeni Water, 1996; Ninham Shand, 1997). In the plan, wetlands have been recognized as integral components of the catchment system. Although specific details of how the catchment's wetlands should be managed are not given in the plan and at the initiation of this investigation there was little information available on the nature and state of wetlands in the catchment, their contribution to water quality enhancement and flow regulation are recognized in principle in the plan.

The benefits that wetlands provide in terms of enhanced catchment water quality and maintenance of biodiversity have been widely demonstrated (Begg, 1986; Mitsch and Gosselink, 1986). Breen and Begg (1989) emphasise that in a semi-arid country such as South Africa, some important consequences of wetland loss are: poorer water quality; less reliable water supplies; and threatened wildlife resources. Kotze *et al.* (1995) show that the extent of wetland loss in South Africa has been high.

A cornerstone of South Africa's new National Water Act, which became operational in October 1998, is that integrated management of natural resources, including water, requires the participation of stakeholders within a catchment (DWAF, 1998). This is an extremely difficult goal to achieve. The issues involved are often intimately linked to stakeholder culture and value systems, forming a mosaic of social interactions, operating at different scales within a hierarchy of decision making levels (Jewitt, 1998). With the new management approach embodied in the concept of Integrated Catchment Management (ICM) and formalized in the new South African Water Law, management decisions must include large areas of interest, multiple spatial and temporal scales, across many different organisational hierarchies, and involve a diversity of stakeholders (DWAF, 1998; Jewitt, 1988).

General systems theory states that in spite of obvious differences among the many kinds of living and non-living systems, they share certain general characteristics. Furthermore, social, biological and physical systems are interwoven, and may be nested much like respiratory or circulatory systems are nested within the whole human organism (Hong *et al.*, 1997; Jewitt, 1998). The view of a hierarchical system made up of sub-components interacting in some way implies the notion of environments within and outside of the system and boundaries between them, which are not fixed or impermeable (to materials, energy and information). The ICM approach allows clear segmentation of river systems into functional management units (catchments and sub-catchments) which are linked together to form an overall management plan for an entire river basin (DWAF, 1996). A hierarchical and systems approach to ICM is discussed in more depth by Jewitt (1998) and Jewitt and Kotze (in press).

Management decisions need to be addressed at multiple spatial and temporal scales, and across both natural and jurisdictional boundaries, to fully consider their effects. No single set of hierarchical criteria will be entirely adequate, and rather than being conducted in isolation, analyses and management need to be integrated and conducted at multiple scales. Using space and time as the basic reference elements, hierarchical levels may be scaled by the scope of either structures within a catchment, or physical processes occurring therein, allowing integration of data from diverse sources (Jewitt, 1998). Figure 8.1 presents a systematic conceptual view of a comprehensive hierarchical classification system applicable to South African catchments in the context of ICM, and with a focus on wetland systems. The hierarchy is based on relative rather than absolute scales, and moving around the circle through horizontal sub-systems at the same level will provide some idea of the components which are applicable at the same spatial and, often, temporal scale. The diagram provides a useful tool for placing catchments, rivers, wetlands, their habitats and other components in a wider biophysical and administrative context.



CMA - Catchment Management Agency

CMC - Catchment Management Committee

TLC - Transitional Local Council

Fig. 8.1 A framework for the development of hierarchical systems to aid in ICM and wetlands management in South Africa (adapted from Jewitt and Kotze, in press).

8.2 The study area and its water quality situation

The upper Mgeni catchment covers an area of 1100 km^2 and is located in the province of KwaZulu-Natal on the east coast of South Africa (Fig. 8.2) which is one of the higher rainfall areas of the country. Although most of the upper Mgeni catchment has a mean annual rainfall in excess of 900 mm, rainfall over the catchment is spatially variable, with mean annual rainfall ranging from in excess of 1 200 mm to less than 800 mm (Tarboton and Schulze, 1992). Soils tend to be dystrophic in the higher rainfall areas and mesotrophic in the lower rainfall areas (Scotney, 1970). Altitude ranges from 1 020 m to 1 950 m, and there are three main physiographic areas: the low altitude plateau (<1 100 m) plateau; the mid-altitude valleys (1 100 m - 1 700 m); and the high altitude plateau (> 1 700 m). These three areas were used as the basis for describing ecoregions within the study area.

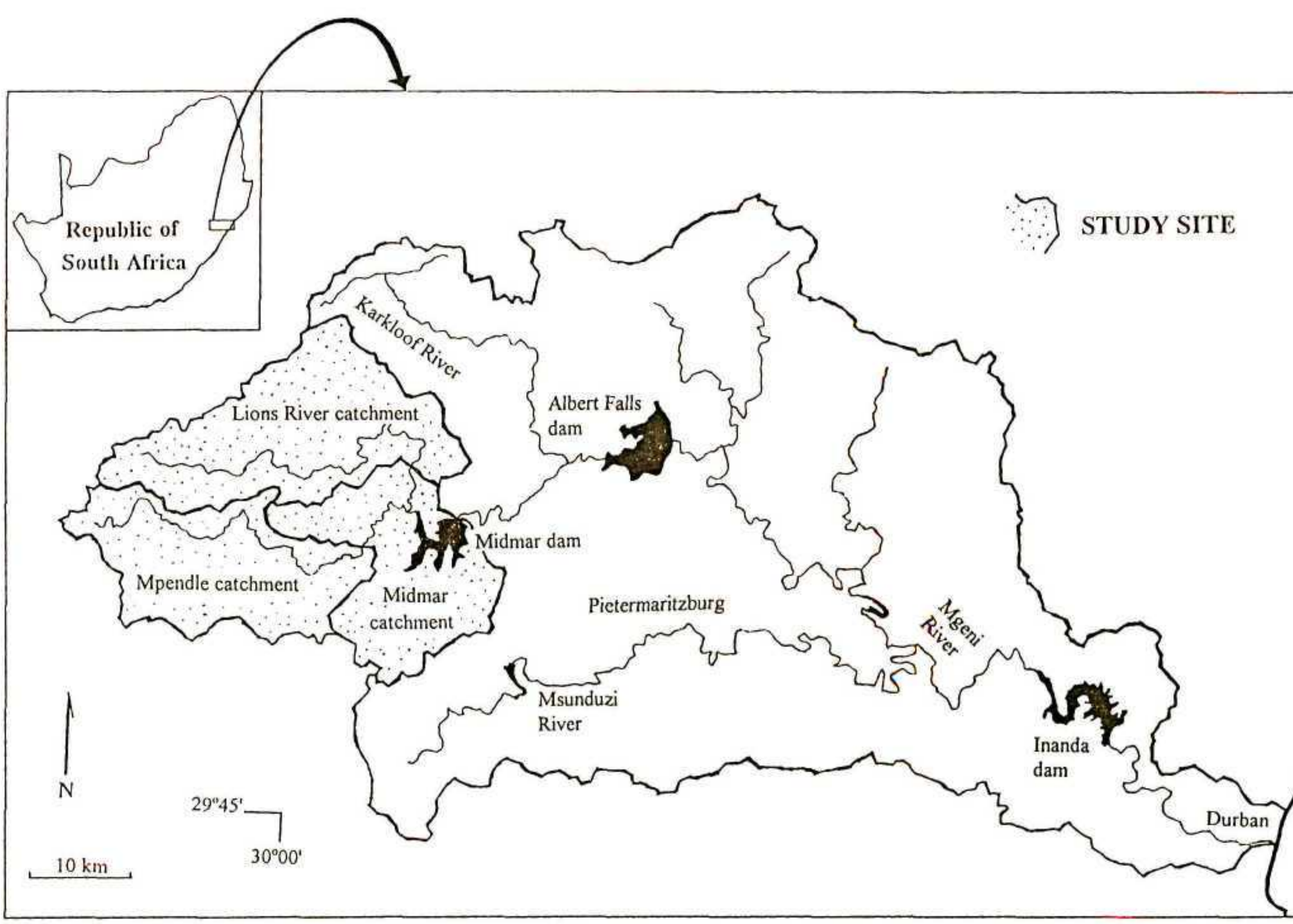


Fig. 8.2 Location of the study area in relation to the overall Mgeni catchment and South Africa.

In this investigation, the catchment and sub-catchments of Kienzle *et al.* (1997) were used for sub-dividing the study area into catchment units (Fig. 8.3). The Lions River and Mpendle catchments have similar areal extents, physiographic features and annual streamflow levels. Overall, however, the Lions River catchment has been subjected to higher levels of intensive agricultural development and has a higher concentration of dairies and piggeries, which are potential point sources of pollution (Seed and Hunter, 1993). The Midmar catchment, which has a smaller total surface area than the other two catchments, has levels of intensive agricultural development similar to the Lions River catchment (Seed and Hunter, 1993). Mean annual *E. coli* concentrations from non-point sources and non-point source phosphorus yield were generally lowest in the sub-catchments within the Mpendle catchment, intermediate within the Lions River catchment and somewhat higher in the Midmar sub-catchment (Fig's. 8.3 and 8.4) (Kienzle *et al.*, 1997).

The population in the catchment of about 45 000 is relatively low, with about 75% residing in the formal and informal settlements in the town of Mpophomeni in the Midmar Dam catchment. Mpophomeni constitutes the most important pollution source in the study area.

The differences in degree of intensive use of the three catchments is reflected in their respective water qualities. Based on long-term water quality measurements, the Mpendle catchment has been identified as having acceptable water quality but the Lions River and Midmar catchments are considered to have water quality problems, particularly in terms of high phosphate and *E. coli* levels (DWAF and Umgeni Water, 1996).

8.3 The historical extent of wetlands in the study area

The best currently available information on the historical distribution and extent of wetlands in the study area was a detailed soil map at a scale of 1: 50 000 compiled by Scotney (1970) for the Howick Extension Area, which includes most of the Midmar catchment and some of the upper Mooi River catchment. The boundaries of all those areas shown on the map of Scotney (1970) with soils known to characterize wetland areas (i.e. soil types with a gleyed horizon close to the soil surface) were digitized and incorporated into an Arc-Info GIS (Geographical Information System) with each polygon being assigned a unique number. The system is maintained by the local water management organization, Umgeni Water, as part of their general information management system.

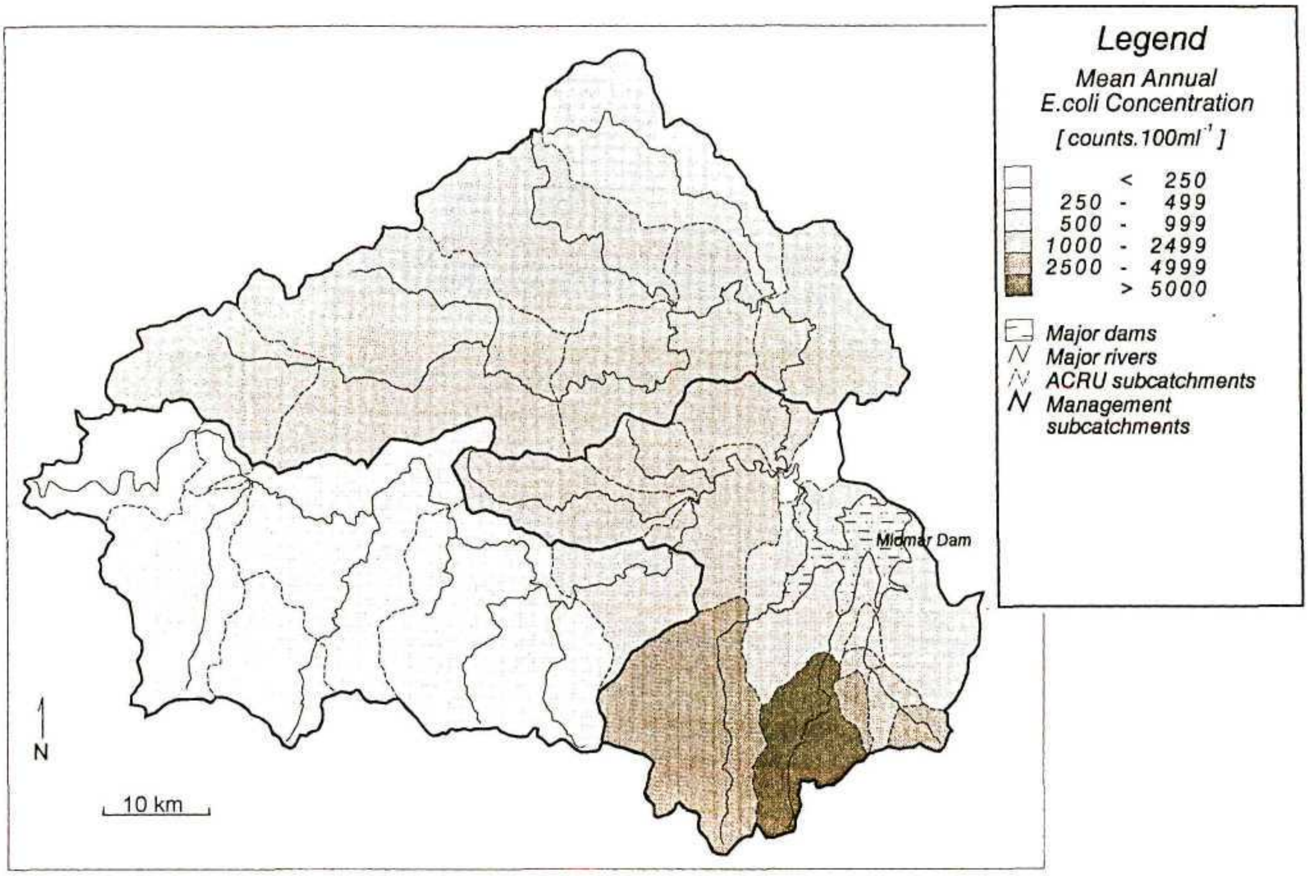


Fig. 8.3 Mean annual *E. coli* concentrations from no-point sources per subcatchment (from Kienzle *et al.*, 1997).

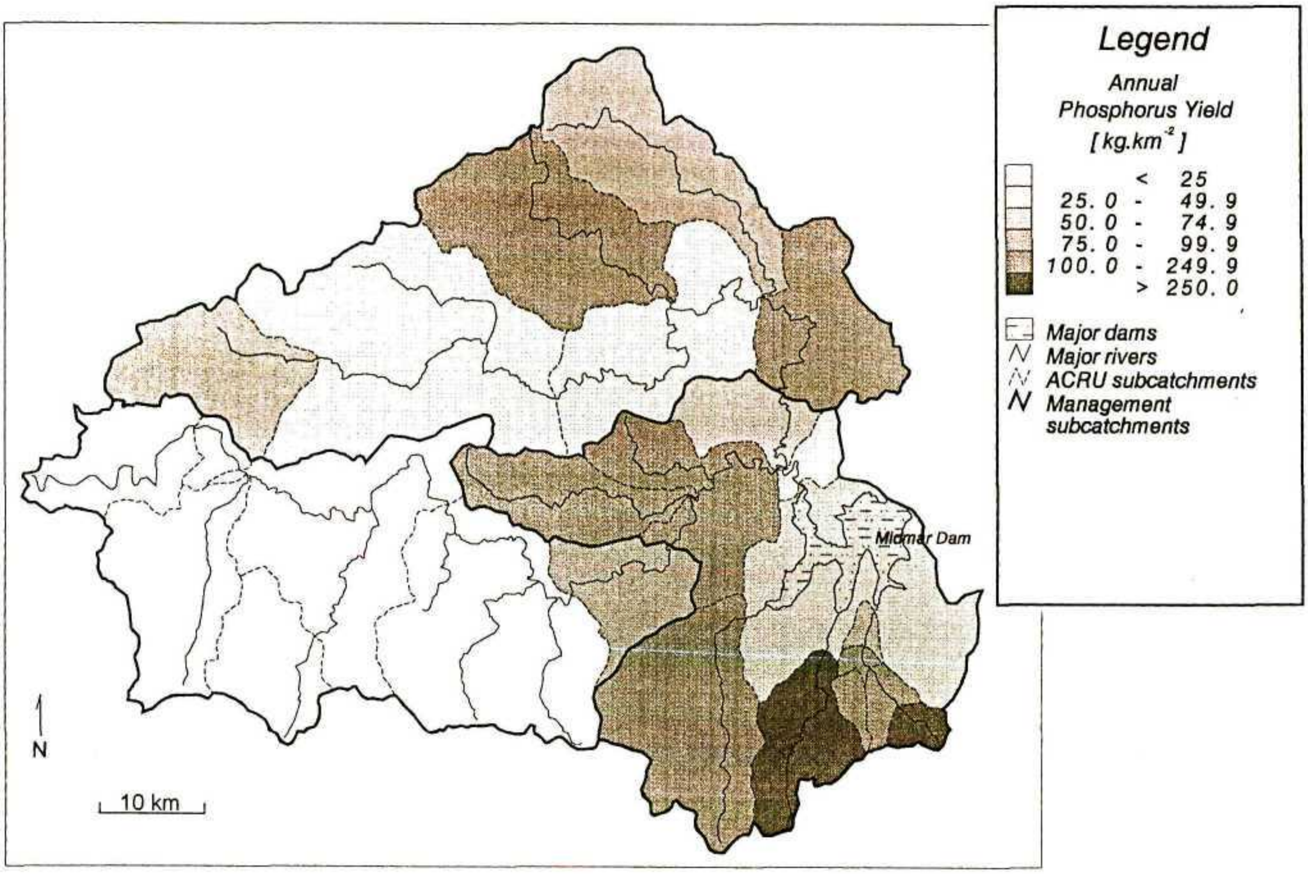


Fig. 8.4 Mean annual phosphorus yield per subcatchment (from Kienzle *et al.*, 1997).

8.4 Overall approach of the WIN Initiative

The WIN (Wetland Information Network) Initiative, which was facilitated by the Institute of Natural Resources, commenced by the stakeholders agreeing on a common overall vision and structure for the initiative. It was conceptualized as an informal network of stakeholders with different interests sharing standardized wetland information. Subsequently, it evolved to include explicitly various related activities, including data gathering, prioritization, training, awareness and management (Fig. 8.5). A full list of all stakeholder organizations, which included representation of water supply, biodiversity conservation and agricultural and forestry production interests, is given in the "Acknowledgements" section of this thesis.

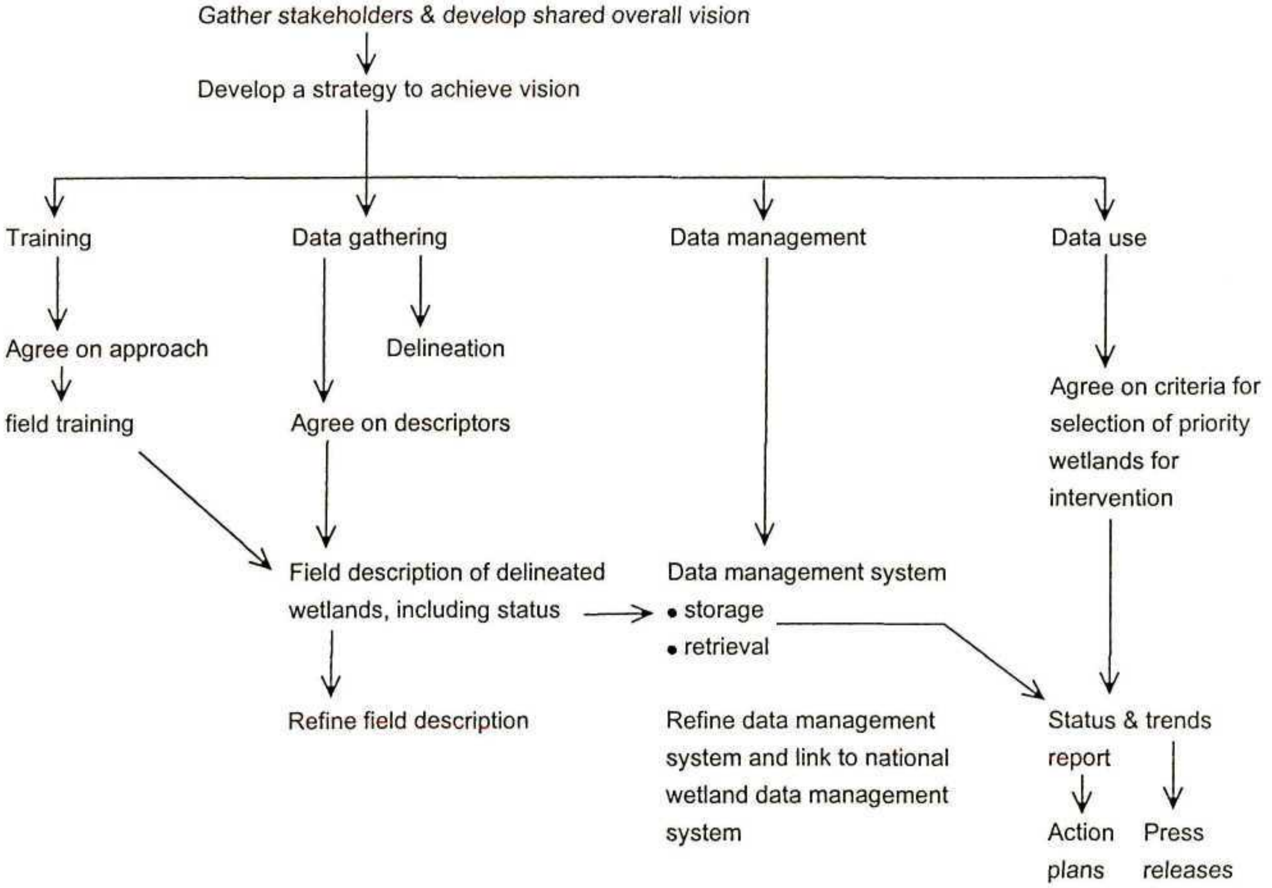


Fig. 8.5 Conceptual structure of the WIN (Wetland Information Network) initiative.

As the focus of the WIN Initiative expanded to implement a broader range of actions more directly influencing the pressure and state of wetlands, some of the organizations involved formed the Midlands Wetland Working Group. This group essentially evolved out of the WIN Initiative, and the main activities of this group have been the raising of awareness among individual farmers and facilitating the rehabilitation of artificially drained wetlands. To date, however, a formalized, multi-organizational overall strategy within which to structure these activities has not yet been developed for the catchment.

8.5 Data gathering and storage

In order to gather information on the nature and status of the delineated wetlands, a data sheet derived from WETLAND-USE (Kotze *et al.*, 1994a) was compiled with input from stakeholders. Descriptors on the data sheet included:

* landform setting (i.e. flat, channel, or channelled flat) and terrain type (i.e. crest, midslope, valleybottom) (Kotze *et al.*, 1994a);
* areal extent of current land cover within the wetland (e.g. natural vegetation, planted pastures, dams), with landcover classes being agreed upon by stakeholders; and
* extent of factors, notably artificial drainage, damming and alien plant infestation, which are commonly associated with wetland degradation.

Two data gathering events, which included individuals from several different stakeholder organizations, were undertaken using a field workshop approach. This allowed participants from a diversity of stakeholder groups to increase their skills and share experiences as data were being collected. Each data gathering event comprised three phases: introduction (1.5 days); data gathering (2 days); and summary and evaluation (2 hours).

The introduction included familiarizing participants with basic wetland functioning, values, impacts and rehabilitation, and with the field description of wetlands. Specifically designed booklets were used for this purpose (Kotze, 1997a and b). Most of the participants had at least some previous experience with wetlands. After introductory lectures all the participants worked in a single group on the same wetland. Data sheets were completed by individuals, following discussion amongst the whole group. The overall group then split into three groups and each group independently assessed a second wetland, which included a range of impacts. Their results were compared in order to reveal differences in interpretation of the datasheet and promote consistency among groups. Points of interpretation of the datasheet were clarified and some minor amendments were made to the datasheet. During the remaining two days, wetlands within different areas of the catchment were described by each group, which included a leader/demonstrator with previous experience in the field description of wetlands. A total of 23 wetlands were described in the first event and 19 in the second event.

The datasheet made provision for supplying recommendations to address problems within the wetland (e.g. erosion and alien plants). This has provided a useful basis on which the local extension services could approach landowners/managers and encourage them to improve their management. Where possible, on-site discussions were held with the landowners/managers regarding their wetlands and the level of impact that human modifications and land-use practices were having on the wetland. At the end of each day the three groups came together briefly to discuss their findings and any problems encountered, and at the end of both events an evaluation of each event by the entire group was undertaken.

Besides the specifically designed information gathering events, data for a further 19 wetlands were contributed by EIA practitioners and a research project investigating cranes at a national level. Thus, of the 169 wetlands identified in the catchment, 61 were described in the field. The remaining wetlands were described using interpretation of 1: 30 000, 1996 airphotos. Some of the descriptors could not be described using aerial photograph interpretation. Notably, the level of alien plant invasion could not be assessed and it was impossible to distinguish reliably between planted pastures and crops, and these were grouped together as cultivated lands.

The data for all of the wetlands described were captured in a QUATROPRO spreadsheet file set up to mimic the datasheet, saved in ASCII format and loaded into the Arc-Info GIS, with wetland numbers corresponding to those of the polygons of the digitized wetlands. These data may be accessed spatially using readily available GIS software.

8.6 Results, presented according to the cumulative impact considerations of Chapter 7

The natural extent of wetlands

Based on hydric soil data, wetlands were found to have covered 6227 ha (5.7%) of the catchment. Although approximately half of the wetlands were less than 10 ha (see Fig. 8.6), collectively these wetlands made up only 7.5% of the total wetland area. Almost all of the wetlands were associated with the drainage network and could be described as riparian systems. In terms of natural cover type, all were found to be palustrine, emergent, with natural tree and shrub wetlands being largely absent.

Of the 169 wetlands described, 92% were situated in a valley bottom position, 5% in midslope positions and 3% on footslope positions. No wetlands were found on crest positions. The average size of midslope and footslope wetlands were found to be 2 ha, and 11 ha respectively, which are considerably smaller than the overall average size of the described wetlands which was 37 ha. (This is the same trend as that revealed in Chapter 5). The minimum mappable unit of wetlands in the study area was one hectare, and the above results indicate clearly that there are particular wetland landforms, notably slopes, which are likely to be under-represented in the wetlands described owing to their characteristically small size.

While 7% of the channelled flats contained depressions, no wetlands consisted entirely of a depression setting. The majority of the wetlands either consisted entirely of, or contained, a channelled flat (76%). The next most frequent landform was the non-channelled flat (25%) followed by the slope (7%), and depression (5%). Again, the latter two landforms were characteristically small (see Chapter 5) and are therefore likely to be under-represented in the wetlands described.

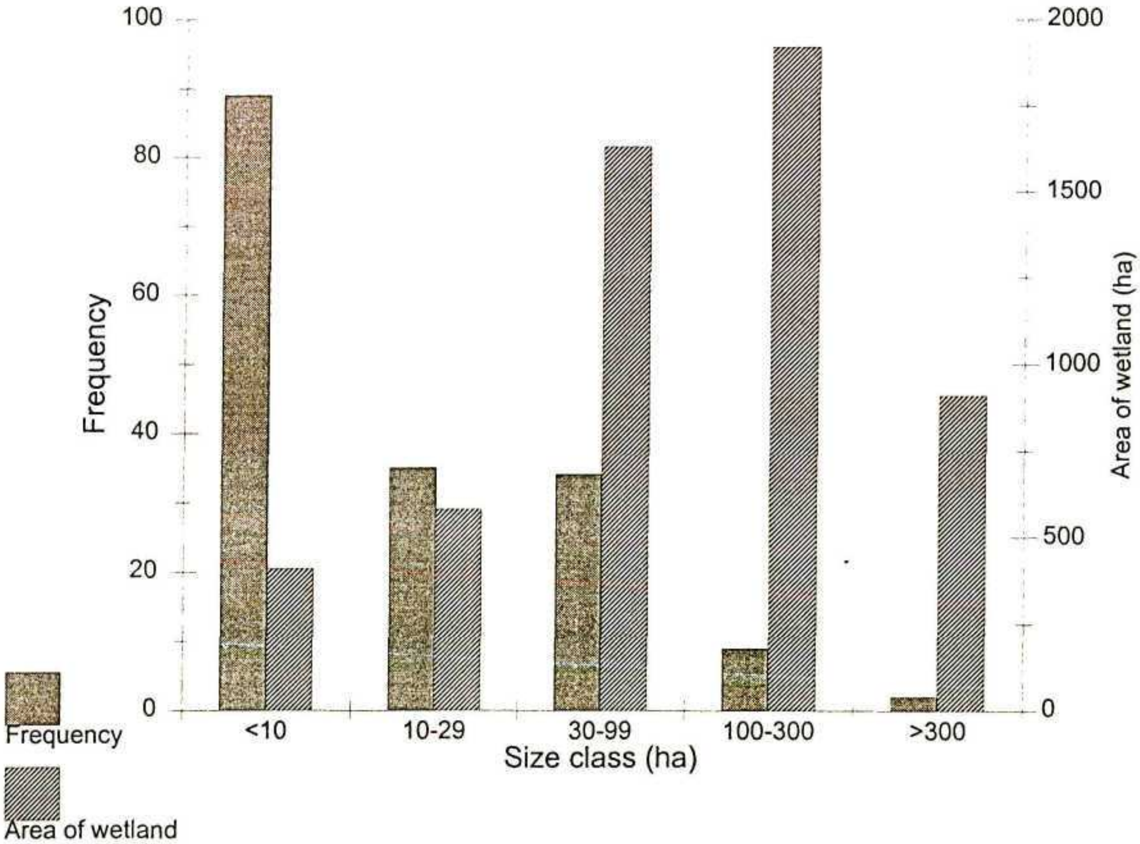


Fig. 8.6 Frequency of occurrence of wetlands and total area occupied by wetlands in different wetland size classes in the upper Mgeni catchment.

The extent of wetland loss in relation to catchments

The results indicate that 66% of the wetland area in the study area had been lost to human-induced causes. The extent of historical wetland loss was greatest in the Midmar catchment (71% of the original area lost), owing in part to the complete loss of an extensive wetland flooded by the Midmar Dam, followed by the Lions River catchment (68% lost) and then the Mpendle catchment which had the lowest loss (59% lost).

The extent of wetland loss in relation to altitudinal zones

Historical loss across the study area increased from intermediate levels at the highest altitudinal zone (47% of the original wetland area lost) to high levels in the mid altitude zone (67% lost) and still higher levels in the low altitude zone (73% lost). Alien plant infestation within wetlands followed a similar trend and was found to be greatest in the lower altitudinal zone (92% of wetlands infested) and decreasing with increasing altitude (76% of mid-altitude wetlands infested and 43% of high altitude wetlands infested).

The extent of wetland loss in relation to causes of loss

The greatest loss of wetlands was as a result of drainage and cultivation (mainly for pastures) followed by deep flooding by dams (Fig. 8.7). Wetlands of the study area generally have fertile soils and favourable positions for irrigation, making them popular areas for cultivation. They also provide suitable sites for farm dams as they are characterized by an impermeable foundation or obstruction and a gentle gradient (Nanni, 1970). Several wetland areas were found which had been drained and then abandoned, and were not currently being used for agricultural production. The amount of wetland lost to erosion and infra-structural development was very low but loss to infra-structural development may increase in the future with increasing urbanization.

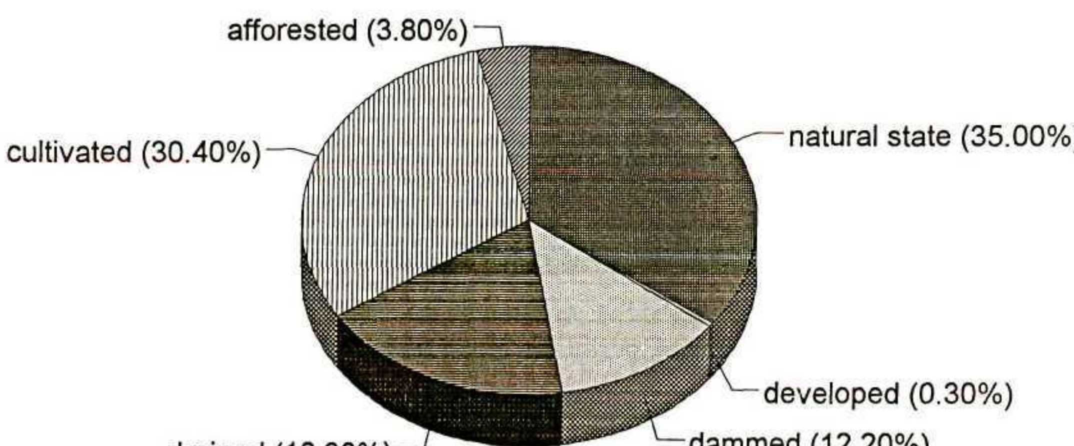


Fig. 8.7 Proportional land-use cover in the wetlands of the upper Mgeni catchment.

Wetland context

The wetlands in the study area varied greatly according to the extent of development in their surrounding catchments. Although an accurate measurement of the extent of transformation in the surrounding area was not possible, an estimate was made using a three class scale for those wetlands which were verified in the field (Table 8.1). It is clearly recognized that this index of connectivity is a simplification and needs to be explored in more depth. Nevertheless, there is a general trend of wetlands which had low levels of connectivity with other natural areas also having high levels of transformation within the wetland (Table 8.1). However, as indicated in Table 8.1, the variability in the level of transformation of wetlands with similar connectivities was great, and in the low connectivity class, for example, some wetlands were encountered which were untransformed on site. Although these wetlands are likely to be important from a water quality enhancement point of view owing to their good on-site condition and likely opportunity for purifying water, they would not be ideal candidates as sites chosen to represent the biodiversity of wetlands.

Table 8.1 Level of on-site transformation associated with wetlands verified in the field having different levels of connectivity with surrounding natural areas

Level of connectivity with surrounding natural areas	n	Mean percentage extent of on-site transformation ± SE
Low=wetland surrounded predominantly by transformed areas	9	80 ±78.2
Medium=wetland surrounded by a mixture of natural and transformed areas	27	54 ±39.0
High=wetland surrounded predominantly by natural areas	24	43 ±27.8

The context of wetlands was also examined from the point of view of a reduction in mean annual runoff, based on the estimates of Kienzle *et al.* (1997) which show that the impact of present land-use on mean annual runoff varies considerably among quaternary catchments. In the Mpendle quaternary catchment all sub-catchments have less than 20% reduction in mean annual runnoff, while the Midmar and Lions River quaternary catchments, which have been transformed to a greater extent, both include sub-catchments with >40% reduction in mean annual runoff. This indicates that the supply of water to wetlands in these latter two catchments has generally been disrupted to a greater extent than in the Mpendle catchment.

Wetland spatial configuration

The proportional reduction in the extent of large wetlands has been much greater than that of small wetlands, with the 100-300 ha class having the lowest area remaining under natural vegetation (Fig.8.8). Similarly, 45% of individual wetlands smaller than 10 ha had at least 75% of their area remaining under natural vegetation compared with 10% for wetlands larger than 30 ha. This provides a possible basis on which to focus on larger wetlands in order to ensure representation across the different size classes. It should be emphasised that the basis of this recommendation is certainly not that small wetlands are generally less important than large wetlands, as indicated by Gibbs (1993) and Semlitsch and Bodie (1998) who demonstrate the importance of small wetlands.

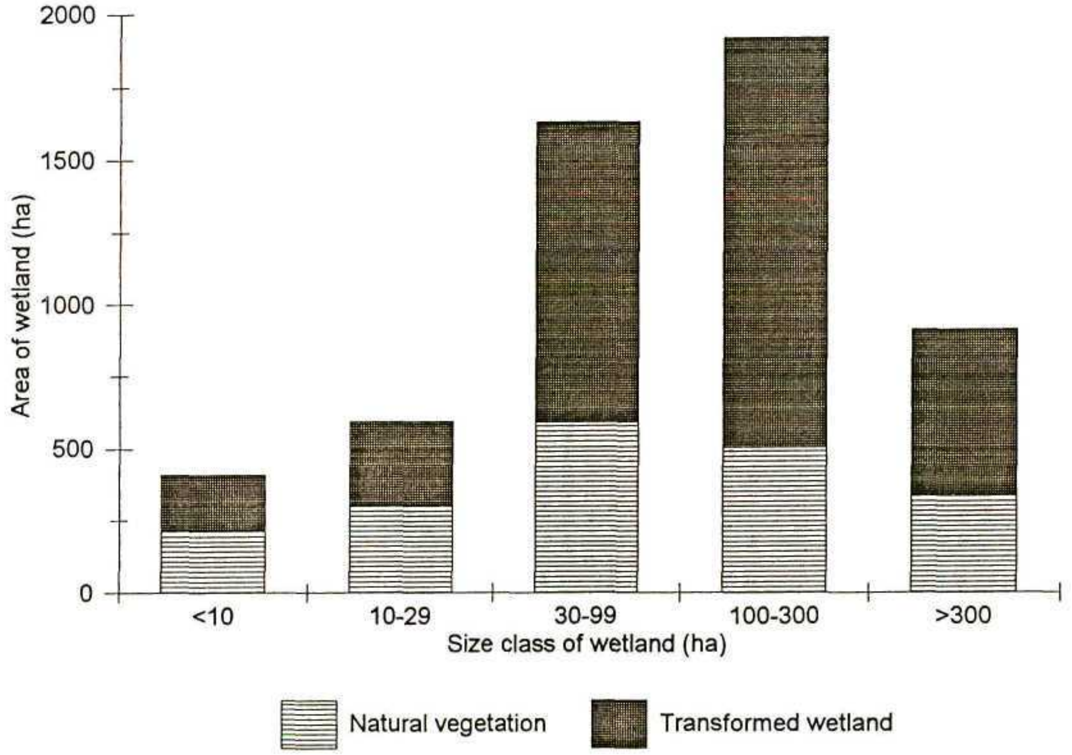


Fig. 8.8 The proportion of developed and natural wetland area in the Midmar catchment across wetland size classes.

Representation within wetlands

Where virtually all of the areal extent of a particular wetland has been developed, such as is the case for some of the wetlands in the study area, then it can be assumed that all hydrological (wetness) zones in that particular wetland have been lost to the same degree. In certain wetlands, such as the Lions River flats, the wettest, lowest lying areas such as deep oxbow depressions have been left undeveloped. However, in most developed wetland areas, particularly those that have been flooded by dams, it was generally not possible to determine the particular zones that had been lost. Thus, although it would appear that within the study area the less wet zone has been lost to a greater degree than the wetter zones, this could not be substantiated.

8.7 Recommendations for selection of priority wetlands for management intervention

The recommendations given below, which are based largely on the cumulative impact considerations derived from the literature (see Preston and Bedford, 1988) and given in Chapter 7, are that extension workers should focus on those wetlands:

1. within the catchments where loss has been highest, namely the Mpendle and Midmar catchments (this is particularly important for the Midmar catchment where the proposed raising of the dam is estimated to be causing the loss of a further ca. 40 ha of wetland);

2. at altitudes where wetland loss has been high (i.e <1700 m);

3. that, in the case of maintaining biodiversity, have high levels of connectivity with other natural areas and relatively low pollutant input, particularly that of P. High nutrient levels have been shown to affect wetland integrity to a much greater extent that high *E coli.* levels, particularly by promoting the growth of certain plants, notably *Typha* species, at the expense of other plant species (Coetzee, 1995);

4. that, in the case of optimizing the water quality enhancement benefits provided by wetlands, should have pollutant input (*E. coli* or P), providing the wetland with opportunity for providing such benefits. (Nevertheless, the use of natural wetlands should not be seen as an easy substitute for addressing pollution at source and constructing artificial wetlands [Coetzee, 1995] and point sources would need to conform to the requirements of the new Water Act);

5. that, in the case of wetlands identified for rehabilitation, consist of previously drained areas now abandoned, avoiding the need to take land out of active production; and

6. that have receptive and willing landowners.

As indicated in the Chapter 7, it is recognized that criteria 4 and 5 may be conflicting. Where a wetland's surrounding catchment has a high level of intensive use and anthropogenic input of pollutants, the opportunity for enhancing water quality is high but the biotic diversity benefits it provides are likely to be reduced as a result of reduced connectivity and the pollutants having a negative affect on the wetland's fauna and flora. As indicated, however, certain pollutants (e.g. high nutrient or salinity levels) tend to have a much greater impact than others (e.g. *E. coli*).

In examining the extent to which wetlands representative of the range of wetland types found across the catchment had been secured, it was found that the only wetlands to be secured in a formally protected area were confined to the high altitude zone, comprising the Mgeni vlei and four small adjacent wetlands. Only a single wetland in the catchment has been declared a Site of Conservation Significance (see Appendix A, page 6), and this was situated in the high altitude zone. Thus, it is considered important that wetlands at mid and, particularly, low altitudes, where there have been considerably higher levels of wetland loss, should be secured, at least through declaration as Natural Heritage sites or Sites of Conservation significance (see Malan and Whal, 1996).

In the Midmar Integrated Planning Initiative (Ninham Shand, 1997) the high altitude wetlands of the headwaters of the Mgeni were singled out as being "the most sensitive" and the lower altitude wetlands as less sensitive. With the exception of the wetlands immediately adjacent to Midmar Dam, the wetlands in this headwater zone were identified as requiring particular conservation attention. It is contended that the system of zoning proposed by Ninham Shand (1997), which is contrary to the recommendation of securing mid- and low altitude wetlands, would be at the expense of wetlands lower in the Midmar catchment, which are more important from a cumulative impact point of view. As described, these lower wetlands have been subject to higher levels of loss and are probably more important for enhancing water quality than the headwater wetlands. The results of this investigation indicate that there is no evidence as yet to show that they are any more sensitive than lower altitude wetlands, unless the presence of Red Data species is used as the primary criterion for determining sensitivity. In fact, the lower altitude wetlands tend to be more sensitive to erosional degradation as shown both by the occurrence of erosion and the erodibility of their soils.

The selection criteria given in this section are not intended to provide a complete assessment of priority. On-site features, namely the presence of Red Data species, erosion hazard of the site and factors which relate to the effectiveness of the wetland in purifying water (e.g. flow patterns) could also be included. These on-site factors are the primary focus of WETLAND-USE and are dealt with in detail in Chapter 3 and Appendix D.

There was agreement among stakeholders in the initiative that although it is often more cost effective to secure existing, intact wetlands than to rehabilitate degraded or developed wetlands, the rehabilitation of strategically placed wetlands (e.g. wetlands in areas where water quality problems exist) would justify the costs of re-habilitation. In some instances the destruction of wetlands is unavoidable and re-habilitation of these strategically placed wetlands provides opportunities for off-site compensatory mitigation, particularly in the case of large storage dams. For example, the three alternative sites for a proposed dam in the upper Mooi River catchment, which is adjacent to the Mgeni catchment, will all flood in excess of 50 ha of wetland to great depth. The wetlands which have been drained and subsequently abandoned provide ideal candidates for undertaking rehabilitation as they do not require that land owners forgo agricultural production in the rehabilitated areas. Although off-site mitigation is not general practice in South Africa, there is increasing pressure for organizations to conform to accepted international standards of environmental management. Thus, it should be promoted, while remaining aware of its limitations (see Mitsch and Wilson, 1996; Young, 1996; Streever, 1997).

8.8 Integration achieved in the initiative

Horizontal integration

Based on the fact that a diversity of stakeholder organizations (who would be using the information) have been involved in specifying which information was to be collected according to their needs, the information is likely to be useful to many organizations. Involvement of a wide range of stakeholders in the gathering of wetland information has also provided a valuable opportunity for different organizations to share experiences regarding wetlands. The information gathered is readily available through the GIS systems of the provincial conservation body and the local water authority, and has been collated to ensure that it is used effectively. A report of the collated information for the Midmar catchment was circulated to all stakeholder organizations and is currently being used as one of the information sources for the development of an Integrated Catchment Management Plan for the Midmar catchment. A formalized information management system is still, however, required to ensure that the information is efficiently and readily available to a wide spectrum of users. At present the information is still largely being used in an informal manner based on the preliminary rules of thumb. The procedure used has not been integrated formally into the legal system as is the case for the synoptic assessment procedure of Abbruzzese and Leibowitz (1997). This study nevertheless provides an indication of some key elements and their practical consideration. As indicated, there is also not a formalized organizational structure to ensure linkages across organizations. An important factor contributing to this is that, to date, there has been no overarching catchment management plan, including policy and strategy, for the Midmar catchment and the wetlands it contains, nor is there a catchment management authority.

Vertical integration

A brief four page document for landowners and managers indicating wetland values and impacts and wetland management in a catchment context was developed for distribution during the data gathering. This is only a small step in addressing the inward vertical integration to the level of individual wetlands. A coordinated and ongoing effort, particularly through the extension services, will be required in order for inward integration to take place in a systematic and sustainable way. This should be made easier by the fact that extension workers and other individuals in the Midlands Wetland Working Group were involved in data gathering and are therefore familiar with some of the individual wetlands and their broader context.

These activities are being undertaken by the Midlands Wetland Working Group, which is currently involved in facilitating the rehabilitation of wetlands identified by the WIN initiative as having a high priority, thereby promoting vertical integration to lower organizational levels. This approach of multi-organizational collaboration to survey wetlands and identify those for conservation action is also being repeated through six other such working groups in different parts of South Africa, including the Free State, Mpumalanga, Eastern Cape, Western Cape and Northern Province. These working groups are being facilitated by the Rennies Wetlands Project, an NGO funded by local business. Thus far these groups have described in the field a total of 3 600 ha of wetland (extending for a total of 450 km) using the general procedure adopted in the WIN initiative (Lindley D, 1999. *Pers. comm.* Rennies Wetlands Project, Johannesburg). During 1998, a forum was established termed the South African Wetland Action Group (SAWAG) which aims to link more localized initiatives, including the working groups, and allow areas of common interest to be addressed in a synergistic way. The Group has provided very valuable feedback through field workshops for the refinement of WETLAND-USE (see Chapter 12), which they, in turn, will use in their ongoing extension work. Thus, vertical integration to higher organizational levels is being explicitly addressed. This is, however, still at a fairly informal level, only selected areas of the country are represented, and further stakeholders that should be included have been identified. Thus, it needs to be formalized and its base expanded to include more stakeholders and a wider geographic area.

A national wetland inventory facilitated by the Department of Environmental Affairs and Tourism has recently been initiated. To date, national standards and classification systems are being developed. The approach of the WIN Initiative was presented at a national wetland inventory workshop, and this has contributed to the ongoing development of these national standards. In turn, once the national standards have been developed further, it may be necessary to modify particular descriptors used in the WIN Initiative to ensure effective linkages between the different organizational levels. Similarly, the protocols for prioritizing wetlands in the study area, which were developed in the absence of any national protocols or guidelines, could contribute to a national initiative for prioritizing wetlands. The WIN protocols may, in turn, need to be revised in line with national standards.

8.9 The initiative in relation to the pressure-state-perceptions-policy framework

The primary focus of the WIN Initiative has been on characterizing the state of individual wetlands and aggregating this information to further characterize the state of wetlands in sub-catchments and the overall upper Mgeni catchment respectively. By collating the information and making the results as readily accessible as possible, the initiative has also, to a lesser extent, attempted to address perceptions at various organizational levels, from those of the individual landowner to organizations at higher organizational levels, such as the local water management authority.

Ideally, the initiative should be nested in a broader initiative to promote the integrated management of the catchment. However, as indicated such an initiative was not in place, and vertical and horizontal integration are required for the development of policy at the different levels and the translation of this policy into actions that reduce the land-use pressure on the wetlands in the catchment. The new National Water Act will create a more enabling environment for this to take place, and extensive input will be required at various levels in the organizational hierarchy, particularly at the level of individual landownership. The development of custodianship protocols by the South African Wetland Action Group is aimed directly at policy at the individual wetland level (see Chapter 12). Although, to date it is unlikely that the WIN Initiative has had a significant influence on the pressure exerted on wetlands at a catchment and sub-catchment level, it is hypothesised that once effective policy has been developed across organizational levels this situation will change.

8.10 Conclusions

In the short term, at least, the initiative is considered to have achieved its objectives. A useful data-set has been generated that is accessible to a wide range of stakeholder organizations. These data show that in the upper Mgeni catchment only 34% of the original wetland area remains in an undeveloped state with loss being particularly high in certain altitudinal zones and catchments. Based largely on the rules of thumb generated in the previous chapter, wetlands considered to have the highest priority for management intervention were identified as a means of focussing management intervention in the study area.

An examination of the integration of the system showed that both vertical and horizontal integration had been explicitly addressed: (1) vertical outward integration through the South African Wetland Action Group; (2) vertical inward integration through extension workers and other individuals in the Midlands Wetland Working Group; and (3) horizontal integration through the multi-stakeholder nature of the initiative. Nevertheless, several aspects need to be addressed to improve integration, notably establishment of a multi-stakeholder catchment management strategy and authority. As will be discussed in greater depth in Chapter 12, there is a great need for policy development at all organizational levels, from national to individual wetlands.

WETLAND-USE provided useful frameworks for field training and characterizing individual wetlands across the catchment in a manner acceptable to a diverse range of stakeholder organizations and which allowed aggregating the information to build a picture of the state of the wetlands at a sub-catchment and catchment level. Based on this description, the rules of thumb developed in Chapter 7 were used to identify priority wetlands from the point of view of accounting for cumulative impacts on wetlands. However, WETLAND-USE and the rules of thumb did not provide an overall framework with supporting legal instruments within which cumulative effects could be taken into account. Thus, this chapter by illustrating the usefulness of WETLAND-USE as well as its limitations in accounting for cumulative impacts, has: (1) contributed to addressing, to some extent, an important deficiency of the WETLAND-USE prototype; and (2) highlighted particular instruments outside the scope of WETLAND-USE that need to be developed for considering cumulative impacts on wetlands. In the following chapter, a further deficiency of the WETLAND-USE prototype, namely its omission of land-uses commonly practised in communal areas, is addressed. The following chapter also includes the consideration of cumulative impacts within a single wetland site.

CHAPTER 9

APPLICATION OF WETLAND-USE TO A WETLAND UNDER COMMUNAL USE: ASSESSMENT OF BIOPHYSICAL IMPACTS OF LAND-USE PRACTICES

9.1 Introduction

In South Africa, although the greatest area of wetland falls within the privately-owned, large-scale, commercial agricultural sector, many wetlands also fall within the communally-owned, small-scale agricultural sector. For example, of the 21 wetlands identified by Begg (1989) as priority for KwaZulu-Natal which are outside of formally protected areas, seven are communally owned or include communally owned portions. There are marked social, cultural and economic differences between these sectors. Because of these differences, which influence decisions such as choice of crops and modes of production, it was anticipated that the WETLAND-USE prototype, which was developed for application in the commercial agricultural sector, would have important deficiencies when applied to wetlands in the small-scale/subsistence agricultural sector. As part of refining WETLAND-USE to make it more widely applicable it was applied to a wetland in this sector, the Mbongolwane wetland, in KwaZulu-Natal. The overall goal of the study reported in this Chapter is to examine the underlying premises and recommendations of WETLAND-USE in a small-scale farming context. The specific objectives of the study, which focuses on two of the main land-uses in the Mbongolwane wetland, the harvesting of the sedge *Cyperus latifolius* Poir and the cultivation of taro (*Colocasia esculenta* (L). Schott), are the following.

1. Describe the Mbongolwane wetland and resource use practices applied to the system using the frameworks given in WETLAND-USE.

2. Assess the impact of these practices on the wetland using the rapid assessment criteria from WETLAND-USE and determine the acceptability of the practices based on the guidelines given in WETLAND-USE.

3. Examine the results in relation to the overall objectives of WETLAND-USE, and provide insight into any internal inconsistencies between the principal assessment criteria and the specific recommendations of WETLAND-USE, and recommend refinements to WETLAND-USE.

9.2 Historical and legal context of the investigation

Extensive wetland areas have been developed to commercial cropland in South Africa, most of this taking place prior to the 1980's with government support in the form of advice (see Hill *et al.*, 1981) and subsidies (Kotze *et al.*, 1995). During the 1980's, with increased awareness of environmental issues, government support for wetland transformation declined and legislation for wetland protection was developed. The Conservation of Agricultural Resources Act 43 of 1983 makes provision for wetland protection in requiring that a permit be obtained for cultivating or draining a wetland. However, in the commercial agricultural sector, for which this legislation was designed, it has important weaknesses with regard to protecting wetlands (Cowan, 1995b). For instance, the terms vlei, marsh and sponge are used but are not defined, and the enforcement of the legislation is poor. In the subsistence and small-scale farmer sectors this legislation is even less useful and is usually not applied. In this sector, where resources are generally communally-owned, there is the additional factor of different levels of accountability (see Chapter 10), which further complicates the application of this Act.

Based on recent inventories (e.g. Patrick and Verburg, 1996; and the results reported in Chapter 8) and observations by extension workers it appears that there is little new wetland area being transformed for commercial crop production in KwaZulu-Natal. In contrast, the extent of subsistence and small-scale cultivation within wetlands has been increasing noticeably in KwaZulu-Natal and most likely in some of the other provinces. On the whole, the response of government organizations appears to have been not to intervene in the expansion of cropland into wetland areas in this sector (see Chapters 10 and 11). In addition, non-government environmental organizations involved in promoting sound wetland management (e.g. the Rennies Wetlands Project) have worked predominantly with large-scale commercial farmers and commercial forestry plantations.

Owing largely to socio-political factors, notably apartheid policies, Black farmers in South Africa have historically had very limited access to the capital and information required to pursue large-scale development options. This is likely to have contributed to the untransformed and, hence, soundly functioning state of many wetlands in black-owned rural areas. This contrasts with the white-owned, intensively farmed areas where many wetlands have been transformed at a time when the indirect benefits accruing from these systems were afforded low priority in relation to the direct benefits from transformed systems.

As access to funding for development and markets for products increase with the new political system, Black farmers are increasingly looking towards areas such as wetlands to improve their economic situation. At the same time, however, the international community and many government and non-government organizations and initiatives (e.g. Davis, 1993; Whyte, 1995) are discouraging the destruction of wetlands in principle as the indirect benefits of these systems are becoming increasingly recognized. Thus, in the context of historically disadvantaged communities, the potential level of conflict between the goals of conservation and economic development is great, and is compounded by the increasing human population and high levels of poverty.

9.3 Methods

The wetland description using WETLAND-USE Component 1

The Mbongolwane wetland and its current utilization was described using the WETLAND-USE prototype (Appendix C), which included a field survey and a comparative analysis of air photographs (from 1937, 1953, 1964, 1975, 1983 and 1991). The following aspects of the wetland were described using the protocols given in the first component of WETLAND-USE:

1. degree of wetness of soil described according to whether the soil was permanently, seasonally or temporarily wet (see Chapter 4);

2. landform setting, which has a strong bearing on water flow patterns in the wetland (see Chapter 5);

3. erosion hazard based on soil erodibility, slope, and landform;

4. distribution of vegetation types, based on the dominant species;

5. fauna and flora, with particular attention being given to any Red Data species (Smithers, 1986);

6. land-use activities (including a description of their distribution and extent) and the benefits that accrue (qualitatively assessed);

7. the nature and extent of land-use practices in the surrounding catchment; and

8. the extent of wetlands in the surrounding landscape.

Wetlands in the surrounding landscape were examined within a 21 400 ha area surrounding the wetland, as delimited by, and obtained from, the nine 1: 10 000 orthophotographs including and surrounding the Mbongolwane wetland. Those wetlands delineated on the orthophotographs which were close to roads were verified in the field. The extent of wetlands in the areas surrounding two other wetlands of comparable size, namely Mgeni vlei and Ntabamhlope vlei (see Begg, 1989) were also examined for comparative purposes.

Besides information gained from the biophysical description of the wetland, information on local people's resource-use patterns was gained through community workshops; interviews with wetland users encountered in the wetland during the field survey; and focus groups comprising different users (e.g. plant harvesters). The guidelines for participatory research given by Chambers (1994) were used in gathering this information. The use of wetlands embraces several elements which are summarized in the perceptions-policy-pressure-state framework described in Chapters 3 and 9. This study has focused on characterizing the pressure (i.e. the modes of wetland use) and how this affects the state of the wetland at Mbongolwane. The other elements and inter-relationships are addressed in Chapters 10 and 11, which examine organizational involvement in wetland management.

Biophysical criteria of WETLAND-USE for assessing land-use impacts and providing management guidelines

In order for the goal of sustainable use to be measurable and practically implementable, assessment criteria are required. If a system such as a wetland is being used in a natural or near-natural state, assessment of sustainable use primarily involves assessing sustained yield of the particular resource/s being used. However, where use requires transformation of the system, assessment is more complex. Besides assessing sustained yield, an assessment is required to determine how far a system can be modified before the natural properties are "no longer being maintained" as indicated in the Ramsar Convention Bureau definition. In other words, what are the limits of acceptable cumulative change? To answer this question it is necessary to consider the functions and properties of wetlands which indirectly and directly benefit people. As elaborated in Chapter 3, indirect benefits considered by WETLAND-USE include water quality enhancement, streamflow regulation, flood attenuation, erosion control, biodiversity support, and biogeochemical cycling. Direct benefits derived from wetlands include: fibre for weaving and construction; land for cultivation; a supply of water; and grazing for domestic stock.

Guidance in assessing the severity of impact of human uses on the hydrological and erosion control values is given by the WETLAND-USE prototype based on the following principal criteria, which are largely qualitative and based on the literature (Kotze *et al.*, 1994a):

1. the extent to which flow patterns in the wetland are altered (e.g. through drainage) thereby reducing the degree of wetness (Goode *et al.*, 1977; Lavesque *et al.*, 1982; Brinson, 1988; Ingram, 1991);
2. the degree to which the soil is disturbed (Miles and Manson, 1992);
3. the degree to which the soil organic matter content is likely to decrease as a result of a lowered water table and/or greater soil disturbance (Ingram, 1991; Miles and Manson, 1991);
4. the extent to which the roughness coefficient of the wetland is decreased, either by smoothing out microtopographical surface irregularities such as hummocks or by replacing the natural vegetation with new vegetation that offers less resistance to water flow because it is shorter, softer, less dense, and/or less perennial (Reppert *et al.*, 1979; Adamus *et al.*, 1987);
5. the degree to which potentially polluting substances such as pesticides are added to the area (Preston and Bedford, 1988);
6. the degree to which soil subsidence takes place (soils with high *n* Values (Pons and Zonneveld, 1965) and/or organic contents are most susceptible); and
7. the extent to which wetland area is reduced (Adamus *et al.*, 1987; Brinson, 1988; Preston and Bedford, 1988).

The assessment of ecological impacts by WETLAND-USE accounts mainly for effects on threatened species and obvious changes in the hydrological regime or water quality. Since an excess of water is the dominant factor affecting the plant and animal communities in a wetland (Cowardin *et al.*, 1979) it may be assumed that the greater the disruption of the hydrological regime, the greater will be the loss of ecological benefit. Thus, in most cases where land-use activities detract from the hydrological benefits of a wetland, they will also detract from the ecological benefit. WETLAND-USE Component 2 provides guidelines for determining the acceptability of generic land-use categories (e.g. planted pastures), with "threshold levels" given for key descriptors (e.g. erosion hazard) beyond which the land-use is considered likely to have unacceptably high impacts, as described in Chapter 3.

WETLAND-USE Component 3 provides guidelines for the ongoing management of particular land-uses which are designed to minimize the environmental impacts of these land-uses. For example, if the chosen land-use is crop production then recommendations designed to minimize the leaching of fertilizers and depletion of soil organic carbon through soil disturbance are provided.

Generalizing the results of the study

In order to determine the extent to which the findings of the Mbongolwane case study could be generalized to a wider area, a workshop was held with 18 extension workers operating in different communal areas in the KwaZulu-Natal. The participants were introduced to wetland functioning and values and were given an outline of the Mbongolwane wetland and how it is used and managed. Participants were then questioned on the use of wetlands in their district. Discussions were also held with extension workers from Mpumalanga and the Eastern Cape on the wider applicability of the Mbongolwane study.

9.4 A description of the wetland and its use by local people

Mbongolwane wetland (28°56'S; 31°13'E), situated at the headwaters of the Amatikulu catchment 20 km west of Eshowe (Fig. 9.1), is approximately 395 ha in extent, and extends 12.3 km from its upstream end (585 m) to its outlet (510 m). Most of the wetland has no clearly defined channel and is characterized by diffuse flow and predominantly permanently to seasonally saturated soil and herbaceous, emergent marsh vegetation. However, for some of its length the wetland comprises a floodplain with a well defined stream channel, with temporarily wet soil and grassland vegetation on either side of the main channel (Fig. 9.2). As described in Chapter 5, comparison of photographs shows that since at least 1953 the extent of diffuse flow areas has been increasing owing to the deposition of sediment in some channel areas and spreading of water flow.

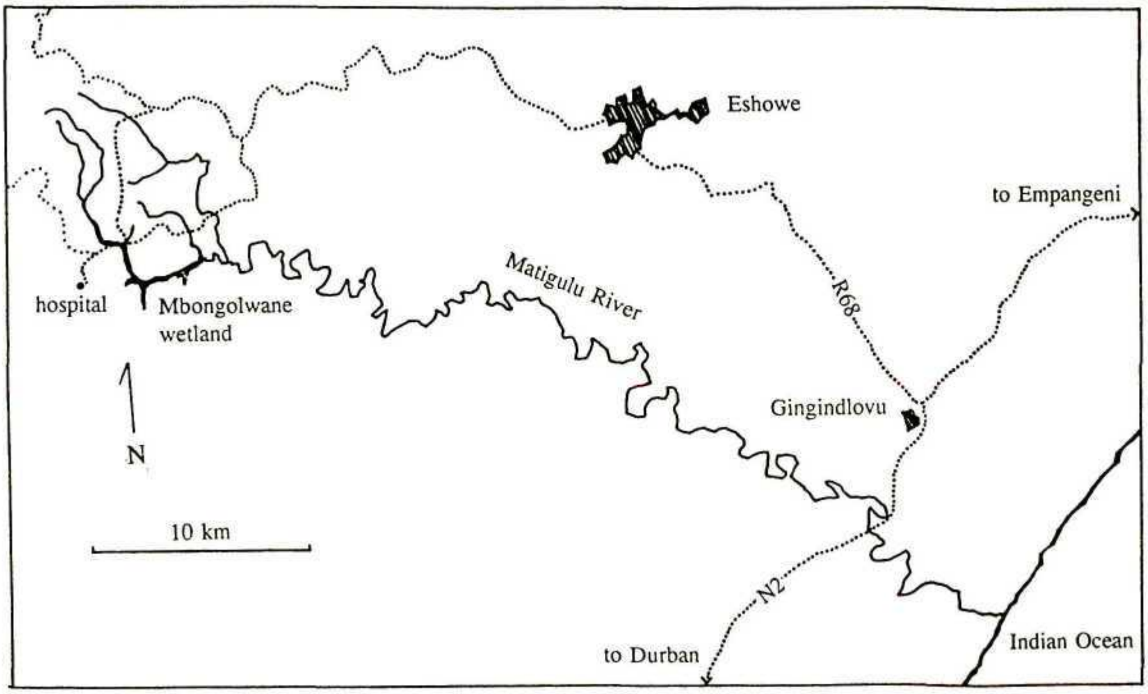


Fig. 9.1 Location of Mbongolwane wetland.

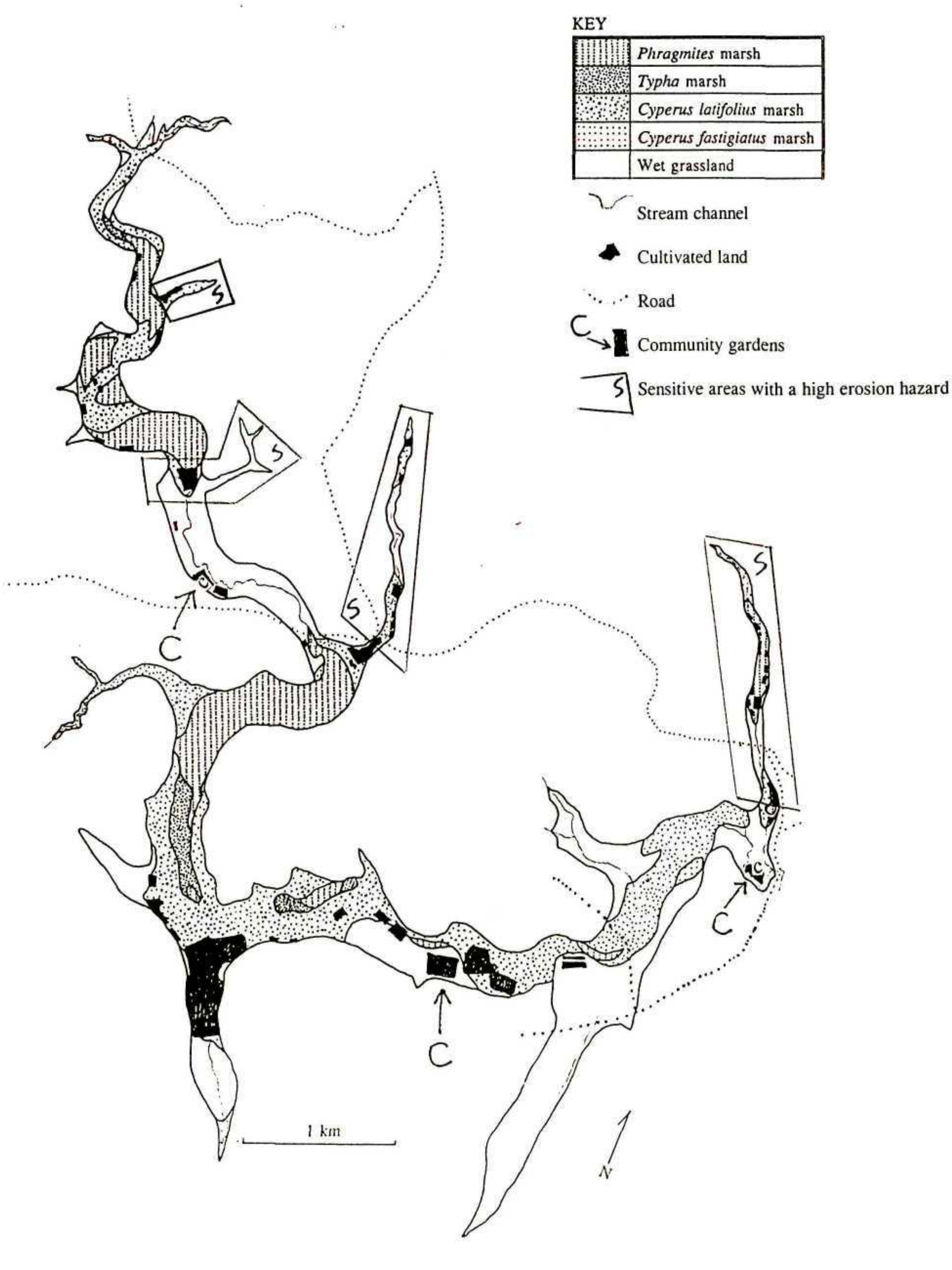


Fig. 9.2 The distribution and extent of vegetation types, cultivated land and sensitive areas within the Mbongolwane wetland.

The three most extensive vegetation types are reed (*Phragmites australis* [Cav.] Steud.) marsh in permanently waterlogged areas; *Cyperus latifolius* marsh in permanently to seasonally waterlogged areas; and wet grassland in temporarily waterlogged areas (Fig. 9.2). The wetland supports breeding crowned crane (*Balearica regulorum regulorum* Bennett), a threatened species, as well as a wide range of other wetland-dependent species such as the crocodile (*Crocodylus niloticus*), purple heron (*Ardea purpurea purpurea* Linnaeus) and marsh owl (*Asio capensis capensis* A Smith). The wetland occurs within Veld Type 5 (Acocks, 1953) which is highly transformed, with <10% of its native vegetation remaining and only 1% in protected areas (Scott-Shaw *et al.*, 1996). Thus, native vegetation areas in this region such as at Mbongolwane have particularly high conservation value.

Further adding to the importance of the wetland is the fact that the Mbongolwane wetland contributes a large proportion (69%) of the total wetland area within the 21 400 ha area surrounding the wetland. This compares with 15% and 27% of the total wetland area contributed by the Mgeni vlei and Ntabamhlope vlei within the 21 400 ha areas surrounding these respective wetlands. Mbongolwane wetland also provides important hydrological benefits, notably through improving the quality of water. There is evidence of sediment trapping within the wetland, and the wetland is probably also important in assimilating nutrients, given the opportunity it is provided owing to human activities in its catchment.

Interviews and the field survey showed that the wetland provides a range of direct benefits to the local people, including fibre for handcrafts and construction, land for cultivation, grazing for livestock, water for domestic use, and wild sources of medicinal plants (e.g. *Ranunculus multifidus*). The species most widely harvested for fibre are the sedge *Cyperus latifolius,* (referred to by the Zulu people as ikhwane and commonly used for the production of woven sleeping/sitting mats) and *Phragmites australis*, commonly used for thatching. The interviews revealed that many households have individuals involved in weaving mats for own use or local sale. All households, both poor and wealthier, make use of mats, which have a high cultural value, being used as traditional wedding gifts. However, only the poorer households still follow tradition and use mats as sleeping surfaces. Similarly, greater use is made of *P. australis* thatching by poor households as the wealthier households more commonly use alternative commercially produced roofing materials.

Historically, plant harvesting was the most extensive practice carried out in the wetland but recently the extent of cultivation in the wetland has increased markedly. Households are granted rights by the Tribal Authority to use particular areas of the catchment for cultivation purposes. Traditionally, little cultivation of the marsh areas occurred and rights to these areas are not as clearly defined as in the rest of the catchment. In most cases permission is not obtained for cultivation (The Tribal Authority's control over cultivation and plant harvesting is addressed in Chapter 10).

The most common crop in the wetland is taro, a root crop referred to by the Zulu people as amadumbe, which is native to southeast Asia and introduced to southern Africa several centuries ago (Shanley, 1966). It is tolerant of waterlogged conditions and at Mbongolwane is grown mainly in *C. latifolius* marsh. Mixed vegetable patches (including maize, potatoes, tomatoes, cabbages, pumpkins and legumes) are found predominantly in the wet grassland areas, but several of these patches, especially those with maize and pumpkins, are also in *C. latifolius* marsh. Taro is grown primarily for its starchy corms, which have small starch grains that are easily digestible. Young leaves are also used as spinach, which provides a dietary supplement to maize (Shanley, 1966). Taro is eaten by most Mbongolwane households and is a traditional crop that has been grown at Mbongolwane for as long as local people can remember. It is a preferred food at Mbongolwane to the extent that alternative cheaper carbohydrate sources such as potatoes are not regarded as substitutes (IPS, 1996).

It was found to be difficult to obtain an accurate estimate of the extent of cultivation from air photographs alone as many cultivated areas were too small to be visible on the photographs unless they comprised several contiguous patches. Extensive ground verification was therefore required to obtain an accurate estimate for the most current situation. An approximation was obtained from the photographs alone for the preceding times. Allowing for the level of under-representation encountered in the current situation, the estimate of the extent of cultivation in the wetland prior to the 1960's was ca. 13 ha. By 1973 this had increased to ca. 18 ha, and by 1995, 46 ha of the wetland was cultivated. Local informants with a good historical knowledge of the area said the extent of cultivation had more than doubled in the last 25 years, which confirms the trend revealed in the aerial photographic analysis.

Most households within at least 1.5 km of the wetland cultivate taro. The total wetland area under cultivation has been increasing since at least the 1950's, as indicated by interviews and the air photograph interpretation. The expansion of cropland has largely been into *C. latifolius* marsh areas. The rate of conversion appears to have accelerated in the early 1990's owing to a combination of several consecutive dry years and an increasing human population in the area (IPS, 1996). However, over 1996 and 1997 the extent of cultivation within the *C. latifolius* marsh areas declined slightly, which may be partly owing to intervention from outside organizations but appears to be owing more to the fact that these have been above average rainfall years, resulting in favourable conditions for dryland cultivation outside of the wetland and less favourable conditions in the wetland as a result of more prolonged soil saturation. The average annual rainfall for the 10 year period, 1988 to 1997, measured at a comparable site 5 km north of the wetland was 846 mm which compares with 1056 and 1006 mm measured for 1996 and 1997 respectively and a 742 mm average for the preceding dry period from 1990 to 1995.

The principal land-covers in the catchment are: sugar cane (51%); natural vegetation (29%); cropland

(16%); and infrastructure, including houses, roads and tracks (<5%). The agricultural and domestic activities in the catchment are certain to have increased the amount of sediment and nutrients entering the wetland. Although there are some boreholes in the catchment and limited pumping directly from the stream there are no dams and little irrigation or afforestation in the catchment. Thus, the quantity and timing of the wetland's inflow is unlikely to have been greatly altered from its natural state.

As discussed more fully in Chapter 10, The wetland falls within a tribal area, the Ntuli Tribal Ward, which has 22 sub-wards, nine of which include portions of the wetland, and the human population has approximately doubled in the last 60 years.

9.5 Environmental impacts of land-uses

An overall assessment was conducted, based on the WETLAND-USE prototype's seven primary assessment criteria listed in Section 9.3, of the main land-use practices at Mbongolwane, namely the hand cutting of natural vegetation and hand cultivation of taros (Table 9.1). This was done in relation to land-uses associated with commercial farming areas based on characteristics commonly associated with these practices.

Table 9.1 Assessment, based on WETLAND-USE's primary assessment criteria, of hand cutting of indigenous vegetation and hand cultivation in relation to land-uses associated with commercial farming areas

Principle criteria determining impact[1]	**Impacts of different land-uses**			
	Hand cutting[2]	Mechanized cutting[2]	Hand cultivation	Mechanized cultivation
Change in flow pattern	Negligible	Negligible	Medium	High
Soil disturbance	Negligible	Low	Medium	High
Soil organic matter reduction	Negligible	Negligible	Medium	High
Roughness coefficient reduction	Low[3]	Low[3]	Medium	Medium
Addition of polluting substances	Negligible	Negligible	Low	Medium/high
Subsidence of soil	Negligible	Negligible	Low	Medium/high
Wetland area reduction	Negligible	Negligible	High	High

[1]The principal criteria refer to those of the WETLAND-USE prototype listed in Section 9.3.
[2]Cutting refers to that of the natural vegetation.
[3]It is assumed that harvesting takes place once in the year and regrowth is rapid.

Harvesting of C. latifolius

Harvesting of *C. latifolius* leaves by hand with sickles begins in December and takes place predominantly after the end of January, which is the latter part of the growing season. At present, the total area of *C. latifolius* harvested each year is <10% of the total extent of *C. latifolius* dominated areas at Mbongolwane, and there is a shifting from year to year of the areas that are harvested. Furthermore, the removal of leaf material through other factors is limited as the wetland is not extensively burnt (in all of the years 1995 to 1998, <15% of the wetland was burnt each year) and *C. latifolius* is subject to low levels of grazing by cattle and other herbivores. The fact that *C. latifolius* also rapidly re-colonizes disturbed areas provided that they are sufficiently wet, as observed under the shifting cultivation system at Mbongolwane, further adds to the resilience of this species to human disturbance.

Although the WETLAND-USE prototype does not provide guidance for assessing the acceptability of vegetation harvesting by hand it provides such recommendations for mechanized harvesting of natural vegetation. According to the acceptance criteria given in WETLAND-USE Component 2, harvesting is not acceptable in permanently wet areas or areas with moderate to high erosion hazards. These wetness and erosion hazard limitations were designed specifically for mechanized, tractor-drawn cutting and are thus inappropriate for hand cutting, which involves no mechanical disturbance to the soil.

Current harvesting practices conform to the guidelines for ongoing management given in WETLAND-USE Component 3, which specify that not more than 40% of any of the three wetness zones should be cut in a given year if the wetland is also grazed by domestic stock, sensitive areas be cut by hand and no known threatened species be adversely affected. It should be added, however, that although no threatened species appear to be adversely affected, if harvesting took place predominantly in the early season and was considerably more extensive than is presently so then species such as the red-chested flufftail (*Sarothrura rufa*) would be adversely affected. At present, much of the harvesting takes place towards the end of the breeding season of *S. rufa* and most other bird species that use the area, thereby minimizing direct disturbance of the birds. Furthermore, in the areas where harvesting takes place in a particular year, the habitat for rallids is improved in the following year through the reduction of standing dead material, which would otherwise develop under the infrequent burning regime. Such moribund plant material reduces plant and invertebrate productivity, decreases the potential nest sites and restricts the movement of rallids (Taylor, 1994; Taylor, 1997 *pers comm.* Department of Zoology and Entomology, University of Natal, Pietermaritzburg).

Cultivation of taro and other crops

Cultivation within Mbongolwane wetland takes place by hand with hoes. Mixed crops are grown predominantly in the temporarily wet zone, mostly within community gardens, and taro is grown predominantly within the seasonally wet zone in individual patches. While most of the cultivation takes place in areas with a low erosion hazard, approximately 11.5 ha (25%) of the area cultivated has a medium or high erosion hazard (Table 9.2, Current scenario). Although cultivation is generally undertaken without major drainage channels, raised beds, which increase the height of the soil surface relative to the water table, are used for taro cultivation.

Table 9.2 Areas (ha) cultivated in Mbongolwane under different degrees of wetness and erosion-hazard for 3 different scenarios of use, with each scenario including a total of 45.5 ha distributed differentially across the three wetness and erosion hazard classes

Wetness	***Erosion hazard***		
	low (ca. 325 ha)	medium (ca. 50 ha)	high (ca. 20 ha)
Temporary 141 ha	Current scenario (1): 21.0 ha Recommended scenario(2): 45.5 ha Modified recommended scenario (3): 26.0 ha	Scenario 1: 4.0 ha Scenario 2: 0 ha Scenario 3: 0 ha	Scenario 1: 1.0 ha Scenario 2: 0 ha Scenario 3: 0 ha
Seasonal 114 ha	Scenario 1: 13.0 ha Scenario 2: 0 ha Scenario 3: 19.5 ha	Scenario 1: 3.5 ha Scenario 2: 0 ha Scenario 3: 0 ha	Scenario 1: 2.0 ha Scenario 2: 0 ha Scenario 3: 0 ha
Permanent 140 ha	Scenario 1: 1.0 ha Scenario 2: 0 ha Scenario 3: 0 ha	Scenario 1: 1.0 ha Scenario 2: 0 ha Scenario 3: 0 ha	Scenario 1: 0 ha Scenario 2: 0 ha Scenario 3: 0 ha

1. Current scenario: area which is currently cultivated in a given category of erosion hazard and wetness.
2. Recommended scenario: area cultivated in a given category which would result if the recommendations of the WETLAND-USE prototype were followed.
3. Modified recommended scenario: area cultivated which would result if the recommendations of WETLAND-USE were followed with relaxed wetness zone restrictions.

Commercial large-scale cultivation generally has severe impacts resulting from: (1) alteration of the hydrology, usually by means of drains, which often diminishes the wetland's capacity for regulating streamflow and improving water quality; (2) removal of the indigenous vegetation and its replacement by plants which are less effective in slowing down water flow and controlling erosion; (3) regular disturbance of the soil, which depletes soil organic matter and renders the soil more susceptible to erosion; and (4) application of fertilizers and pesticides which detract from water quality. According to the WETLAND-USE prototype, crop production in a wetland is acceptable only if several conditions are met, including: low wetness (i.e. temporary), low erosion hazard and no known Red Data species. Although approximately 46% of the cultivated area within Mbongolwane meets these requirements, the remaining area fails to do so largely because it is in areas where the degree of wetness exceeds the wetness threshold and, in some areas, where the erosion hazard threshold is exceeded (see Table 9.2). Thus, according to WETLAND-USE cultivation should be moved out of the wetter and the more erosion-prone areas (see Table 9.2, scenario 2). Given that alternative areas for cultivation available elsewhere in the catchment are very limited, if the recommendations of WETLAND-USE were to be followed then Scenario 2 is likely to result, where a disproportionate area of the temporary zone is transformed through the cumulative effect of individual cultivated plots.

In response to the recommendations of WETLAND-USE it is important to note that based on the principal criteria of WETLAND-USE, although more disruptive than cutting of natural vegetation, the low input/traditional cultivation methods employed at Mbongolwane are likely to be considerably less disruptive than large-scale commercial cropping. (1) The most commonly planted crop, taro, is tolerant of waterlogging, minimizing the need to alter the water regime. (2) Tillage and harvesting is by hand, which results in less disturbance, and hence potential erosion, than mechanical tillage and harvesting. (3) Pesticides and artificial fertilizers are not used, reducing the impact on water quality. (4) Mineral soils are cultivated, with some of the soils in areas where sediment from excessive erosion in the uplands has recently been deposited, and thus cultivation does not lead to extensive depletion of soil organic matter as would be the case in cultivated organic soils.

Further differences between traditional, small-scale cultivation, as practised at Mbongolwane and large-scale cultivation which were not revealed by the WETLAND-USE prototype are: (1) areas cultivated are shifted from year to year, with most individual patches being continuously cultivated for less than 4 years compared with large-scale cultivation where areas are continuously cultivated and not shifted; (2) the spatial configuration of areas cultivated is generally in the form of small isolated areas rather than larger consolidated areas, which is more favourable for rallids (Taylor P B, 1997. *pers comm.*); and (3) short term positive effects on the habitat value of the wetland resulting from abandonment of patches, particularly in the context of a shifting cultivation regime and an infrequently burnt wetland which has been subject to the removal of disturbance by large indigenous herbivores. As is the case with harvesting of *C. latifolius*, the reduced extent of moribund material in the year following abandonment contributes to enhanced habitat value for rallids (Taylor P B, 1997. *pers comm.*).

Based on the differences between the respective modes of cultivation revealed by WETLAND-USE, it is argued that the wetness restriction for crops given by WETLAND-USE Component 2 should be relaxed to allow cultivation in both temporary and seasonal areas, thereby accounting for the traditional cultivation of crops tolerant of waterlogged conditions. If this were to be done then the application of the modified WETLAND-USE system would result in Scenario 3 where the transformation is spread across the temporary and seasonal zones but erosion-prone areas are excluded (Table 9.2, Scenario 3) thereby reducing cumulative impacts.

Further arguments based on within-system cumulative impact consideration (see Chapter 7) are given in support of a "modified recommended scenario". (1) The temporary zone, which is the focus area for recommended development, has a plant species composition and structure distinct from the other zones (see Chapter 6). Thus, in order to maintain the wetland as a representative site there would need to be a good representation of all zones (see Chapter 7), which would not be achieved under Scenario 1, particularly as the demand for land for cultivation increases with the increasing human population. Similar recommendations for fringe cultivation have been made in Uganda (Anon, 1996) which is also likely to result in under-representation of the fringing zones. (2) In adhering to the "recommended" scenario, consideration also needs to be given to the costs and benefits of cultivation in alternative sites. For example, if taro were to be grown in alternative temporarily wet and non-wetland sites nearby, water would have to be abstracted (which, in itself, would have impacts on the wetland) and transported to irrigate the crop (which would require resources such as pumps, piping and energy to drive the pumps).

As with Component 2, recommendations for ongoing management for crop production given in WETLAND-USE Component 3 are tailored specifically for mechanized cultivation with high levels of fertilizer application. The primary focus of these recommendations is minimizing the loss of nutrients resulting from mineral fertilizer application and reducing soil organic matter depletion. These include measures such as the correct timing and amount of fertilizers applied and ley cropping to restore soil organic matter. At Mbongolwane, mineral fertilizers are used to some extent, mainly in the community gardens but they are generally not used for taro production. Thus, although these recommendations are of relevance to some of the cultivated areas they do not apply to most taro cultivation at Mbongolwane.

Although WETLAND-USE Component 3 recommends ley cropping, no recommendations are given for shifting cultivation. At Mbongolwane, most taro growers shift their cultivated patches after 2 or 3 years. *Cyperus latifolius* which re-grows in abandoned cultivated plots is recognized by local farmers for its contribution towards enhancing the fertility of previously cultivated areas, but this has not been formally investigated. Based on the information supplied by local farmers, the cultivation of taro is considered sustainable from the point of view of sustained yield of taro provided that shifting cultivation is practised and the sensitive areas of the wetland are avoided. Furthermore, current cultivation practices do not forego the future option of use of the natural vegetation because it re-establishes rapidly. In the Logone floodplains of Chad a shifting system of taro cultivation is practised, with cultivated lands lying fallow for two to three years after the crop has been harvested (Dadnadji and van Wetten, 1993). Similarly in Trinidad, where taro is normally grown in flat wet situations, the best crops are produced on land which has been cleared for the first time (Purseglove, 1972).

Limits of acceptable change

WETLAND-USE lacks protocols for structuring the input from different stakeholders in defining the limits of "acceptable change". This is considered necessary in certain circumstances, particularly when there are many stakeholders. It is impossible to prescribe limits without taking the social context of the wetland into consideration. This is recognized by WETLAND-USE but the system does not provide protocols including such considerations. This was done in this study by giving consideration to on-site environmental factors, broader-scale landscape factors (based on information gathered using WETLAND-USE) and socio-economic factors. In considering on-site factors, WETLAND-USE was used as the basis for zoning the wetland in terms of its sensitivity (i.e. areas which are erosion-prone, support important habitats or species, or are important drinking water supply areas). Furthermore, it is essential that the dynamic nature of the wetland be accounted for, including year-to-year variability driven by climate and longer term geomorphological and successional changes taking place in the wetland. Such changes may, for example, result in the areas suitable for cultivation shifting as sediment is deposited in particular areas (see Chapter 5).

Regarding broad-scale considerations, further loss of the particular type of wetland type represented at Mbongolwane should be kept to a minimum because, as described, it has a limited extent and is under-represented in formally conserved areas. However, because of the socio-economic importance of cultivation in the wetland at Mbongolwane it could be argued that some level of loss should be allowed. Had the wetland been in the context of a large-scale commercial enterprise then a lower limit would have been recommended. This raises the issue of: to what extent should the socio-economic circumstances of the potential user/s determine the level of impact, and associated loss of benefits to society, that is considered acceptable? Starting with the premise that all people, whether wealthy or poor, have a certain responsibility to society, with increasing poverty one usually finds that an individual's alternative courses of action become increasingly limited (WWF, 1993a) diminishing capacity to exercise that responsibility. It is acknowledged in the national strategy for Integrated Environmental Management in South Africa (DEAT, 1998b) that in order to develop the country, an initial substitution of primary environmental resources (e.g. soil) with secondary resources such as skills will be acceptable. This is described as weak "sustainability". Thus, in placing limits on direct users in order to represent the interests of society one can justifiably be more accommodating if the users are poor and have limited alternative options. This would, however, need to be within certain bounds of acceptable change to the system.

Having examined on-site, landscape and socio-economic factors, the key question which was addressed was "how much of the wetland should be allowed to be cultivated, assuming that the sensitive areas will be excluded from cultivation?". To answer this it is necessary to examine the effect of progressive loss on wetland functioning and associated benefits. Based on the current level of information and understanding of the wetland, no clear thresholds are apparent. At levels greater than 30% it would not be possible under a shifting cultivation regime to maintain adequate rest areas. It is also likely that the extensive natural marsh areas required by some of the wetland-dependent bird species utilizing this habitat, such as crowned crane would be compromised. At current levels of harvesting, infringement on the supply of *C. latifolius* for crafts is likely to be encountered at cultivation levels greater than approximately 35%. The opinion of five professionals and local organizations was sought regarding the maximum permissible area for cultivation. For professionals this ranged from 14% to 19% and for local people it varied greatly from 0% to over 50%, but was generally less than 30%.

Three of the professionals focused on the sustainability of current practices as a primary criterion. In order to allow for a three year recovery period for every year cultivated, the first professional recommended that not more than 34% of the area of land available for cultivation should be cultivated. This translates into 18% of the overall wetland. The second professional was more conservative in not allowing more than 30% of the available area, which translates into 15% of the overall wetland. The third professional added a further criterion of excluding additional area to give greater protection to the sensitive areas. This effectively reduced slightly the land available for cultivation which, together with a 30% restriction, translates into 14% of the overall area. The two remaining professionals focused on avian habitat as their primary criterion. The first recommended that less than 30% of the three broad wetness zones be "lost" and the second that less than 25% of these zones be "lost", both on the assumption that developed areas continue to be distributed as small patches. As the wettest zone is unavailable this translates into less than 19% and 16% of the overall wetland respectively. The more conservative recommendation of the last professional was owing to the inclusion of a criterion to minimize the negative effect of human presence on breeding cranes.

9.6 WETLAND-USE re-visited

Component 1 (INFO-COLLECT)

Component 1 provided a framework for describing the overall wetland system in terms of functionally relevant features such as degree of wetness and landform setting. These are considered applicable to wetlands in both the commercial, large-scale, mechanized agricultural sector and in the small-scale, non-mechanized sector. Although not validated against detailed assessments, these accord with current literature. As is the standard procedure with WETLAND-USE, this investigation did not directly measure wetland processes and functions but focused rather on readily measured parameters which have demonstrated general relationships with wetland functions, based largely on American and European literature (Kotze and Breen, 1994) and existing wetland functional assessment techniques (e.g. Adamus *et al.*, 1987; Amman and Stone, 1993).

Component 2 (ENVIRONMENT-ASSESS)

The general principles given in Component 2 for rapidly assessing land-use impacts were also considered applicable to both sectors. However, the generic system employed by WETLAND-USE for recommending acceptability of different land-use types did not adequately account for the particular type of cultivation practised within the traditional, small-scale context at Mbongolwane. This was found to be quite different to that practised in the commercial, mechanized sector and to have a considerably lower impact based on the general principles given in WETLAND-USE (see Table 9.1). Although the mowing recommendations were relevant to the harvesting of wetland vegetation, the particular plant harvesting practices at Mbongolwane were not fully accounted for. These inadequacies could be accounted for by WETLAND-USE by adding two additional generic categories: namely traditional, non-mechanized cultivation (which accounts for shifting cultivation) and hand-cutting of natural vegetation to take account of the particular harvesting practices. The results also suggest that WETLAND-USE place more emphasis on the general criteria for assessing impacts. This would make the system more robust in that if a land-use is encountered that does not fall within the generic land-use categories of the system, the user is still able to make an assessment based on the general criteria. Such a procedure was developed and requires that a user: (1) refer to Box 1 (Appendix D, Part 1) and answer the 8 questions each dealing with a particular aspect of impact; and (2) assess how the above are affecting the indirect benefits provided by the wetland, by referring to a matrix which depicts the effect of the described impacts on the indirect benefits provided by wetlands (Table 3.1, Appendix D, Part 1). Such an assessment would, however, be open to a greater degree of personal interpretation than with the generically based assessment and would require a higher level of experience. Thus, both modes of assessment have been included in the revised system.

The application of WETLAND-USE to Mbongolwane also revealed that under certain circumstances the land-use acceptance criteria given by Component 2 would lead to the temporary zone being greatly under-represented relative to the other zones. To address this it will be necessary to refine the cumulative impact considerations of WETLAND-USE to account for cumulative loss of particular zones and not just overall wetland area. The study also highlighted the importance of placing less emphasis on Red Data species and including more clearly defined criteria for assessing impact on biodiversity (e.g. the inclusion of a general criterion relating to the extent to which indigenous vegetation is lost), which would improve its application to both the small- and large-scale agricultural contexts.

Based on the assessment of traditional cultivation practices at Mbongolwane, it is clear that a blanket recommendation/policy decision that there should be no further conversion of any seasonal or wetter areas of wetland to cropland, as recommended by WETLAND-USE for the KwaZulu-Natal Midlands, is inappropriate for the Mbongolwane context. In Zimbabwe, Whitlow (1991) describes seasonally waterlogged dambos which were more sustainably used under traditional gardening than under year-round intensive grazing, which frequently led to severe gully erosion. This highlights the importance of developing wetland policy and reviewing the current legislation and its enforcement.

Component 3 (LAND USE-RECOMMEND)

The recommendations given by Component 3 for both cultivation and natural plant harvesting are tailored for large-scale, mechanized operations. Thus, a further set of recommendations for non-mechanized small-scale operations would need to be developed to increase the applicability of the system to Mbongolwane and other wetlands in similar contexts.

Socio-economic considerations of the overall system

As indicated, overall WETLAND-USE does not adequately address socio-economic and organizational factors determining particular resource-use patterns (see Chapter 10). It is important that this be done in the context of both large-scale and particularly small-scale agriculture, because of the greater organizational complexity encountered in this sector. A framework is required which will allow multi-stakeholder input in the setting of limits of acceptable change to a wetland system, as guided by a shared overall vision.

It should be emphasised that while cultural and economic considerations were taken into account, the focus of this investigation has been mainly on environmental sustainability and it has not addressed the concept of sustainability in its fullest sense, which encompasses economic and social sustainability as well (Goodland, 1995).

9.7 The applicability of the findings of the Mbongolwane case study to other wetlands

The participants in the workshop including extension workers from several different areas in KwaZulu-Natal (see Section 9.3) indicated that taro was one of the most commonly grown crops in wetlands within communal areas, and the cultivation practices employed at Mbongolwane were also widespread in communal areas. Taros are also cultivated using similar cultivation methods in certain communally used areas in other provinces, notably the north eastern parts of the Eastern Cape (Qonya, *Pers. comm.*, 1998. Eastern Cape Department of Economic Affairs, Environment and Tourism, King Williams Town) and in the lower altitude, warmer parts of Mpumalanga (Shabane *Pers. comm.*, 1998. Department of Agriculture, White River; A Linstom, 1999, *Pers. comm.,* Mpumalanga Parks Board, Lydenburg).

The wider applicability of the Mbongolwane case-study was examined with reference to: (1) the biophysical nature of wetland site; and (2) the wetland's biophysical context (defined in terms of constraints on agricultural production in surrounding non-wetland areas).

The biophysical nature of the wetland sites

Based on discussion with participants, the conclusions reached regarding the impacts of cultivation practices on the functioning of the wetland at Mbongolwane were also considered to be fairly widely applicable to most herbaceous wetlands that fall within communal areas. However, within the coastal margin region many of the wetland areas cultivated in communal areas are forested, which is structurally very different to herbaceous wetland areas such as at Mbongolwane. The impact on wetland functioning of converting forested wetland to cultivated land, whether cultivation is by hand or mechanized, is likely to be greater than cultivation of an equivalent area of herbaceous wetland because:

1. a greater change in the structure of the vegetation results, with surface roughness consequently being reduced by a greater margin. Surface roughness has an important influence on the hydraulic properties of the wetland and consequently its functioning (Adamus *et al.* 1987);

2. following abandonment and recovery of the hydrology, forested wetlands, because of their physiognomy, are generally slower than herbaceous wetlands to recover to a state similar to that prior to modification; and

3. forested wetlands have been identified as a particularly threatened wetland type (Wessels, 1997; J Dini, 1998. *pers comm.*, Department of Environmental Affairs and Tourism, Pretoria). Although there are likely to be certain herbaceous wetland types which are threatened, at present none have been identified.

Thus, the conclusion reached in this chapter that traditional cultivation practices at Mbongolwane detract less from the indirect benefits provided by wetlands than mechanized cultivation would generally apply to a lesser degree to forested wetlands than to herbaceous wetlands such as at Mbongolwane.

The biophysical context of the wetland

The dependence of taro cultivators on wetlands is likely to be inversely related to the suitability of the surrounding land, as determined by factors such as soil moisture regime and nutrient status. At Mbongolwane, where the rainfall is approximately 900 mm, taro cultivation is almost entirely absent from the land outside of the wetland. However, at nearby areas with rainfall exceeding 1000 mm, namely Siwasamanqe (28° 56'S, 31° 13'E) and Ntumeni (28° 52'S; 31° 18'E) both within 20 km of the wetland, extensive taro cultivation outside of wetland areas takes place. Extension workers from both the South East and the North East Regions of KwaZulu-Natal similarly reported that in low rainfall areas, taro cultivation is absent outside of wetland areas. Furthermore, taro cultivators at Mbongolwane contend that it is too dry outside of the wetland for taros. Based on this empirical evidence and local knowledge it appears that for there to be sufficient soil moisture to grow non-irrigated taros under non-wetland conditions requires rainfall in excess of approximately 1000 mm per annum.

Not all areas with high rainfall are, however, suitable. In areas with aeolian sandy soils, which are common in the North East Region, taro cultivation is also largely restricted to wetland areas even though much of these areas have high rainfall. This appears to be owing largely to the lower nutrient status and lower water holding capacity of the non-wetland areas compared with the wetland areas. At Mandlazini, Richards Bay, for example, the nutrient status of wetland areas were found to be considerably greater than the surrounding non-wetland sands (A Wilson, 1998. *Pers comm.* University of Zululand, Kwadlangezwa). Many of the aeolian sandy soils in KwaZulu-Natal fall within the Fernwood series which, based on chemical analyses conducted by Beater (1970) is deficient in plant nutrients and soil organic matter, often highly so. A further constraint to crop production which is characteristic of these soils is the high incidence of nematodes (Thompson, 1983), the incidence of which tends to be lower under hydric conditions.

In summary therefore, there are extensive areas in KwaZulu-Natal where for reasons of insufficient soil moisture (owing to relatively low rainfall) or low fertility (owing to deep aeolian sands) and possibly also as a result of the greater incidence of nematodes, the cultivation of taros is restricted to wetland areas.

In seeking to reduce the land-use pressure on wetlands it is important that possible means of addressing the constraints on taro production outside of wetland areas be sought. If soil moisture is the primary limitation then irrigation provides a possible means of overcoming this constraint on production. However, as indicated the impacts of damming and abstracting water for irrigation may, in some cases, be potentially greater than cultivation in the wetland. Amelioration of nutrient deficiencies is difficult under very sandy conditions with low soil organic matter. The addition of filter-press, a readily available fibre-rich by-product from sugar production, provides a possible means of increasing soil organic matter and plant nutrients (A Wilson, 1998. *Pers comm.* University of Zululand, Kwadlangezwa).

9.8 Conclusion

This preliminary investigation indicates that within KwaZulu-Natal, and probably also in the Eastern Cape and Mpumalanga, the results of this chapter can be generalized fairly extensively. This is provided, of course, that due consideration be taken of the wetland context (in terms of constraints on production outside of the wetland) and of the structure of the wetland, notably whether it is herbaceous or forested.

One of the biggest pitfalls when building a decision support system is choosing a problem that is too broad to handle adequately (Waterman, 1986). For this reason the scope of the prototype WETLAND-USE system was restricted in terms of its consideration of geographical areas, land-uses, social contexts and hydrological and ecological services. The investigation in this chapter has made a valuable contribution to expanding the land-uses considered by the system. Its application to traditionally-used wetlands as represented by Mbongolwane has revealed several important shortcomings in the system when applied to the particular circumstances encountered at Mbongolwane. These shortcomings have been addressed primarily through the inclusion of additional generic land-use categories that were able to account for the particular types of traditional land-uses encountered at Mbongolwane (see Chapters 3 and 12).

The cumulative impact of many small transformations may detract as much from the benefits to society yielded by a wetland as a single large transformation (see Chapter 7). Mechanisms are therefore required to control even small transformations. In South Africa, while resources are available for assessing large developments, resources for conducting assessments of small developments, particularly those in communally used areas, are generally much more limited than in developed countries. Thus, certain impact assessment tasks generally reserved for specialists in developed countries will need to be carried out by less-skilled people if they are to be carried out at all. In view of this, WETLAND-USE is seen as having a potentially important contribution in empowering extension workers to contribute to the assessment of alternative land-use options. The alternative to having extension workers applying a consistent assessment approach is for there to be no assessment or inconsistent assessment with little guidance, as is currently the case. Lawrence (1997) identifies environmental impact assessment as an important instrument for facilitating sustainability and argues for integration of the two. WETLAND-USE provides a tool which, given that the required modifications revealed in this study are made, will contribute to this.

The application of WETLAND-USE must be seen in the context of wetland policies and conservation strategies which are lacking in South Africa and a regulatory system which is flawed. This study has highlighted factors (notably, the particular nature of traditional cultivation) that need to be addressed when revising the law and developing policy which is applicable to wetlands. As indicated by Davis (1993) and Scoones and Cousins (1993) local-level research can inform larger scale decisions and policies. Clearly, however, this cannot be expected to happen automatically. In the case of this investigation the link is being created through: (1) workshops with extension workers from a wide range of geographical areas where the wetland management issues that they face were elicited and compared with those at Mbongolwane in order to assess the wider applicability of the Mbongolwane case-study; and (2) informing key individuals involved in the development of broad-scale policy.

Chapters 4 to 7 concentrated almost exclusively on biophysical aspects relating to wetland management and WETLAND-USE. This chapter and the preceding chapter have retained this focus but have raised several social/organizational issues. In Chapters 10 and 11, the main focus will shift to social/organizational elements, with the geographical area of interest of the first of these chapters remaining on Mbongolwane.

CHAPTER 10

APPLYING WETLAND-USE IN A COMMUNALLY USED WETLAND: ORGANIZATIONAL ISSUES EXAMINED

10.1 Introduction

The WETLAND-USE prototype does not explicitly address social factors, including the organizations that influence the use of wetlands (see Chapter 9). Under communal ownership, the social and organizational contexts of wetland management are considerably more complex than for a wetland under a single owner. It was therefore anticipated from the outset that the WETLAND-USE prototype, which was designed for the latter situation, would have important inadequacies in relation to the social and organizational context of wetland use, particularly in communally-owned wetlands with many different direct users dependent on a diversity of resources from a wetland. The objectives of the investigation reported in this chapter are the following:

1. Provide a conceptual overview of the organizational and property regime context of natural resource use and the intervention of organizations in this use.

2. Describe the organizational context of a case-study wetland under communal ownership and multiple-use, the Mbongolwane wetland, with the aid of the above frameworks.

3. Develop explicit criteria by which the effective application of WETLAND USE could be determined.

4. Examine where and how WETLAND-USE could be meaningfully applied within the context of the particular organizational arrangements and property rights regimes described at Mbongolwane wetland.

5. Identify the modifications and additions to the WETLAND-USE prototype required based on the findings of the study.

10.2 Conceptual background to the study

Property rights regimes, security of tenure and distribution of benefits and costs

A central theme in describing the organizational context of resource use is that of property rights. These refer to the set of rights and obligations governing the access of an individual or group to the stream of benefits which can be derived from a resource (Turner, 1995). Property is thus a concept determined by social relationships rather than a physical commodity such as land or water. Four resource regimes are commonly recognized: state property regimes; private property regimes; common property regimes and situations of open access (non property regimes). A resource regime is a set of rights and duties characterizing the relationship of individuals to one another with respect to a particular resource (Bromley, 1991).

Under state property regimes, rights of ownership and management of the natural resources are vested in the state. Under private property regimes, these rights are vested with an individual "owner"; and under common property regimes they are vested with a specified group of people. In situations of open access no resource ownership regime applies and no property rights are recognized (Turner, 1995). A common situation in Africa is the disintegration of common property regimes into ones of open access as a result of several factors, including increasing levels of poverty and a break down of local organizations and institutions (Turner, 1995).

Contrary to the assumption of the "tragedy of the commons" model (Hardin, 1968) "common property" is not "everybody's property" and is distinct from open access. Rather, common property rights accrue to specified groups or communities of people. Nonmembers are excluded from use, and sets of rules define the rights and duties of members and nonmembers (Ciriacy-Wantrup and Bishop, 1975). Common property and private property are similar in the sense that they both exclude nonmembers. The situation is often more complex than these analytical categories suggest, as there may be a spatial overlap in regimes or a change over time (e.g. through the seasons) (Turner, 1995).

Closely tied with property rights regimes is the issue of security of tenure. Security, or rather insecurity, of tenure is commonly defined as the perceived probability of losing ownership of the land. Ownership, however, encompasses much more than simply the land. Sjaarstad and Bromley (1997) emphasise that the above definition is inadequate in communities where land is seen as a bundle of resources rather than a geometric area, and where multiple tenure determines the access to these resources. Barrows and Roth (1990) define it more broadly as " the perception of the likelihood of losing a specific right to cultivate, graze, fallow, transfer or mortgage". However, even this definition does not include resources such as natural vegetation used for crafts. Thus, for the purposes of this investigation security of tenure was defined as "the perception of the likelihood of losing a specific right to a resource (e.g. natural vegetation or soil)".

This discussion relates mainly to access to direct, tangible benefits that accrue locally. A broader range of benefits and costs can potentially be considered. Uphoff (1986) identifies four dimensions along which natural resource management benefits and costs can vary with respect to the users (or potential users) involved:

1. a temporal dimension: (a) benefits accrue immediately or very soon, or (b) benefits accrue after a long time;
2. a spatial dimension: (a) benefits accrue locally, or (b) benefits accrue remotely;
3. tangibility: (a) benefits are quite evident, or (b) benefits are relatively hard to identify; and
4. distribution: (a) benefits accrue to the same persons who bear the costs of management, or (b) benefits accrue to different persons from those who bear the management costs (the assumption being that management has some cost either through direct investment in labour and funds or through abstaining from some present use).

Types of organizations influencing wetland resource use

Organizations are "structures of recognized and accepted roles" (Uphoff, 1986). This study refers specifically to organizations that have arrangements, rules and procedures that influence natural resource management. Organizations vary in their degree of institutionalization. An organization is considered an institution if it has acquired special status and legitimacy for having satisfied people's needs and for having met their normative expectations (Huntington, 1965; Uphoff, 1986). Thus, although many organizations may be considered to be institutions, the term institution is not synonymous with organization. This investigation did not address the question of how institutionalized the respective organizations examined were. Delimiting what constitutes "local" may also be complex (Uphoff, 1986) and for the purposes of the investigation "local" was taken to include the levels of the relatively self-contained social unit of a Tribal Ward and its respective sub-wards at the level below.

Organizations of relevance to local natural resource management include: both local and external organizations; and organizations primarily concerned with environmental issues and organizations concerned with local governance and rural development. The following categories of organizations adapted from Uphoff (1986) are identified:

1. administrative organizations: government organizations (e.g. Department of Agriculture) and staff, accountable to bureaucratic superiors;
2. local government: elected or appointed bodies having authority to deal with regulatory and development tasks, accountable to local residents;
3. membership organizations: local self-help organizations (including cooperatives) that exist to create benefits for members;
4. service organizations that exist to create benefits outside of membership; and
5. private business.

Institutions do not necessarily exist as organizations, and non-organizational institutions of relevance to natural resource use comprise community norms and personal understandings of the limits and possibilities of resource use (Roe and Fortman, 1982).

A framework for representing organizational intervention in the use of a natural system

As described in Section 3.2.1, interventions are defined as purposive actions or roles (which may or may not be intrusive) taken to influence events. In the pressure-state-response framework (see Section 3.2.1) there are four different forms of intervention based on the particular points at which intervention takes place (see Fig 3.2). Interventions at point 1 are aimed at influencing the perceptions of potential users, primarily by alerting them to the impacts of particular land-uses on the stream of costs and benefits from a system, especially those which are less tangible, accrue remotely and/or after a long time. The assumption is made that users' perceptions of a system are shaped by the benefits and costs that they observe to be derived from the system, and once users are more informed of these costs and benefits, their perceptions will change accordingly. It is assumed further that perceptions shape local policy and cultural norms. It is recognized, however, that awareness of particular land-use impacts does not necessarily alter perceptions. A wetland user may, for example, consider the diminished benefits to society that result from a particular use to have a very low priority compared with the direct benefits that the user receives. Furthermore, it is also recognized that even if perceptions are altered users may not have the means, particularly if they are poor, to change patterns of resource use.

Interventions at point 2 are aimed at influencing policy which, as elaborated in Section 3.2.1, refers to a purposive course of action based on shared values in dealing with a matter of concern. Interventions at point 3 are aimed at influencing the demand for particular wetland benefits (e.g. use of the soil resource for crop production). For example, interventions which could result in a decreased demand for use of the soil resource in the wetland for cultivation include: (1) increased access to alternative land, (2) increased attractiveness of alternative uses of the wetland (e.g. by providing access to markets for craftworks produced from wetland plants) and (3) compensatory payment for non-use. Interventions at point 4 are aimed at influencing how the demand for a particular wetland resource is translated into type, pattern and level of use through regulation. For example, stringent and effectively enforced regulations may maintain the level of use considerably lower than would otherwise have been the case if individuals had a free choice. Regulations may also be designed to promote lower impact land-use practices (e.g. by confining use to particular spatial areas where sensitivity to impact is relatively low) without decreasing the previous level of use. Interventions at point 5 include physical measures (e.g. erosion control structures) to reduce the impact of (i.e. to mitigate) a particular type and level of use that is or has been carried out.

The conceptual link between organizational structures and application of WETLAND-USE

In this section the following explicit criteria are developed for characterizing organizational structures in terms of their likely influence on the application and effectiveness of WETLAND-USE.

1. Effective communication channels. WETLAND-USE is designed for use by fieldworkers working with local wetland users/owners. Clearly therefore if the communication channels between extension workers and local wetland users are poor, WETLAND-USE stands little chance of success.

2. An understanding of wetland system function. As discussed in Section 12.3, there is clearly a limit to the extent to which scientific information can be simplified, and field workers facilitating the sustainable use of wetlands require a reasonable understanding of wetland functioning and impacts. The contribution that local knowledge can make towards this understanding is also recognized.

3. A management system which encompasses a policy and measurable goals. As will be elaborated in detail in Chapter 11, such a system is required in order to measure success of management and promote accountability among resource conservation managers.

4. Rules and enforcement. Mechanisms (including both formal legislation and customary law) for enforcing agreed-upon land-use and management actions are required to deal with transgressions by individuals.

10.3 Methods and study site

Information about organizations and their influence on the use of the wetland was gathered through: interviews conducted with individual users of the wetland encountered in the field; focus groups comprising different groups of users; interviews with key informants; community workshops; and interviews with individual organizations (including the Tribal Authority), drawing on the approach and protocols of Chambers (1994). Details of all meetings are given in Table 10.1.

Table 10.1 List of workshops, meetings and interviews used as sources of information for the investigation

Purpose	Date	Group composition	Number of participants	Facilitators
Workshop to identify the key management issues for the wetland	15/ 08/95	All stakeholder groups	ca. 70	INR, UN
Interviews to gain perceptions of Community Garden Committees regarding cultivation of the wetland	13/ 11/95	Community garden representatives	ca. 20-25 in each of 2 groups	IPS
Interview to gain the perceptions of the Tribal Authority regarding the management of the wetland	10/ 01/96	Tribal Authority members	12	IPS
Workshop to clarify the structure of the local development committee	12/ 11/96	Local development committee and Tribal Authority Members	ca. 40	IPS
Workshop to clarify the structure of the Wetland Management Network and roles and responsibilities of members	04/ 02/97	All stakeholder groups	ca. 32	INR, UN
Meeting to identify local craftworkers and the issues they face	07/ 03/97	Local craftworkers	ca. 35	INR, UN
Meetings to establish and constitute a local craftworkers organization	10/ 04/97	Local craftworkers	21	INR, UN
Meeting and craft display for external craft-buyers to observe local crafts and comment on quality and demand	19/ 06/97	Local craftworkers and external craft buyers	ca. 40	INR, UN
Transect walk and individual interviews with wetland users encountered	04/ 09/97	Taro cultivators, plant harvesters and medicinal plant users	ca. 27	INR, UN

INR=Institute of Natural Resources, UN= University of Natal, IPS=Integrated Planning Services

Time did not permit a comprehensive household-to-household survey. For resources used in the wetland, information was gathered concerning: the level at which decisions are made, who makes and influences the decisions; how much latitude they have; and the extent to which decisions are sanctioned/unsanctioned by the management authorities. This was done within the conceptual frameworks given in Section 10.2. The information gathered from different groups was checked against each other to see to what extent they were in agreement.

Over the past 50 years the human population at Mbongolwane has been increasing, particularly in the area around the wetland. Based on aerial photograph interpretation, the number of dwellings within 1.5 km of the wetland has increased from 301 in 1937 to 470 in 1972 and 566 in 1991, which indicates that the human population around the wetland has approximately doubled in the last 60 years. According to the 1991 census figures only 10% of the population in the region are formally employed but an undetermined proportion are self employed or deriving income from sale of products, notably agricultural produce. As the human population in the area surrounding the wetland continues to increase, there is increased pressure from the local community, particularly through the rapidly increasing extent of cultivation in the wetland (see Chapter 9).

10.4 Findings of the study

Organizations relevant to resource use within the Mbongolwane wetland

Several organizations influence the use of resources within the wetland. These vary greatly according to their primary focus areas of operation, the resources they influence (Table 10.2) and for how long they have been influencing resource use.

Table 10.2 General features of the organizations influencing the use of different resources at the Mbongolwane wetland

Organization	**Category of organization**	**Primary focus**	**Resources influenced**
Local organizations			
Tribal Authority	Local government	Customary law, conflict resolution, land allocation	Soil (for crop production), reeds, water, grazing
Development committee	Service	General development, especially infrastructure	Water
Craft Group[1]	Member	Craft enterprise development	*C. latifolius*
Garden committees	Member	Agricultural development	Soil (for crop production)
Entumeni Mill Cane Committee	Member	Agricultural development	Soil (for sugar production)
External organizations			
Dept. of Agriculture	Administrative	Agricultural development	Soil, water
Nature Conservation Services[2]	Administrative	Environment	Soil and vegetation
Dept. of Health	Administrative	Community health	Water
South African Sugar Association	Business	Agricultural development	Soil
NGO's: INR, IPS[3]	Service	Environment, planning	Soil, water, *C. latifolius*

[1] The Craft Group is a new organization, founded in 1997.

[2] During 1997 there was a gradual restructuring of the Nature Conservation Services, with some of the personnel being incorporated into the newly formed provincial Department of Environmental Affairs, which has continued with the work of the Nature Conservation Services at Mbongolwane. For the purposes of this study both organizations will be referred to as the Nature Conservation Services.

[3] NGOs have been involved in minor projects in the last three years.

Mbongolwane falls within the former KwaZulu, which is divided into 26 magisterial districts, with each district divided into wards and each ward into sub-wards. Tribal Authorities remain the primary organizations for local government at the ward level. Each ward is headed by a chief (inkosi) who typically inherits his position, and each sub-ward has a headman (induna), who may be selected or inherit his position. The Mbongolwane wetland falls within the Ntuli Tribal Ward, which has 22 sub-wards, 9 of which include portions of the Mbongolwane wetland. The Tribal Authority at Mbongolwane still commands a high level of respect but the present inkosi, whose health is poor, is considered to have less authority than his father (IPS, 1996). As is general practice with Tribal Authorities, authority is delegated to the headmen for many matters. At Mbongolwane the degree of authority and level of control of the headmen over use of the wetland varies greatly among sub-wards (IPS, 1996).

The importance of KwaZulu Tribal Authorities to the former Government's administration and control of KwaZulu is widely known (Davion, 1996). Although generally having little involvement in service delivery, the functions of Tribal Authorities have included culture, dispute resolution, administration of customary law and, very importantly, allocation of land (McIntosh, 1995). Although there are several weaknesses in the Tribal Authority system, certain Tribal Authorities, particularly those in the more remote, rural areas, enjoy a high level of legitimacy. Because of the considerable power and influence wielded by Tribal Authorities in the rural areas of KwaZulu-Natal any initiative which attempts to marginalise the Tribal Authority would most likely be doomed (Davion, 1996).

The Ntuli Tribal Ward has a local development committee comprising elected representatives with a brief of facilitating a range of developments (e.g. water supply, roads and schools). At workshops focussed on development it was identified that there was much confusion regarding the existing local organizations and the roles and responsibilities of individuals regarding development. Barnes and Morris (1997) note that KwaZulu-Natal's rural institutional environment generally fails in terms of efficiency, adaptability, transparency and equitability because clear policy defining organizational responsibility is lacking, provincial and local government are poorly structured, and community participation in service delivery is poorly coordinated.

The community gardens, which were initiated by the Department of Agriculture in the 1970's, continue to be run through elected Garden Committees, which serve the interests of members of particular community gardens. The Craft Group is also administered by an elected committee.

Prior to 1995 the Department of Nature Conservation extension staff had virtually no involvement at Mbongolwane but this has increased. The main area of involvement has been in creating environmental awareness. The Department of Agriculture has a much longer history of involvement at Mbongolwane, with the main area of involvement being the provision of expertise and logistical support for improving production in the community gardens and sugar cane plots. There has been a high turn-over of staff in the extension services of both the Department of Agriculture and Nature Conservation. For example, from 1995 to 1997, the local agricultural extension worker has been transferred and replaced on two occasions.

The Entumeni Mill cane committee, which includes local cane growers, and the South African Sugar Association provide logistical support and expertise to local cane growers. The Department of Health's concern with the wetland lies with its importance as a source of water-borne diseases, notably bilharzia. The main contribution of NGOs has been in: (1) gathering and synthesising management-related information (biophysical and social); (2) facilitating the networking of stakeholder organizations; (3) providing advice; and (4) directly raising awareness. While the importance of capacity building and facilitation was recognized from the outset by the involved NGOs, they have been unable to raise the resources to contribute greatly in this area, other than for selected areas such as craft production. Thus, they have been unsuccessful in facilitating full integration of initial research and planning with implementation. Overall therefore it can be seen from the discussion that relations among organizations are complex and operate across a range of organizational levels (Fig. 10.1)

In response to the observation that there was no organization concerned with the overall management of the wetland and that links between organizations influencing wetland use were poorly developed, a Wetland Management Network (including local and external organizations) was established. Through the Network an overall vision for the sustainable use of the wetland was developed and specific issues that needed to be addressed to achieve the vision were identified. Mini-projects focussed on specific issues were initiated, including: overall co-ordination; craft enterprises; ecotourism; education and awareness; cultivation and erosion; health relating to the wetland; and infrastructure (e.g. bridges). Difficulty has been encountered in formalizing the Wetland Management Network and sustaining particular initiatives. Important factors contributing to this are: the confusion and conflict already present in the community regarding the roles of existing local organizations and individuals in these organizations; the limited capacity of local organizations; and the inconsistent level of input from external organizations (see Chapter 11).

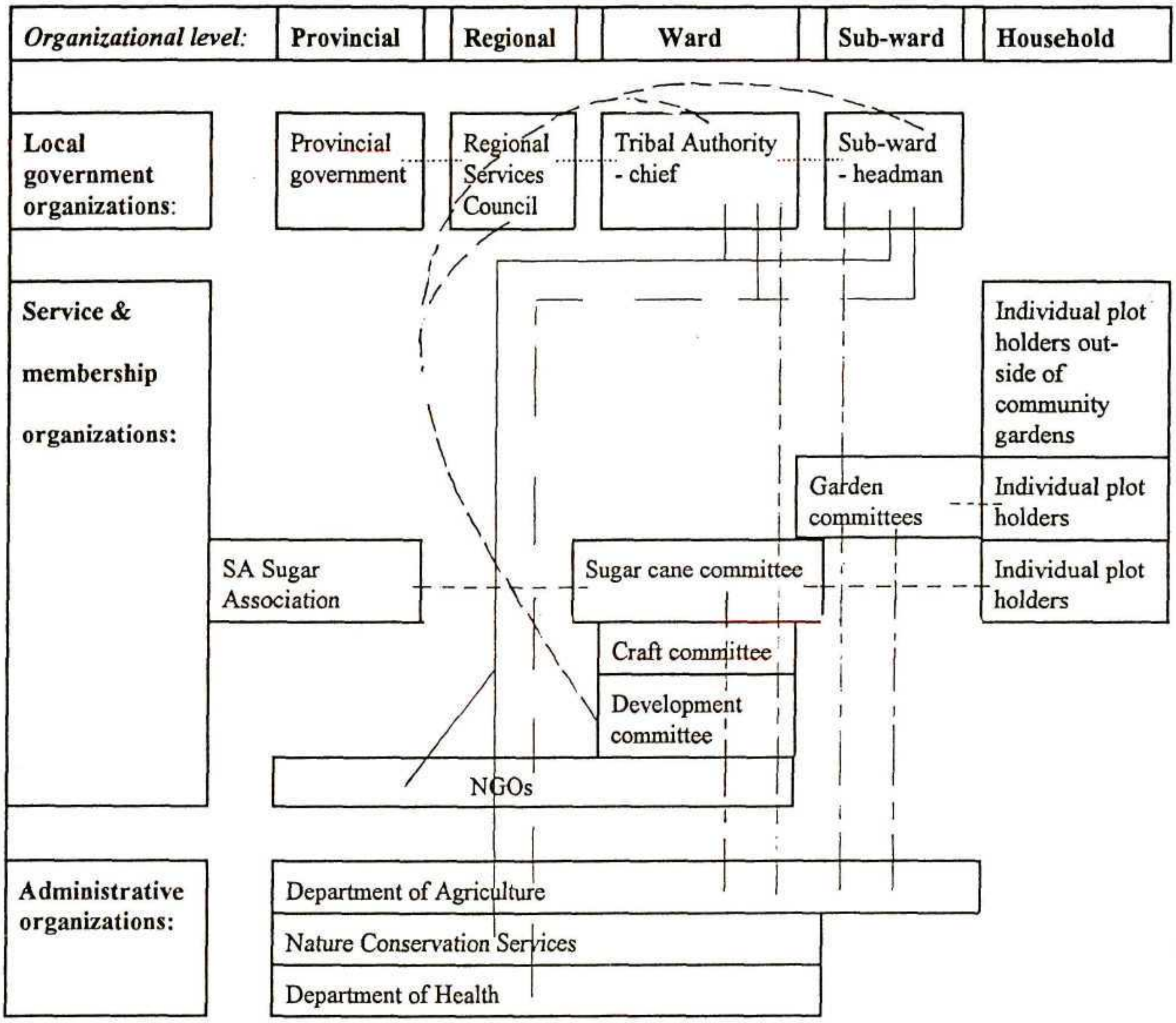


Fig. 10.1 Schematic diagram of relations among organizations at different hierarchical levels of organization, showing linkages discussed in this chapter

Organizational control over the use of particular resources in the wetland

Wetland resources used at Mbongolwane vary greatly according to such factors as the supply/demand ratio, whether or not there are rules governing use and under what property rights regimes the resources are controlled (Table 10.3).

Table 10.3 Features of wetland resources commonly used in the Mbongolwane wetland

	Soil (cultivation)	**Reeds**	***C. latifolius***	**Water**	**Grazing**	**R. multifidus**
Products derived from the resources	crops (taro, maize & vegetables)	thatch	woven crafts	domestic products & crops	livestock products	medicine
Supply/ demand ratio[1]	Low	Low	High	Low	Low	Very high
Rules of use	Yes	Yes	No	No	Yes	No
Property regime	common/ private	common	common/ open access[2]	common	common	open access

[1] This was not accurately quantified but was determined based on discussion with users and observed and documented conflict over particular resources.

[2] There are no truly open access regimes operating at Mbongolwane as access is confined largely to members of the Ntuli Tribal Ward.

Cultivation is largely controlled by the Tribal Authority and a range of categories of land allocation for cultivation at Mbongolwane can be described (Table 10.4). Allocation of land for community gardens and sugar cane plots, where the use of communal land is entrusted to individuals and security of tenure is relatively high, takes place at the ward and sub-ward level and involves several structures. These include the Tribal Authority, garden committees and the Department of Agriculture for community gardens; and the Tribal Authority, the Entumeni Mill Cane Committee and Department of Agriculture for sugar cane plots. The allocation of land for sugar cane takes place almost exclusively outside of the wetland and thus does not directly impact on the wetland. The extensive cultivation of sugar cane in the catchment surrounding the wetland has, however, indirectly increased pressure on the wetland by greatly decreasing the amount of land outside of the wetland which is available for other uses such as crop production (IPS, 1996). Community gardens are confined to the fringes of the wetland in areas with low erosion hazards (i.e. less sensitive areas), while the individual parcels occupy both the fringe and the wetter part of the wetland, where taro is predominantly grown. Although community gardens are "common property" assets in the sense that members co-operate in accessing expertise and seeds and seedlings; plots within the garden are individually cultivated. Allocation of sub-parcels to individuals within a particular community garden is controlled by the group itself and membership is open to all households in the ward. The degree of control over allocation of land for cultivation within small individual parcels outside of the community gardens varies according to sub-ward (IPS, 1996). Although in some sub-wards permission is obtained from the headman before cultivating, in most cases no permission is obtained. Consequently, in at least half the wetland there is a very low level of control over individual parcel cultivation. Of the 16 cultivators interviewed on an individual basis in the field 11 said they had not obtained permission from the Tribal Authority to cultivate. While one of the headmen indicated that he had a greater level of control over the allocation of small land parcels for cultivation than was indicated by interviews with cultivators in his ward, there was general congruency between the low level acknowledged by the headmen and that indicated by the cultivators.

Table 10.4 The three broad categories of land allocation for cultivation at Mbongolwane

Categories of land allocation for cultivation	**Degree of control**	**Organizational level of control**	**Degree of external support for production**	**Security of tenure**
Large (>0.1 ha) individually used parcels used for the production of sugar cane	High	Ward	High	High
Small individually used sub-parcels (<0.1 ha) within community gardens	High	Overall: ward Within the garden: garden committee	High	Medium
Small individually used parcels (outside of community gardens)	Generally low but may be medium in some sub-wards	The individual plot holder	Very low	Low

Local taro growers have not expressed a desire for a taro growers' organization to assist with its production as taro is not prone to disease and has well established traditional production methods (Yengwa N, 1997. *Pers. comm.*, Department of Agriculture, Eshowe). There is little that the agricultural extension services are able to do to increase the level of production from this crop, and it will be unlikely that taro growers will support the formation of an organization that has a purely regulatory function (Yengwa N, 1997. *Pers. com.*, Department of Agriculture, Eshowe).

The Department of Agriculture has an important influence on the cultivation of the wetland, not through regulation but rather through incentives (in the form of advice and access to seeds, fertilizers, etc.) for particular modes of cultivation, and for cultivation in particular areas (notably, in the community gardens). The Department of Agriculture initiated the community gardens and continue to provide expertise and logistical support. The motivation for the Department of Agriculture to support these gardens was not specifically to influence the use of the wetland in a more environmentally sensitive manner but rather to increase the food security of local households. Nevertheless, it is hypothesised that if there were no community gardens, which serve to consolidate cultivation in localized areas of low wetness and environmental sensitivity, the cultivation would be more widely dispersed across the wetland, and a greater proportion of sensitive areas would be cultivated. However, the production in community gardens of crops such as potatoes which are potential alternative starch sources to taro are unlikely to have reduced the demand for, and cultivation of, taro in the wetland. This is because taro is a preferred crop (i.e. potatoes are not viewed as a substitute for taro) (IPS, 1996).

The only organization found to be having a significant influence on the harvesting of reeds was the Tribal Authority, who are responsible for ensuring that harvesting takes place after the end of April. This restriction is supported by a traditional belief in "Inkanyamba", a seven-headed serpent spirit which lives in the wetland. According to the belief, if harvesting takes place too early "Inkanyamba" is disturbed and causes a violent and catastrophic storm. The timing of the restriction is biologically meaningful as it is the time when natural die-back of the reeds takes place, resulting in minimal impact to the plants. The majority of cutting takes place after April, but the restriction is now less effectively enforced than in the past, with some cutting taking place before the allotted time. The relevance of "Inkanyamba" was raised independently by the Tribal Authority and wetland users, and although the belief in "Inkanyamba" still persists, particularly in the older generations, it is declining in the face of a general breakdown of traditional belief systems. Therefore, traditional controls and beliefs are becoming progressively less effective in influencing local people's use of the wetland. Controls are also proving less effective in dealing with resource users from outside of the Tribal Ward. Both the Tribal Authority and the focus group dealing with harvesting of wetland plants identified that occasionally outsiders harvest reeds on an unsanctioned basis. At present this is not a very common practice but could increase as there are not clear control measures in place regulating this form of activity. Both the users and the Tribal Authority independently agreed that better control of outside harvesting was required.

The local community does not consider it necessary to have rules governing the use of *C. latifolius* and *R. multifidus* by members of the Ntuli Ward. The supply greatly exceeds the demand for both of these resources, and presumably the gains from specifying rights would be too small relative to the costs involved. The Craft Group is newly formed and is currently having little influence over resource use in the wetland. However, should the levels of harvesting of wetland plants significantly increase, the Craft Group could potentially influence such practices, particularly through its influence on members of the group.

Not all sub-wards include wetland areas but those lacking wetland areas still have access to the wetland. Thus, membership is not defined at the sub-ward level. However, based on interviews with wetland users, a form of less clearly defined membership applies in that people living immediately alongside a particular wetland area tend to have "first option" to the soil and vegetation resources. They have a stronger sense of the wetland being "theirs" by virtue of their closer proximity. Thus, levels or degrees of membership can in some instances be defined.

In summary, the organizations discussed vary greatly regarding the forms and levels of intervention (as defined in terms of the pressure-state-perceptions-policy framework given in Section 10.2) in the use of soil and vegetation resources in the wetland (Table 10.5). The primary organization responsible for direct regulation of the wetland is the Tribal Authority which, in the face of declining levels of control and increased resource use pressure is now being provided with some additional support by the Wetland Management Network. Interventions by external organizations are confined primarily to non-regulatory interventions, which are complementary to the regulatory interventions. In supporting restricted access to a particular resource through regulation the assumption is made that, particularly in the case of poor users who have very limited choices, alternative sources of benefit should be sought. The three main foci of external organizations, as given in the conceptual framework in Fig 3.2, have been to (1) engage in activities designed to raise awareness amongst local people of the long term, remote and less tangible benefits that accrue from the wetland (these activities have included school projects and wetland awareness days); (2) assist in the development of local policy; (3) the provision of assistance, mainly by NGOs, with marketing and development of more marketable products from natural vegetation; and (4) support, by the Department of Agriculture, for community gardens, which provide a generally less environmentally destructive alternative to the uncontrolled cultivation in the wetland.

Table 10.5 A summary of the form and level of intervention[1] by organizations in the use of the natural vegetation and the soil for crop production

Forms of intervention	Intervening organizations						
	Tribal Authority	Development committee	Craft Group[2]	Garden groups[2]	Dept. of Agriculture	Nature Con. Services	NGO's
Influence perceptions	Low	Low	Low	Low	Low	Medium	Medium
Local policy development	Medium	Low	Low	Low	Low	Low	Medium
Promote alternative forms of production	Low	Low	Medium[4]	High	High	Medium	High
Regulation (direct)	Medium	Low	Low	Low	Low	Low	Low
Regulation (indirect[3])	Low	Low	Low	Low	Low	Medium	Medium

[1]The level of intervention by local and external organizations for the different forms of intervention, was assessed on a scale of: "Low", "Medium", and "High" based on the relative amount of time allocated to the particular form of intervention. This rating was based on information from interviews and has not been rigorously quantified. Levels are not necessarily directly comparable across organizations.

[2]The intervention of these organizations is restricted to specific activities within their particular user groups.

[3]Indirect regulation refers to activities such as supplying information and lobbying but excludes any form of enforcement of regulations.

[4]At present the influence of the craft group is small because it operates on a very limited scale and has a small membership (<20) relative to the overall number of cultivators (>500 plotholders outside of community gardens).

10.5 The potential application of WETLAND-USE within the social context described at Mbongolwane

The investigation thus far has revealed some of the property rights governing use of different resources and the influence of various local and external organizations on the use of these resources. In this section this information is used together with the criteria developed in Section 10.2 as the basis for: (1) determining if WETLAND-USE could potentially aid decision making and who would apply the system; and (2) for contrasting the situation at Mbongolwane with the situation for which WETLAND-USE was developed (i.e. a single or part owner who is literate).

Effective communication channels and understanding of the wetland system

The results of this study reveal that WETLAND-USE will be strongly dependent on extension workers in administrative organizations as channels for its application, as is also the case in the commercial sector. It is therefore unlikely to be effectively applied unless supported by these organizations, which will also need to effectively engage local communities. As previously mentioned, the effectiveness of extension services is also limited by inconsistent support for initiatives. Furthermore, at Mbongolwane extension workers have acted largely as technical advisors and are not well equipped to engage communities and play facilitatory roles. Botha (1995) and Jiggins (1997) indicate that in South Africa generally there is a lack of skills among agricultural extension staff for applying their technical knowledge to the development of smallholder agriculture and the broader challenge of rural development. The general observation of Murphree (1993) that existing state organizations in southern Africa were created during the colonial period and have continued more or less unchanged into the independence period is of relevance to Mbongolwane. Murphree (1993) adds that these may be authoritarian, and directive even when they lack the (monitoring and policing) resources to fulfil the responsibilities implied.

A factor relevant to all levels and forms of local decision making is that many local people, including members of the Tribal Authority, are illiterate and cannot speak English. Even in situations where it could be applied (e.g. in the communal gardens) this severely limits the application of WETLAND-USE which is in English and is a technical document originally designed for use by extension workers working with farmers having a higher level of literacy and numeracy. In addition, the level of training of extension workers working in communal areas such as Mbongolwane is generally lower than that of their counterparts working mainly in the large-scale, commercial farming sector. Furthermore, there is a lack of appreciation and understanding of wetlands among many extension workers (see Appendix A).

A management policy and plan, and control mechanisms

As indicated in Section 10.4, there was a high level of control over the allocation of land for community gardens and sugar cane plots, and the Department of Agriculture is actively involved in the choice of sites. Thus, in both cases extension service is involved in the selection of land for allocation and the mechanisms are in place for WETLAND-USE, or any other guidelines, to be applied in order to enhance the consideration of environmental factors in the choice of potential new sites and in providing ongoing management decisions within existing cultivated areas. A contrasting situation is found in the case of small taro/vegetable patches, where local growers are not represented by an organization and for much of the wetland individual farmers do not obtain permission from the Tribal Authority to cultivate. Thus, users generally have a lot of latitude within which to exercise resource use choices and the avenues through which a system such as WETLAND-USE could potentially influence decision making are very limited.

Although there are clear guidelines promoting the sustainable use of resources such as reeds, this local policy is limited in the extent to which it considers broad issues such as downstream water users and in the extent to which it is able to deal with contemporary conditions such as the rapidly increasing demand for land for cultivation. Although Tribal Authorities possess regulatory powers, their potential to influence/regulate the use of wetlands and other natural resources is limited. They have not had to deal previously with such high resource demands, and even if the full understanding and support of the inkosi and headmen were obtained, key wetland use decisions are being made at Mbongolwane which are out of the Tribal Authority's control. Decisions taken at ward level to influence wetland use patterns are often not followed through to sub-ward level and therefore do not affect decisions taken by individuals in the sub-wards, which is ultimately the level having the most direct effect on the wetland. Although the Tribal Authority clearly supports the concept of increased levels of control, regulation of wetland cultivation is not a high priority in relation to other functions and duties. Furthermore, the Tribal Authorities do not receive guidance from higher levels of governance regarding the regulation of wetlands and there is no regional, provincial or national policy, which further hampers the effectiveness of the Tribal Authority. Similarly, there is no clear policy to guide administrative organizations in dealing with wetland land-use issues. Although management of Mbongolwane as an overall system has largely been lacking, an overall management vision has been established and a network of key organizations has been formed to assist in co-ordinating management. This is discussed further in Chapter 11, where issues such as achievement of measurable goals are examined.

10.6 Summary and recommendations

Although limited mechanisms are present allowing for the meaningful application of WETLAND-USE to Mbongolwane, the local organizational environment as well as the broader policy/legal environment are generally unfavourable for a decision support system such as WETLAND-USE to aid decision making by individual users. This chapter shows that key inputs are required in the development of local policy and regulation capacity at Mbongolwane in order to address organizational, ownership and accountability issues in the wetland. These inputs, which are outside the scope of the original WETLAND-USE system, are likely to be more crucial than in single private owner situations. Several complexities not common to wetlands on private land would be introduced into the process of using WETLAND-USE at Mbongolwane and at other wetlands in similar communal use contexts. These include: (1) the multi-stakeholder situation within the bounds of the wetland; (2) a complex and often weak organizational structure within which to operate; (3) difficulty in achieving accountability at various organizational levels; (4) a lack of agreed-upon and enforced rules governing use, resulting in communal use situations easily becoming open access; and (5) low levels of literacy and numeracy among users. This investigation has also shown that owing to weaknesses in local organizational capacity for promoting development, the potential to intervene through promoting alternative less sensitive modes of production is low.

Two sets of recommendations are provided to address the above issues: (1) recommendations for enhancing the WETLAND-USE prototype to make it more applicable to the Mbongolwane situation; and (2) recommendations relating to the institutional development at Mbongolwane that would be required to enhance organizational control over resource use and the allocation of property rights and create a more favourable environment for the application of a decision making framework such as WETLAND-USE.

Recommendations relating to WETLAND-USE

In its prototype form, WETLAND-USE was confined largely to describing the pressure-state relationship, as a means of influencing the decision making process. This study provides some basis for enhancing its capacity to account for the other elements in the perceptions-policy-pressure-state framework. The results of this study indicate clearly that a component for allowing for the local social and organizational context to be described should be added to WETLAND-USE, including the following:

1. a set of key questions to guide the gathering of information on the primary resources used, local ecological knowledge about use of the resources, and the organizations influencing resource use;
2. frameworks within which the information necessary to answer the key questions should be gathered (notably, the perceptions-policy-pressure-state framework and the land tenure

framework Uphoff (1986));

3. guidelines for interacting with local people and gathering information (e.g. Chambers, 1994);
4. the perceptions-policy-pressure-state framework as a means of assisting extension workers in choosing appropriate modes of intervention;
5. directions to other useful sources of information and expertise; and
6. a range of case-studies to serve as references.

It is important to add, however, that while guidelines, such as those given above, and planning are helpful, it is advisable to proceed inductively, experimentally, and flexibly, rather than following a rigid "blueprint" (Johnston and Clark, 1983; Uphoff, 1986).

A need was also identified for further resource material to address the language and literacy barriers discussed. Key components of WETLAND-USE have been translated into the local language, Zulu, and several of the concepts in the system have been illustrated with drawings for use in meetings and field visits as an aid to reaching a common understanding of the functioning of the wetland. Drawings of different wetland development scenarios have been used in community workshops. A local artist has compiled some drawings of local management issues, which has assisted to some extent in capturing the experiences of the local people. As emphasised by Appiah-Opoku and Mulamoottil (1997) local organizations and experiences need to be incorporated into environmental assessment, which is likely to reduce dependence on external ideas, goals, technology and supervision in environmental management.

Recommendations relating to the situation at Mbongolwane and other areas in similar contexts

In terms of the perceptions-policy-pressure-state framework, interventions at all points is required. It will be necessary, however, to move beyond actions to influence mainly perceptions, which has been the primary focus to date. The most immediate need is for further assistance with local policy development and support for regulation (i.e. interventions points 2 and 3 in the framework) which are in accordance with contemporary conditions. A focus on locally derived mechanisms rather than on those externally imposed will be required, and it will be necessary to work with the authorities down to the lowest level possible (i.e. with the headmen of sub-wards and also with garden committee representatives). Full agreement has been obtained at ward level from the Tribal Authority and from the general community at public meetings that cultivation and other resource use in the wetland needs to be controlled. At sub-ward level commitment has also been obtained from the respective headmen. Leading on from this it will be necessary to continue working closely with these headmen and particularly with the people who are cultivating the wetland. At the same time, however, the building of local organizations should be accompanied by a realism about their effectiveness in the face of contemporary socio-economic conditions (Lawry, 1990). Uphoff (1986) contends that where natural resource benefits are delayed, remote and/or hard to identify (as is the case for many benefits at Mbongolwane) then the capacity of local organizations alone (particularly membership organizations) to successfully regulate resource use is limited.

Clearly the Tribal Authority cannot be expected to carry out regulation alone. Thus, the links established in the Wetland Management Network will need to be strengthened and roles and responsibilities re-clarified so that service and administrative organizations who represent the interests of local as well as the more remote beneficiaries of the wetland, can provide the Tribal Authority with the support that they require. This study emphasised the key role of the organization/s controlling the allocation of land and natural resources, in this case the Tribal Authority. In less remote areas, this is likely to be an alternative organization (e.g. a civic organization) (Barnes and Morris, 1997).

This chapter also indicates that changes in the extension services will be required to address the issues identified in the previous section. This is beyond the scope of this study but readers are referred to the recommendations given by Murombedzi (1991), Scoones and Cousins (1993) and Jiggins (1997). The creation of a more enabling broad administrative and policy environment within which to pursue the above activities is also seen as a priority, and this investigation of a local case-study has highlighted issues that a broad policy initiative should address.

Complementing regulatory measures would be non-regulatory measures which promote self reliance and have a positive reinforcing effect on the sustainable use of a wetland. Thus, the external support given to user organizations (notably the Craft Group) that promote low impact and sustainable resource use practices should be maintained. Related to this, it will be important to strengthen the local development committee which is experiencing ongoing organizational difficulties. Until effective local development institutions exist, effective interventions to promote more environmentally sustainable modes of production (i.e. at point 4 in the framework) are unlikely to be achieved. A focus only on interventions designed to physically rehabilitate degradation in the wetland (i.e. at point 5 in the framework) is certainly not seen as desirable as it does not address the human factors contributing to the degradation.

This study did not investigate the extent to which an integrated system for management of the overall wetland was operating at Mbongolwane nor did it make comparisons with other sites. It is anticipated that these investigations would further enhance WETLAND-USE, and are addressed in Chapter 11. Besides the Mbongolwane case-study, the chapter will also include four other wetlands from a diversity of social contexts.

CHAPTER 11
INTEGRATED MANAGEMENT OF WETLAND SYSTEMS
FIVE STUDY SITES EXAMINED AND COMPARED

11.1 Background to the investigation

The effect that a particular use of a wetland has on the state of the wetland and how this in turn affects perceptions and policy (see Section 3.2.1) takes place within an organizational environment which is likely to vary among wetlands. It is generally recognized that the contribution which technical expertise can bring to sustainable use is limited and the social/organizational context within which wetlands are used is paramount (WWF, 1993a and b; Gopal, 1991). As demonstrated in Chapter 10, the WETLAND-USE prototype lacked components accounting for the organizational context of wetlands, which was recognized as a shortcoming at the outset of refinement of WETLAND-USE. In order to develop these components it was considered necessary to draw on a broad range of contexts and gain a better understanding of how organizations influence (through both regulatory and non-regulatory means) the use of wetlands.

Internationally, and in South Africa, the 1970's was a decade of heightened public and government concern for the environment, which has been increasing through the 1980's, into the 1990's. New legislation relating to the environment was introduced, and several non-government conservation organizations were formed (Rabie and Fuggle, 1992). International conventions, notably the Ramsar Convention, provide an additional means through which the public could exert influence on wetland users through national government and relevant departments. Businesses, in response to consumer pressure, have incorporated environmental management into their business management structures, and international trading standards are being enforced by the international business community through means such as the ISO standards (see Appendix D, Part 2, Section 5). Thus, it would appear that the state and various NGOs acting on society's behalf have a potentially high level of control over wetland use under private property regimes and, to a lesser extent, also under communal regimes.

The specific objectives this chapter are to: (1) briefly describe the organizational and land tenure context of wetland study sites representing a diversity of social contexts; (2) determine the extent to which an integrated management system for the overall wetland system was operating; (3) identify the likelihood of WETLAND-USE being applied at the sites examined; and (4) recommend specific components to be included in WETLAND-USE based on the findings of the chapter.

The information for this study was gathered through interviews with local wetland users, managers and individuals in relevant organizations conducted in 1996 and 1997 and examination of workshop and meeting proceedings. It is recognized that this investigation is largely qualitative. Furthermore, the author was involved as an NGO worker to varying degrees in all of the study sites, which is a source of bias in the evaluation: ideally the evaluator should not to be "part of" the studies being evaluated. Nonetheless, the "action research" approach (sensu Carr and Kemmis, 1984) of this study, where the researcher participated in organizations affecting change, is considered a legitimate research approach, which enhances the social relevance of the research (see Carr and Kemmis, 1984; Taylor, 1997). The objectivity of the study was promoted as far as possible by using uniform criteria on a diverse range of study sites, for which it was possible to compare the different approaches to intervention and identify key issues and lessons learnt.

11.2 The land tenure and organizational context of the sites

Five wetland sites, Wakkerstroom vlei, Mandlazini wetland, Mbongolwane wetland, Ntabamhlope vlei and Blood River vlei[8], which represent a wide range of land-tenure contexts were examined (Table 11.1). The study sites were chosen so as to represent communal land, private farmland, and commercial private forestry land.

Wakkerstroom wetland is situated immediately adjacent to the small rural town of Wakkerstroom and is owned by the Wakkerstroom Town Council. The Wakkerstroom Natural Heritage Association (WNHA), founded in 1991 and with a membership of 160 by 1996, gained a 10 year lease of the wetland from the Town Council. Mbongolwane wetland falls within the Ntuli Tribal Ward and its details have been described in Chapter 10. The Mandlazini wetland, which is adjacent to Mzingazi Lake, Richards Bay is owned by the Mandlazini Community Trust which represents the 570 families making up the Mthiyane Tribe. The Tribe was forced by the State to vacate the land they had traditionally occupied and in 1995 they were successful through campaigning by the Mandlazini Development Association in having a portion of their land returned in terms of a Land Restoration Agreement. Resettlement, which involved zoning of the wetland, was implemented through close co-operation between the Mandlazini Development Association and an NGO, Integrated Planning Services. Blood River is typical of many of the larger wetlands of KwaZulu-Natal in that it extends through the boundaries of several individual private landowners. Finally, Ntabamhlope vlei is owned largely by a single company, Masonite, who have afforested much of the wetland's catchment.

[8] A sixth wetland, Boschoffsvlei, which was similar to Blood River vlei in comprising several portions privately owned by farmers, was also considered. Although a survey of the biophysical state of the wetland was conducted (see Kotze, 1994b) no involvement by the extension services in the management of the wetland was found and no overall management system had been attempted. Thus, for the purposes of this study it was not examined any further.

Table 11.1 The land tenure and organizational context of the five wetland study sites

	Wakkerstroom	Mbongolwane	Mandlazini	Blood River	Ntabamhlope
Wetland size	950 ha	380 ha	ca. 100 ha	6000 ha	285 ha
General setting	A small town in a rural setting	Rural agricultural area	Peri-urban area	Rural agricultural area	Rural forestry area
Dominant land-uses	Livestock grazing; bird watching;	Harvesting of sedges and reeds for crafts and construction; cultivation; water supply	Cultivation and harvesting of plants for crafts	Grazing; water supply - enhanced through the construction of several dams for irrigation	Areas for firebreaks; illegal grazing
Land tenure	Communal townlands leased by the Wakkerstroom Natural Heritage Association (WNHA)	Tribal lands; primarily communal but with rights of uses of some areas delegated to individual households (see Chapter 10)	Individual private plots and communal commonage	Approximately 50 individual privately owned farms	Private company land
Management authority	Wakkerstroom Town Council delegated to the WNHA	Ntuli Tribal Authority	Mandlazini Development Association (MDA)	No overall authority; individual owners with authority over their land	Masonite Timer Company
Level of control by authority over the direct use of the wetland	High	Moderate with regard to certain resources; declining with regard to others (see Chapter 10)	High, but anticipated to decline owing to weakening of community structures	High, but only on an individual owner basis, low overall control	High, but requiring a high level of law enforcement to prevent illegal grazing
Direct user groups	Many: Bird watchers Livestock owners Mowing of natural vegetation	Very many: Natural vegetation harvesters; Cultivators; Livestock owners; Medicinal plant harvesters; Domestic water abstractors	Many: cultivators, vegetation harvesters; wood harvesters	Few: Cattle owners Irrigaters	Many: Masonite-firebreaks; Cattle owners Grass harvesters
Organizations influencing use	Many: WNHA Town Council Nature Conservation Dept. NGO's	Very many: see table 10.2 & Fig. 10.1	Many: MDA Development planners & other NGOs Dpt. Nature Conservation Dpt. Agriculture	Few: Dpt. Agriculture Dpt. Nature Conservation	Few: Masonite Dpt. Nature Conservation

Table 11.1 shows that the sites encompass a range of land tenure situations from different forms of communal use to multiple and single private ownership. Blood River, which essentially has 50 different management authorities operating largely independently contrasted with the other wetlands that all had some form of overall management authority.

Although in most of the wetlands the level of control by the authority is high, in three of the wetlands there are clear indications that it is declining. In the case of the WNHA, use of the wetland is controlled by selling grazing rights and employing a guard to prevent illegal grazing. The Mandlazini Development Association has a high level of legitimacy among the Mthiyane Tribe and control of the use of the wetland is implemented through a development plan that the Association administers. It is, however, anticipated that now that families have successfully had their land returned and much of the infra-structural development has taken place, the level of authority and control implemented through the Mandlazini Development Authority will decline (W Forse, 1997. *Pers. comm.* IPS, Mtunzini). As discussed in detail in Chapter 10, at Mbongolwane the control exerted by the Tribal Authority varies according to the particular resource. At Blood River, individual land-owners had a high level of control over any land-uses on their properties. At Ntabamhlope an important issue dealt with by the management authority was the issue of uncontrolled grazing by neighbouring communities. Initially grazing rights were sold at a nominal fee. However, paying individuals were not prepared to assist in excluding non-paying people for fear of being victimized even though the grazing they had paid for was being reduced by the "free riders". Thus, the situation was tending towards free access. A central problem in controlling grazing in the wetland is that the cattle came from several wide-ranging geographical areas, with the result that there is no single well defined community with which to negotiate a mutually agreeable solution. Added to this is the general political instability and poverty which make it difficult to formalize long term solutions. In response, Masonite disallowed any grazing and excluded it through law enforcement applied by a private security company, which has not dealt with the problem at its source.

Table 11.1 indicates that Mbongolwane had an organizational complexity noticeably greater than the other wetlands both in terms of the number of direct user groups and the organizations influencing use of the wetland. The simplest organizational arrangements were those at Natabamhlope. It should be noted, however, that had the management authority continued to work out a mutually agreeable arrangement with livestock owners the complexity would have increased. Nevertheless it is argued that this is likely to have increased long term sustainability. Manadlazini and Wakkerstroom had similar levels of complexity, with a well defined management authority serving the interests of a range of user groups and maintaining a high level of control over use.

11.3 The operation of a management system

In order to determine whether a management system was effectively operating at a wetland, the organizational environment within which each wetland was managed was characterized by determining if:

1. an organizational structure for management of the overall wetland existed;

2. roles and responsibilities had been clearly defined;

3. a vision was in place for management of the wetland with measurable objectives and goals which are regularly reviewed;

4. integrated management decisions which balance the benefits derived by direct users of the system with benefits derived by society were being made;

5. responsibility had been assumed by local people for the management system; and

6. consistent support was provided by outside organizations.

The organizational structure was examined in terms of whether there was a formalized structure (e.g. with a constitution) with recognized procedures (e.g. regular management review meetings). Regarding a formal management system encompassing a management vision, objectives and measurable goals it was recognized that in certain social contexts which lack a written culture, local cultural norms and regulations effectively serve these functions, and interviews were conducted to reveal these. It is assumed that if local users and extension workers have a management system through which they can work to set and measure attainment of goals then the likelihood of sustainable use is increased. Whether integrated management decisions were being made was determined through management records and inspection by the author of management related features such as erosion gullies and cultivation within the site itself.

Table 11.2 shows that the extent to which an integrated management system was operating varied considerably among wetlands. With the exception of the Blood River, there was some form of overall organization structure operating in all wetlands, with Wakkerstroom being the most developed. The WNHA had an elected committee, held regular planning and review meetings, administered funds and controlled access to the wetland. Although Ntabamhlope did not have a specific organization in place for management of the wetland, Masonite timber company, which owned most of the wetland, had a formalized arrangement between the management team of the Masonite estate and the company's environmental officer. This included regular meetings with the two parties to deal with management issues related to the wetland and assess management actions.

Table 11.2 Extent to which various management system- related criteria are met in the respective study sites

Management system-related criteria listed in Section 11.2	**Wakkerstroom**	**Mbongolwane**	**Mandla-zini**	**Blood River**	**Ntabamhlope**
Overall organizational structure present	Yes	No, but the Tribal Authority is the primary management authority	Yes	No	Yes
Roles and responsibilities clearly defined	Yes	No	No	No	Yes
Overall management vision	Yes	Yes	Yes	No	Yes
Measurable objectives and goals set	Yes, but inconsistent	No	No	No	Yes, but inconsistent
Monitoring and regular review of goals & objectives	Yes, but irregular	No	No	No	Yes
Integrated management decisions carried out	Yes	-	-	-	Yes, but constrained by afforestation in wetland's catchment
Local responsibility assumed	Yes	No	No	No	Yes
Consistent outside support	-	No	No	No	-

Although Mbongolwane did not have a formalized management structure, an informal multi-organizational network with commitment to a common vision and annual review meetings was present and attempts were made at clearly defining roles and responsibilities. At Mandlazini, while organizational arrangements with other organizations had not been clarified, the Mandlazini Development Association committee was formally mandated to deal with environmental issues, of which the wetland was a component. Assistance to the Association was provided by NGOs facilitating planning and development. At Blood River, a committee with farmers represented was formed in 1994 to co-ordinate the overall management of the wetland. However, this dissolved in less than a year, following which there was no organization of any form dealing with the management of the wetland. Previously, an attempt at establishing a conservancy (see Appendix A; Byron, 1997) for the wetland was also short-lived.

Again, with the exception of Blood River, a shared vision for management of the wetland existed for all wetlands. However, the extent to which this had been translated into measurable objectives and goals varied considerably among the wetlands. At Wakkerstroom and Ntabamhlope, while formal management systems were in place with measurable goals, explicit monitoring protocols and workplans with time-frames had not been consistently produced. At Mandlazini a clearly demarcated and mutually agreed upon land-use plan was present which indicated those portions of the wetland where cultivation was not permitted. However, details of acceptable practices were lacking and no monitoring protocols were in place. At Mbongolwane, cultural norms (e.g. accepted harvesting times) had some bearing on the use of resources (see Chapter 9). However, although attempts were being made at developing a management system which accommodated contemporary pressures and modes of use, this was not complete. At Blood River although management guidelines were developed (see Kotze, 1994a) these were not incorporated into a management system of any form. A contributing factor is that there were approximately 50 different landowners each with their individual management priorities.

Review by the management organizations of their management decisions had been undertaken only at Wakkerstroom and Ntabamhlope. Their reviews showed that management objectives were largely being met. At Wakkerstroom, the hydrological, erosion control and ecological benefits appear to have been protected and the wetland has been well utilized for tourism and grazing. However, benefits, particularly to poor local people, from the natural vegetation in the wetland have been low as evidenced by the low level of harvesting. At Ntabamhlope the hydrological and ecological benefits yielded by the wetland have been constrained by the extensive afforestation in the catchment which is likely to have significantly modified the amount and timing of the wetland's water supply.

The extent to which responsibility had been assumed by local people for the management system varied considerably among wetlands. At Wakkerstroom the management system was maintained largely by local people and was not greatly dependent on external input. This contrasted with the situation at Mandlazini and Mbongolwane where, although they were supported by local people, initiatives to promote the sustainable use of the wetland were still dependent on a high level of outside input. At Wakkerstroom the capacity of some local people (e.g. eco-tourism operators) was high, which contrasted with Mbongolwane and Mandlazini, that had historically-disadvantaged rural communities with limited capacity. In developing countries, state funds are generally limited in promoting the sustainable use of wetlands, and thus participation by local volunteers plays a crucial role in the success of such use and management (see Maltby, 1991). In the literature (e.g. WWF, 1993a) it is often implied that if communities are invited or given the opportunity to participate they will be eager to do so. However, a factor often over-looked when making such a general statement about the participation of local people is that participation often requires that individuals in the community contribute considerable time and resources which may have substantial opportunity costs for those individuals. Furthermore, much of the discussion regarding participation of local people in the literature (e.g. Makombe, 1993) is with reference to areas (notably, formally protected areas) where local people have been excluded. In these contexts participation provides the opportunity to increase levels of access. Conversely, in areas, such as Mbongolwane, were local people have historically had a high level of access, participation is likely to lead to decreased access, albeit controlled access in a manner considered generally acceptable by the local people.

The low level of commitment from local farmers at Blood River for taking responsibility for management of the wetland is illustrated by their response to maintenance of state-funded erosion control structures on their property. In 1995 such a structure was constructed in the highest priority erosion site in the wetland, and there was a failure on the part of the two landowners involved to take ownership of the structure and undertake a small amount of maintenance required on the structure. Little initiative has also been taken by any farmers in identifying and erecting erosion control structures of their own accord.

In the study sites examined, outside NGOs were generally involved for only a short time, and ongoing support for extension staff could not be provided. Administrative organizations, including the agricultural and nature conservation extension services, have a long-term commitment to working with local people, and therefore it is sensible that they play a major role. However, a fundamental problem encountered in the study sites was the lack of continuity caused by a high turn-over of employees, changing priorities, and lack of clear policies directing these organizations in relation to wetlands. This has resulted in inconsistent support for particular initiatives by administrative organizations. This was particularly true for Blood River and Mbongolwane. At Mandlazini and Ntabamhlope there was little extension service involvement in wetland management from the outset. While this was initially so for Wakkerstroom, extension input has increased owing, in part, to the successes demonstrated by local initiatives at the wetland.

11.4 Discussion and recommendations

The results of this investigation and that reported in Chapter 10 indicate clearly that the organizational complexity of wetlands varies considerably, from Ntabamhlope, which was the least complex, to Mbongolwane, the most complex. As can be inferred from the studies, a fieldworker would be able to use WETLAND-USE more readily for promoting sustainable use of wetlands in situations that are less complex. It should be added, however, that while on the one hand it is a much simpler task for an extension worker to deal with a single individual landowner, on the other hand, such landowners do not fall under any higher authority. This would make it more difficult to reach a common vision for management of the overall wetland comprising many individual land-owners, as illustrated at Blood River.

Although the contribution of the organizational environment to sustainable use was found to be deficient in all of the wetlands, this varied among the five wetlands examined. It was poorest at Blood River, which lacked an organizational structure of any form, followed by Mandlazini and Mbongolwane, both of which had some form of organizational structure but lacked a well developed management system. At Ntabamhlope, an organizational and management system were present, however important deficiencies in both were identified. Although Wakkerstroom had the best developed organizational and management systems, some deficiencies in both of these were also identified. Where records were kept of the outcomes of management decisions, namely at Ntabamhlope and Wakkerstroom, it was found that an integration of direct and indirect benefits were largely being achieved. The deficiencies identified indicate how the contribution of different organizations to the sustainable use of wetlands could be enhanced. These results indicate that at the study sites generally, there are fundamental organizational obstacles that will hinder the translation of biophysical assessments into integrated management decisions, even if an extension worker who applied WETLAND-USE was well informed. In addition, Mandlazini resembles Mbongolwane in that many of the users are poor and have a low level of formal education, which place important additional limits on the use of a system such as WETLAND-USE by extension workers.

Factors supporting or undermining success in the short to medium term are likely to do so in the long term as well. Furthermore, although external organizations can "prop up" initiatives in the short term, involvement of local people will become increasingly important in the long term if sustainability is to be maintained. It is widely accepted (e.g. Murphree, 1993) that devolution of control over resources from a more central level to a more local level is required, with the assumption that there is control at a more centralized level. However, as demonstrated in the study sites, often even the most localized level of government has little control over resource use. This highlights the importance of building local capacity and the level of control over wetland use. At the same time higher levels of resource governance also need to be strengthened in a manner that reinforces local capacity. Clearly, the management and use of wetlands needs to be addressed at several different organizational scales from local to national and even international. The Ramsar Convention provides broad sustainable use guidelines at an international level. However, this needs to be translated into meaningful actions at the level of individual countries and ultimately down to the level of local communities. In South Africa a national wetland policy and strategy have been noticeably lacking and, furthermore, comprehensive policy guidelines for KwaZulu-Natal which were developed with wide stakeholder participation were never endorsed by the province. Thus, extension workers dealing with land-users do not have clear guidelines of how to approach wetlands. They also generally lack access to relevant information (such as the Ramsar guidelines for wise use) and networks to allow for the exchange of expertise, experience and encouragement between different initiatives. Based on the results of this and the previous two chapters, the following recommendations are given for refining WETLAND-USE:

1. Develop protocols for landowners/users to establish a goal maintenance system. This would provide the means against which success of natural resource management can be measured and greater accountability promoted. As far as possible, the protocols should be nationally standardized and adopted by provincial agencies.

2 Adapt and develop protocols for engaging local communities and building their organizational capacity, with case-studies to serve as examples. It would also be useful to have a directory of initiatives, conventions and legislation applicable to wetlands.

The above recommendations have been undertaken in the refinement of WETLAND-USE (see Chapter 3 and Appendix D, Part 2). This and the previous chapter also provide the basis for providing further recommendations concerning other instruments outside the immediate scope of WETLAND-USE:

1. Establish a national wetland sustainable-use forum and network of individuals involved in particular geographical areas to promote the exchange of ideas and experiences. This forum would assist in horizontal integration by linking local initiatives. It would also assist in facilitating vertical integration by promoting the two-way exchange between local and broader scale initiatives (e.g. the development of national policy and strategy for the sustainable use of wetlands).

2. Develop non-regulatory mechanisms to assist in securing natural assets (including wetlands) on private property through prestige and recognition by promoting the Natural Heritage Sites and Sites of Conservation Significance Programmes and developing further instrument/s to address the inadequacies of these initiatives discussed in Appendix A.

3. Develop policy at national and provincial level to create a more enabling environment for the sustainable use of individual wetlands, which is nested within general environmental policy, and develop a multi-organizational strategy for carrying out the policy. Such a strategy, would greatly add to the value of the policy.

4. Work through existing organizations and initiatives promoting collaborative management (notably conservancies in commercial farming areas or development committees and the Tribal Authority in communal areas) and support and build the capacity of these local organizations.

5. Promote environmentally sensitive modes of production (e.g. craft production and eco-tourism) by local people as alternatives to less sensitive modes of production (e.g. drainage and cultivation).

6. Government and non-government environmental organizations should pro-actively engage disadvantaged communities, which have largely been overlooked in the past as well as engaging the extension services that work with these communities. In KwaZulu-Natal, for example, of the over 400 extension workers, more than 70% are working mainly in formerly disadvantaged areas. As discussed, many of these employees are poorly informed about wetlands and their values and are provided with little support from both within and outside of the department to allow them to promote the sustainable use of wetlands.

7. Adopt a targeted approach, given the limited resources that are available to intervene. For example, greater returns are likely to be obtained within a cohesive community than where community structures are poorly developed and levels of conflict are high.

8. Continue with the process of revising the legislation applicable to wetlands and, very importantly, strengthen the currently weak capacity for enforcing the legislation.

9. The focus of this study was on extension workers, and a specific investigation of the perceptions and motivations of users and integrating these into wetland use and management strategies is required.

Items 1 and 2 above are already being addressed through initiatives that grew out of the research reported in this thesis. The group of fieldworkers assembled to provide feedback on WETLAND-USE found the experience beneficial to their work and it was decided to formalize and continue with the group by forming a forum, termed the South African Wetland Action Group (SAWAG) discussed in Chapter 8. The vision of the group is to "Promote the sustainable use of palustrine (marsh and floodplain) wetlands through the exchange information and experiences and through working together on areas of common interest". Results of this study relating to the lack of an instrument to promote the development of local policy and accountability among wetland users was raised within the SAWAG, and this led to the group developing such an instrument, termed the "Vlei Lily Award". This award gives wetland users recognition for sustainable management practices and promotes their accountability in the management of their wetland by requiring the wetland owner/user to develop their own measurable goals for their wetland (see Section 12.3).

Finally, to emphasise the crucial role that local people play in resource management, as is done in this thesis, is not driven by romanticism but rather is pragmatically grounded in a realistic assessment of Sub-Saharan Africa's present predicament. As emphasised by Atwood (1990), Plateau (1996) and Mafabi and Taylor (1993) a "top-down" approach has failed miserably all over the region. This study has addressed issues of wetland use and management through a "bottom-up" approach, recognizing that, as emphasised by Davis (1993), local-level research can inform larger scale decisions and policies. Specific site projects may often demonstrate the need for more general organizational and policy requirements for the sustainable use of wetlands. The study includes sites from a wide range of contexts, and thus it is well positioned to making a useful and broad contribution to the identification of policy, legislative and institutional requirements. With regard to the management of wetlands, it is clearly recognized that this thesis has drawn heavily on only a few wetland sites and in particular the Mbongolwane wetland. This has, however, also been complemented by drawing on the experiences (through workshops, field workshops and questionnaires) of many different fieldworkers working within a diversity of social contexts (see Section 9.7; Section 12.3; and Appendix A)

This chapter completes the investigations undertaken in Part 2 of the thesis of key biophysical and organizational elements relevant to WETLAND-USE. As indicated in Chapters 1 and 2, findings of these investigations were incorporated into WETLAND-USE at various stages in its development. Chapters 4 and 5 contributed to the prototype system and Chapters 6 to 11 provided inputs towards the revision of the prototype to produce the final system. In the following chapter, the system is evaluated in relation to predefined criteria.

PART 3
OVERALL EVALUATION AND CONCLUSION

CHAPTER 12
EVALUATION AND REFINEMENT OF WETLAND-USE

12.1 Introduction

A wetland assessment system such as WETLAND-USE may be evaluated using various means including: validation, verification, acceptability to users and repeatability of application. Validation refers to demonstrating correspondence with reality (i.e. directly determining the accuracy of a system) while verification refers to an evaluation of the internal consistency and anticipated accuracy of a model (Pritsker, 1984; Adamus, 1991). Validation of a rapid assessment technique is generally implemented by comparing its results with the results obtained from detailed long-term studies. Little validation of the systems reviewed by Adamus (1991) had been undertaken, and in this study, while it is recognized as being desirable in the long term, it was not possible to validate WETLAND-USE owing to a paucity of data for South African wetlands.

WETLAND-USE was verified by the author and its acceptability to users and its repeatability were evaluated by having fieldworkers apply the system in the field. Verification of WETLAND-USE was undertaken by examining: (1) the consistency of the system's rules and the logical structure of its evaluation procedure; and (2) the predicted accuracy of the results (recommendations) given by the system (using the criteria of Adamus [1991] given in Section 12.2.2). Acceptability of the system to fieldworkers was evaluated by obtaining direct feedback from users of the system through: (1) a questionnaire for fieldworkers who had applied the system during the course of their work; and (2) a series of field workshops where fieldworkers applied the system to wetlands under a range of land-uses. The repeatability of WETLAND-USE was determined through independent application of the system by fieldworkers to a variety of wetland sites.

The purpose of this chapter is to present the findings of the evaluations and to discuss how they were used in the successive refinements of WETLAND-USE. As indicated in Chapter 2, the evaluation and revision of WETLAND-USE were conducted in an iterative fashion (see Fig. 2.3) resulting in the various evaluations being interspersed at intervals through the overall study.

12.2 Verification of the system

12.2.1 Consistency and logical structure of the system's rules

Indignizio (1991) describes 5 main types of inconsistency for which rules should be examined: (1) redundant rules, (2) conflicting rules, (3) subsumed rules, (4) unnecessary premise clauses, and (5) circular rule chains. Owing to the small number of rules used by WETLAND-USE, this was relatively straightforward and the examination revealed none of the rule inconsistencies listed above.

The approach that WETLAND-USE employs for making multi-criteria assessments of impacts was evaluated against the mathematical considerations given in Smith and Theberge (1987) for the selection of multi-criterion methods. WETLAND-USE is a non-compensatory method, in the sense that, alternatives are assessed criterion by criterion (Smith and Theberge, 1987). Based on the principles given by Smith and Theberge (1987) such a model is appropriate where criteria are measured on different scales, which is the case for WETLAND-USE. More specifically, in identifying sites with potentially high impact, WETLAND-USE is a disjunctive non-compensatory method which is based on an alternative meeting a minimum standard for at least one of the criteria regardless of its value for the others. For example, if a site has a Red Data species which will be negatively affected by the proposed land-use, even if the impact associated with all of the other criteria are low, the overall impact will be high (i.e. all of the low values do not compensate for a single high value). Disjunctive methods do not require that the criteria be independent of each other, which is an assumption of additive methods (Smith and Theberge, 1987) and several of the criteria used by WETLAND-USE are unlikely to be independent (e.g. presence of Red Data species and loss of native vegetation). Smith and Theberge (1987) further add that (1) the outputs of disjunctive methods can be communicated easily (which is a high priority for WETLAND-USE) compared with methods where criteria are aggregated in a manner that is often conceptually difficult to follow; and (2) a disjunctive model is appropriate where minimum standards are set for each criterion (which is the approach taken in WETLAND-USE).

12.2.2 Predicted accuracy of the results (recommendations) given by the system.

The predicted accuracy of the results was determined by the author through comparison against literature findings and other systems and using the criteria employed by Adamus (1991) for evaluating wetland assessment techniques. This testing primarily involved: (1) identify the extent to which the assumptions of the system were supported in the literature; and (2) evaluating whether important

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