TOWARDS THE ACHIEVEMENT OF ENVIRONMENTAL STANDARDS IN THE SOUTH AFRICAN SUGAR INDUSTRY: THE ROLE OF GIS

by

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PREFACE

The author was responsible for the operation and management of the South African Sugar Association Experiment Station's GIS between 1991 and 1998, and is now GIS Scientist in the Resources Utilisation Section of the Western Cape Department of Agriculture.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any University. Where use has been made of the work of others it is duly referenced in the text.

The study was supervised by Professor Charles Breen.

ABSTRACT

The South African Sugar Industry is a major land user in the South African provinces of KwaZulu-Natal and Mpumalanga. Although offering substantial economic benefits in these regions, monocultural sugarcane production has had a fundamental impact on the natural environment in which sugarcane is produced. Attention was focused on the growing sector of the industry after flood events during the previous decade resulted in major soil erosion of sugarcane land. Widespread intentional cane burning is attracting increasing societal and regulatory pressure. New national environmental legislation in the spirit of the United Nations Conference on Environment and Development (UNCED) Agenda 21 and various other international agreements, demand that industries – including agriculture – demonstrate sustainability in their use of environmental resources. National law now more rigorously addresses biodiversity and wetland environmental issues. New water laws will fundamentally alter the existing water-use paradigm in sugarcane production. These issues are not unique to South Africa, having much in common with those faced by other major sugar producing countries. In order to effectively manage the impacts of production processes on the environment, organisations are turning to internationally accepted environmental management standards, such as the ISO 14000 series, in order to demonstrate their environmental responsibility to government and society, whilst promoting their acceptability to consumers. The SA Sugar Industry is in the early stages of investigating appropriate environmental management systems.

The natural resources required for – and impacted upon – by sugarcane production are variable in space and over time. Effective and responsible environmental management must make optimum use of appropriate technology to effectively utilise the large volumes of often complex data pertaining to these resources and associated environmental processes. Geographic Information Systems (GIS) are computer systems designed for the capture, analysis, storage and display of spatial data and attribute data related to location. Whilst not a new development, recent advances indicate that GIS has substantially matured as a decision support technology and as such is being used successfully by many organisations involved in environmental management, where its use offers unique benefits at a variety of decision levels and spatial scales. GIS is applied at many complexity levels, from simple thematic map production to complex spatial analysis. The major advantage of GIS is considered by some to be its ability to spatially model environmental scenarios, producing graphic results (usually maps). As such, GIS has considerable value in formal Decision Support Systems. The major environmental issues facing South African sugarcane producers are fundamentally spatial in nature. The development and incorporation of environmental GIS capacity into their proposed environmental management system is indispensable in addressing these issues and moving towards achieving and maintaining acceptable environmental standards in the SA sugar growing sector.

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Chapter 1
INTRODUCTION

1.1 THE SOUTH AFRICAN SUGAR INDUSTRY

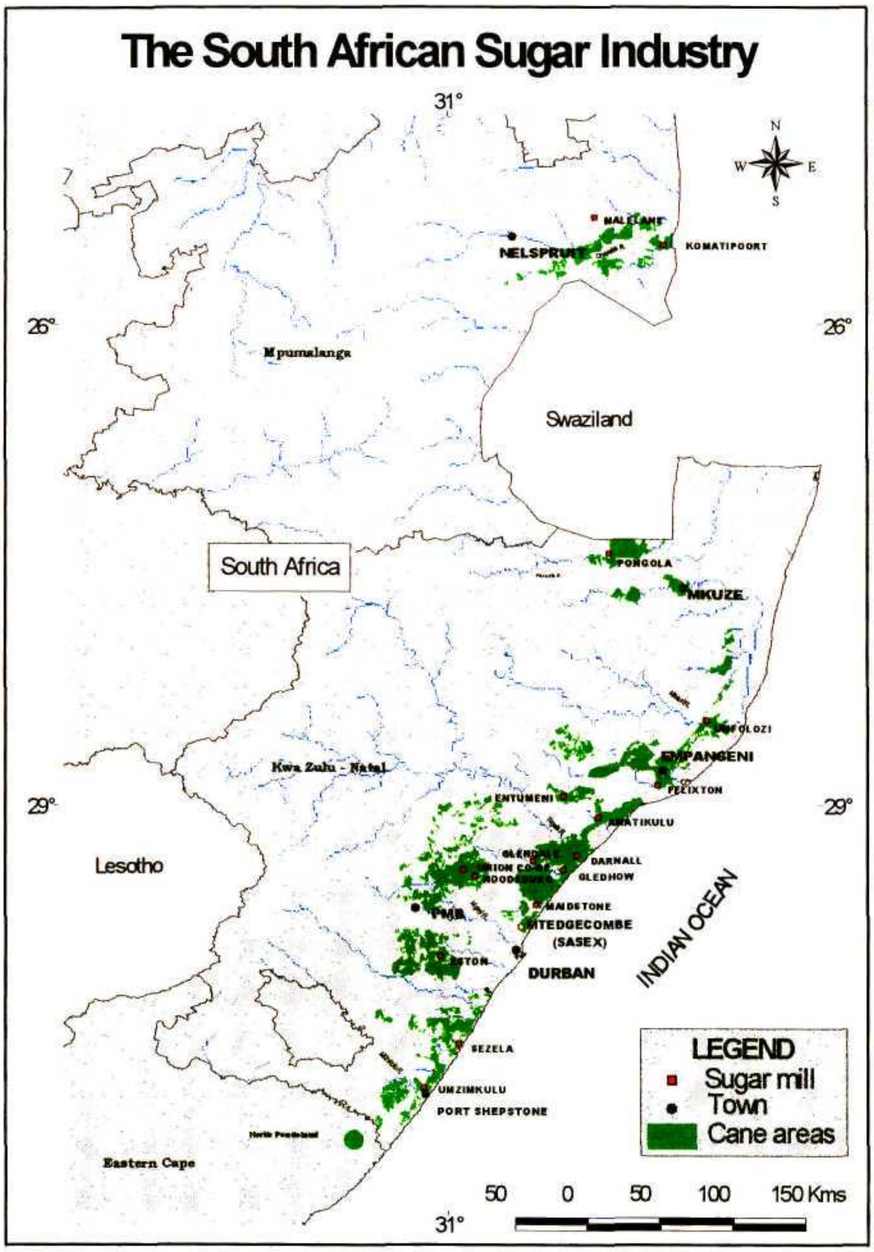

Figure 1.1. Map showing the SA Sugar Industry cane growing areas.

The South African Sugar Industry consists of about 58 000 registered growers producing sugarcane on some 412 000 hectares. Of these, approximately 56 000 are considered small-scale growers, farming about 94 000 hectares (Lynsky, Schmidt and Sugden, 1997). Together, these small-scale growers produce about 10 percent of the total production. The vast majority of the sugarcane production comes from private commercial growers and milling companies. It is calculated that some 95 000 workers are directly employed in this agricultural sector, and production can reach 22 million tons of cane per annum given favourable rainfall (Anon., 1996).

The milling and refining portion of the industry consists of 15 sugar mills located across the cane producing region, employing about 12 000 workers. Investment in the growing and milling sectors is R5.8 billion and R9.4 billion respectively. According to the National Department of Agriculture's 1998/99 Economic Review (NDA, 1999a), sugarcane rated as the largest agricultural product contributor to total export value at R1738 million. Citrus and wine were next at R1385 million and R992 million respectively. The distribution of sugarcane and the location of the mills is shown in Figure 1.1.

The South African Sugar Association (SASA) is the non-profit, governing body of the South African Sugar Industry. Constituted in terms of the Sugar Act of 1936, the Act granted the Sugar Industry statutory powers of self-government. It is composed of two members: the South African Cane Growers' Association, which represents individual cane growers' member organisations and local grower councils; and the South African Sugar Millers' Association, which represents holding companies and individual millers. SASA is structured into seven divisions: finance, industrial affairs, national market, international marketing, public affairs, human resources and the experiment station (SASEX).

1.2 ENVIRONMENTAL ISSUES AND PRESSURES

The South African Sugar Industry is a major land user in the province of KwaZulu-Natal and in parts of the Mpumalanga lowveld. As with any form of widespread monoculture, the industry has had a major impact upon the environment in which it is grown. As a land-use activity it fundamentally alters soil quality and the quantity and quality of water entering rivers, streams and estuaries. It also reduces biodiversity and has, in the past, been responsible for the drainage of significant wetland areas (Hay, 1999). Increasing public and government attention has been focused on the industry recently, following:

- the massive erosion of certain cane lands during heavy storms in 1984 and again in 1987 (Platford and Bond, 1995);
- research reports and surveys on estuary and wetland losses and degradation through sugarcane production and the visible streambank encroachment of cane (Wyatt, 1999, pers. comm.)[1];
- the impact of the industry on water resources in terms of new water legislation; and
- the very visible nature and consequences of increasing cane burning practises.

The consultative process leading to new national environmental legislation has also played a role in placing sugarcane producers under increasing public and government scrutiny. The increasingly aware and sophisticated environmental lobby is forcing sugar industries, both international and local, to take a new look at their "environmentally relevant" activities (Anderson *et al.*, 1996).

The industry has acknowledged its members' role as custodians of the natural resources within the boundaries of the Sugar Industry:

"The South African Sugar Industry, recognising that its constituent members are major custodians of natural resources, shall encourage all its members to promote and take responsibility for the resources which are utilised within the boundaries of the Sugar Industry, and is committed to the laws which govern all relevant environmental issues" (South African Sugar Association Environmental Mission Statement, 1998).

1.3 LEGISLATION AND STANDARDS

Mounting public concern over the quality of the environment and stricter environmental legislation has led to a demand for reliable information on the environmental affairs of

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[1] Wyatt, J. Conservator: North Coast, KwaZulu-Natal Nature Conservation Services (KZNNCS), Durban.

industry and other enterprises (World Bank, 1995). An indication of the interest in improved environmental practices is the emergence of voluntary environmental management standards developed by national standards bodies throughout the world. To address the growing need for an international consensus approach, ISO, the International Organisation for Standardisation, has undertaken the development of international voluntary environmental management standards through ISO Technical Committee 207. ISO's 14000 series Environmental Management Standards are expected to have a significant impact on trade (EPA, 1997), which will inevitably impact on South Africa's current and future overseas sugar markets.

South African national environmental policy is in the process of fundamental, far-reaching change (Jordan & Mokaba, 1996). These changes will require members of the SA Sugar Growing Industry to ensure that:

- all agricultural activities are environmentally sustainable;
- pollution (such as that from cane fires) and environmental degradation (such as soil erosion and degradation of aquatic systems) are suitably managed and kept within standards; and
- costs to the environment will be internalised as far as possible *within* the industry.

Already the implications of the new national water policy (DWAF, 1997) have been felt, with issues regarding increased water tariffs, proposed rainfall interception levies and riparian water rights (Lynsky, Schmidt and Sugden, 1997). Increasingly, sugarcane producers will be required to report to government and the public regarding environmental matters. Sugarcane producers will need to develop acceptable standards to which its members would be expected to comply and, as with other industries, it will be judged according to the extent to which it attains such standards. In order to achieve these standards, an environmental management system is required which:

- identifies and attempts to quantify defined environmental aspects;
- develops a set of "best management practices" and procedures for regulatory compliance;
- sets objectives and targets;
- establishes procedures for monitoring and measurement; and
- provides public access to environmental information.

1.4 THE NEED FOR GEOGRAPHIC OR SPATIAL INFORMATION

Environmental processes have a definite spatial element which needs to be specifically considered if those processes are to be understood and managed (O'Riain and Mills, 1998). In order to effectively implement an environmental management system, the creation and analysis of large, complex, multidisciplinary data sets is usually required to assist in information supply and decision making (Eedy, 1995). In order to make best use of the wealth and complexity of information required in order to effectively manage the environment, one needs to apply the most appropriate tools. Geographic Information Systems (GIS) are computerized, spatial database management systems which lend themselves well to the management, monitoring, analysis and display of large, multidisciplinary datasets. They differentiate themselves from other data tools such as tabular "conventional" databases, computer graphics and Computer Aided Design (CAD) by their ability to handle the spatial component of data (O'Riain and Mills, 1998). Each of these other systems can in fact be considered a component of GIS though, with GIS making it possible to integrate them within one operational framework (FAO, 1999). They also form a basis for management decision support systems in various user-defined forms (McCloy, 1995).

Given their obvious need for spatial information and analysis, GIS technology is regarded as indispensable by many organisations involved in the management of natural resources as well as forestry or agricultural processes. Whilst some have experienced failure through rushing into inappropriate technology, many have established GIS as an integral and successful part of their environmental management systems.

Negative perceptions have evolved in certain quarters regarding GIS technology due to one or more of the following main reasons:

- technology driven "perceived need" adoption of the technology rather than a defined need driven implementation;
- inferior GIS software product;
- complexity of GIS operation;
- misconception regarding GIS capability; or
- inadequate data available, or underestimation of time and costs involved in data capture.

A number of developments in GIS during the last few years should help to address many of these issues (after Crossley, 1999):

- advances in software development;
- increased data availability;
- computing power advances;
- experience and changing attitudes;
- GPS and high resolution satellite data; and
- easier access to the Internet, which has allowed vastly improved dissemination of data, software, GIS advice (through user forums) and research findings.

1.5 SCOPE

Environment is usually defined as encompassing the physical, biological, social, economic, cultural, historical and political aspects (DEA, 1992). This document will deal only with the natural biological and physical environment in which sugarcane agriculture takes place, *i.e.* the impacts on the soil, habitat, flora and fauna, air and water resulting from in-field activities.

The *South African Sugar Industry* is composed of a milling and a growing sector. This document considers only the environmental aspects of on-farm sugarcane *production*, not the sugar milling process.

1.6 SUMMARY

The need for a sound environmental management system in the Sugar Industry can no longer be seen simply as an emotional, moral or ethical issue. Increasing pressure from global to local communities, world to local legislation and future trade requirements will eventually force the sugarcane industry to achieve certain environmental standards or else bear the cost in some way (Ireton, 1999).

This document therefore seeks to:

- introduce sustainability issues inherent in monoculture production systems and then review key in-field processes of sugar cane agriculture;
- examine some of the major environmental impacts of these on the natural resources and the resulting pressures placed on the industry to mitigate its environmental impact;
- assess current environmental policy and standards to which members of the SA sugarcane producing industry should legally and/or voluntarily comply;
- describe the spatial nature of the problem;
- discuss how GIS can be used as a tool for environmental management support; and then to
- demonstrate the crucial role that GIS needs to play in striving to achieve these environmental standards.

Chapter 2
MONOCULTURES AND SUSTAINABILITY: A BROAD VIEW

2.1 MONOCULTURES: PROCESSES AND PROBLEMS

Monoculture refers to the cultivation of a single plant species over large expanses of land to the exclusion of any other species. Apart from its ratoon (annual regrowth) cycle, the broad processes involved in the sugarcane production cycle are similar to those of many other extensive monoculture crops. Figure 2.1 illustrates the basic processes involved in monoculture crop production systems.

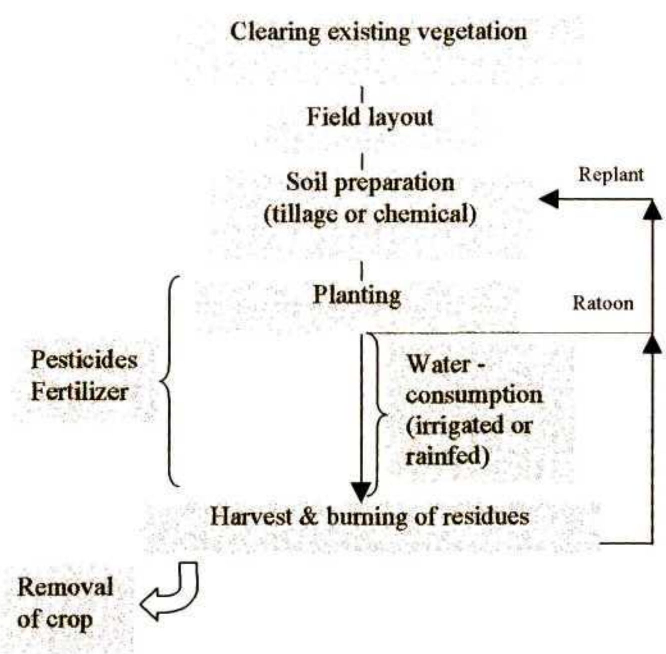

Figure 2.1. Simplified process flow of in-field operations in monocultures.

The timing of operations may differ in various situations and may not all be applicable. Each of these operations has an impact on its surroundings. These impacts may be highly localised or have consequences whose impacts are felt far from the impact's source.

2.1.1 Clearing

Replacement of the naturally occurring biological systems with agricultural ones results in a high degree of biotic simplification, or reduced biodiversity, due to the dominance of (usually) a single species of plant. Some results of this are:

- A local loss of or reduction in plant and animal species, such as the blue swallow (*Hirundo atrocaerulea*) which has become highly endangered due to loss of habitat to sugarcane and timber in Kwa-Zulu Natal (Ledger, 1990).
- The loss of potentially valuable genes which may have been used in plant breeding programs to increase resistance to pest, drought or disease or introduce other valuable characteristics (Giliomee, 1992).
- Possible extermination of plants which may provide a potential source of medicine and other pharmaceutical products. The recent "rediscovery" of the African potato (*Hypoxis* genera) by medical science (Bouic, 1998), has received much media attention recently as a treatment for certain cancers and AIDS and has its centre of diversity in the East Coast grasslands of South Africa (Singh, 1999).
- Wetland clearing leading to a loss of functional values and services provided by wetlands (Kotze & Breen, 1994).
- The replacement of natural vegetation, especially when this is grassland or scrub, by crops or timber, can result in increased loss of water resources to downstream users through increased plant evapotranspiration requirements (Schmidt, *et al.*, 1998).
- A reduction in aesthetics and recreational utility of the landscape. Diversity of plant and animal life in the landscape is a source of enjoyment and recreation to many people.

2.1.2 Field layout, tillage, planting and harvesting

These processes share some major impacts in exposing soil to erosion processes and disturbing soil structure through tillage and/or compaction. In most crops, the soil is ploughed before planting of seed, or *setts* in the case of sugarcane. Although the area put under the plough is on the decrease due to minimum tillage techniques, some 90,5 percent of the area considered suitable for rain-fed crop production is still subjected to tillage of some type (Giliomee, 1992) which has the following effects:

- Regular ploughing changes the structure of the soil, largely due to the increased rate of decay of organic matter resulting in the loss of the soil's natural granular structure and consequently its inherent porosity leading to reduced productivity (Gilliam and Bubenzer, 1990).

- The soil's potential to support sustainable agriculture is reduced as nutrients have to be replenished by adding more fertilizers which in turn add to the cost of production as well as imposing their own threat to the environment as discussed later (Breland and Hansen, 1998).
- The change in structure, especially in conjunction with the weight of machinery used in field operations, leads to slower water infiltration, increased runoff and a higher risk of erosion - the most serious impact of cultivation (Breland and Hansen, 1998).
- Where vegetation is removed and soil turned over, the soil particles are exposed to the full force of moving water and wind, which dislodge them and sweep them away. It is estimated that South Africa is losing 300 million tons of soil into rivers and dams annually (Adler, 1985).
- Siltation of dams and reservoirs is another costly consequence of soil erosion, reducing their life span, capacity and in some cases power generation capability (Brown, 1999; and DWAF & Umgeni Water, 1996).
- The transported sediment has a potentially disastrous effect on aquatic systems through temporary or permanent covering of benthic organisms (Brown, 1999).

2.1.3 Pesticide application

The term "pesticides" encompasses herbicides, nematicides, bactericides, fungicides and insecticides. Modern agriculture, particularly monocultures, rely heavily on pesticide applications for the control of organisms such as nematodes, insects, fungi and bacteria that cause damage or disease to the crop and weeds, which compete with the crop for nutrients, water and possibly light. Their impacts are difficult to quantify, often accumulating slowly and insidiously in the food chain (Carson, 1962). The major concern is their toxicity to non-target organisms, including human beings. Most pesticides are insoluble in water, but are formulated in such a way that they form suspensions or emulsions in water. This facilitates their dispersal in groundwater and streams with the result that these toxic substances may be found far from where they were applied. Some specific impacts are:

- possible pesticide runoff contamination of surface or ground-water (Conrad *et al.*, 1999);
- contamination of public potable water supplies;
- contamination of surface water-bodies leading to stress on biota (Brown, 1999);
- methyl bromide, used as a soil fumigant, is an ozone depleting substance (EPA, 1999a); and
- when crops are sprayed with pesticides by aircraft or ground equipment, they are subject to wind drift and inhalation by animals.

2.1.4 Fertilizer application

In natural ecosystems, nutrients in plant and animal material are continually recycled and made available to plants in the soil. In agricultural systems, large quantities of biomass are harvested and removed from the system. This, together with the fact that many South African soils are inherently low in nutrients, necessitates the inputs of large quantities of fertilizers. This is usually done by way of inorganic fertilizers. During the 1980's some 100 000 tons of potassium, 200 000 tons of phosphoric and 400 000 tons of nitrogenous fertilizers were applied annually to South African soils (Scotney, 1995). Some consequences of widespread fertilisation are:

- Acidification of the soil leading to reduced productivity (Schroeder *et al.*, 1994).
- Inorganic nutrients, particularly nitrates are leached from the soil, contaminating groundwater and streams (EPA, 1999b). Secondary forms of nitrate, namely nitrite and nitroamines, can have serious health impacts on humans if water sources are contaminated (Terblanche, 1991).
- Increased nutrient load in runoff water stimulates organic growth, such as algae when the nutrient levels and productivity within a water body increase. This can result in the depletion of dissolved oxygen, placing stress on other natural communities (Brown, 1999).

2.1.5 Irrigation and rainfall interception

Water is a scarce and valuable resource in dry countries such as South Africa. Agriculture as a major user of water is under threat from industries competing for dwindling water supplies. It has been estimated that our current water resources will be fully exploited by the year 2020 (DWAF, 1996). Some of the major impacts of crop water use on the environment are:

- agriculture uses water that is lost to "downstream" users;
- irrigation can lower the water table;
- to allow sustained irrigation to take place, rivers are often dammed and so much water removed for agriculture that formerly perennial streams may stop flowing during drier periods, as witnessed in recent times in the Mpumalanga lowveld (pers. obs.); and
- water extraction can also lead to concentration of salts in effluent or drainage from industry, agriculture, urban and natural sources downstream, reducing the downstream water quality and affecting aquatic ecosystems.

2.1.6 Burning

The burning of crop residues is usually subject to stringent controls in developed countries and even banned in some places. The impacts on the environment will vary greatly depending on time and place, but generally the concerns are:

- the contribution of agricultural burning to photochemical smog particularly near built-up areas and the associated health impacts;
- health impacts related to the inhalation of particulate matter and other emissions;
- smut fallout or flyash - mainly a problem of urban nuisance;
- impaired visibility from smoke emission; and
- destruction of habitat - albeit temporary habitat - and damage to fauna.

2.2 SUSTAINABLE AGRICULTURE

It is clear that such monocultural practices can not ensure the long-term productivity of our resources for future generations. Efforts in most developed and many developing countries are now attempting to mitigate the negative effects of agriculture on the environment through policies and techniques termed *sustainable agriculture*.

"Sustainable agriculture" is a concept whose definition has varied a great deal. A thorough and workable definition is given in the 1990 USA "Farm Bill" - Sustainable agriculture means:

"an integrated system of plant and animal production practices having a site-specific application that will, over the long term: (a) satisfy human food and fibre needs, (b) maintain environmental quality and the natural resource base upon which the agricultural economy depends, (c) make the most efficient use of non-renewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls, (d) sustain the economic viability of farm operations, and (e) enhance the quality of life for farmers and society as a whole " (Quoted in Runge, 1996).

Perhaps a more appropriate definition is given by Smyth and Dumanski (1993) in the context of sustainable land management:
"Sustainable land management combines technologies, policies, and activities aimed at integrating socio-economic principles with environmental concerns, so as to simultaneously:

- *maintain and enhance production (productivity);*
- *reduce the level of production risk, and enhance soil capacity to buffer against degradation processes (stability/resilience);*
- *protect the potential of natural resources and prevent degradation of soil and water quality (protection);*
- *be economically viable (viability); and*
- *be socially acceptable, and assure access to the benefits from improved land management (acceptability/equity)."*

Any evaluation of the sustainability has to be based on these objectives: productivity, stability/resilience, protection, viability, and acceptability/equity (Smyth and Dumanski, 1993).

The South African Department of Agriculture (NDA, 1995) defines sustainable agriculture succinctly as:
"farming systems which are productive, economically viable and environmentally sound over time".

Sustainable agriculture as a recognised term is a recent phenomenon. Runge (1996) gives a detailed background to its history. It gained major impetus following the United

Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992.

Agenda 21, as adopted at the UNCED Summit meeting on 14 June 1992, is a comprehensive and massive document covering all the issues referred to the UNCED by the UN General Assembly in its Resolution 44/228 of 1989. Following two years of research, drafting and intensive negotiations at the four meetings of the UNCED Preparatory Committee, *Agenda 21* represents the current international consensus (it was signed by 179 heads of government) on actions necessary to move the world towards the goal of truly sustainable development.

The South African government has heeded principals espoused in Agenda 21 in the formulation of its new environmental policy:
"Central to the Reconstruction and Development Program (RDP) is the concept of achieving sustainable development...It is thus important to ensure that management of development conforms to recommended principles which have been outlined in Agenda 21"
(Foreword to the South African Environmental Policy Green Paper, 1996) (DEAT, 1996).

Although Agenda 21 does not itself impose binding legal commitments on governments, its adoption as part of the UNCED outcomes gives its recommendations the force of political commitment at the highest level. Agenda 21 is divided into four sections:
1. Social and Economic Dimensions - examining the underlying human factors and problems of development, along with the key issues of trade and integrated decision-making.
2. Conservation and Management of Resources for Development - the largest section of Agenda 21, presenting the range of resources, ecosystems and other issues, all of which must be addressed if sustainable development is to be achieved at global, national and local levels.
3. Strengthening the Role of Major Groups - looks at the social partnerships necessary if sustainable development is to become a reality. It recognises that Government and international agencies cannot alone achieve sustainable development and that the

community, through representative and industry organisations, must be a key player in the development of policy and in achieving the necessary changes.

4. Means of Implementation - The section examines resources which must be mobilised in support of sustainable futures. While finance and technology are key elements, this section also deals with aspects of education, institutional and legal structures, data and information and the building of national capacity in the relevant disciplines (Environment Australia Online, 1996).

Principles espoused in sections 2 and 4 have distinct requirements for geographic data and associated analysis tools. One of the major themes of the conference was that of *integrated* decision making which in the management of natural resources requires access to an *integrated spatial* database. Section 2, Chapter 10, on Land Resources, emphasises the need for land capability inventories to attempt to match agricultural production systems to natural resource capacity and an integrated approach to watershed and ecosystem management. The development, collection and analysis of spatial data and environmental monitoring and assessment systems are also stressed as being of vital importance to sustainability management.

Whilst Agenda 21 may appear to aimed at a national level, Section IV (chapter 28, in particular), emphasises the role that land use stakeholders (such as sugar growers) and scientific institutions must play in implementing Agenda 21 locally. This sentiment is echoed in the Green Paper on Environmental Policy (DEAT, 1996) and the White Paper on a National Water Policy for South Africa (DWAF, 1997).

Chapter 4 of the Green Paper on Environmental Policy proposes a series of objectives for national environmental policy and addresses the major issues facing environmental management and the sustainable use of resources. Some extracts from this chapter follow:

Objective 44 Local control

To introduce increased local participation in the control of resources and to ensure that programmes are geographically and ecologically specific.

<u>*Objective 46 Planning*</u>

To introduce an integrated approach to the planning and management of land and natural resources.

To develop a land use planning system that takes account of specific ecosystems, and to develop and make available to all a land information system in the interests of sustainable land use.

<u>*Objective 47 Land utilisation*</u>

To ensure that a proper and fully integrated land management system is developed. This must facilitate the allocation of land to uses that provide the greatest sustainable benefit to the greatest number of people.

<u>*Objective 19 Information management*</u>

(The collection and analysis of information and its dissemination in an accessible form is essential for effective, participatory environmental management.)
To strengthen and optimise the capacity of government and civil society to collect, analyse and use multi-sectoral environmental data, information, knowledge and perceptions in decision making and public participation processes.

To ensure open disclosure, accessibility and effective dissemination of environmental data and information.

<u>*Objective 20 Research and development*</u>

To support and facilitate relevant research and development into environmental sustainability, resource management and environmental policy in line with national priorities and needs.

The perceived need for spatial information is clear in a number of the above statements and it is evident that land use stakeholders will need to have the capacity to provide and utilise such information in the management of the resources under their stewardship.

In order to assess whether a production system is sustainable, one needs to examine the status of "environmental indicators" over time.

2.3 ENVIRONMENTAL INDICATORS

Indicators are descriptors that represent a condition and convey information on changes or trends in that condition (CIESIN, 1998) and as such are simplified indications of a more complex reality (Herweg, Steiner and Slaats, 1999). Indicators are in common use for economic and social data, for example, indicators such as income per capita, life expectancy and infant mortality give an indication of social well-being. In the context of sustainable agriculture, they are used in monitoring and evaluation programs to estimate impacts of farming activities and the resulting state of the environment, *i.e.* is it moving towards or away from sustainability (Dumanski, 1997)? A basic problem is that there is as yet no internationally accepted system of indicators for environmentally sustainable development (Herweg, Steiner and Slaats, 1999) and this applies equally to sustainable agriculture in the local context. The Centre for Earth Science Information Network (CIESIN) makes the following general points regarding the choice of indicators:

- indicator programs need to be carefully structured, practical and scientifically sound;
- decision makers at different levels (farm, regional, national, international) may require different kinds of indicators depending on the nature and level of decisions; and
- the probability of greater relevance, utility and application of indicators increases if decision makers and other stakeholders are involved in the choice of indicators and the development of monitoring systems.

Therefore, development of suitable indicators[1] for monocultures is a complex process, involving a sound understanding of processes and systems involved and thorough consultation with all stakeholders.

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[1] Sustainability indicators should ideally cover not only natural resource impacts, but also economic and social impacts at scales ranging from household to region or even country. Only the natural environment is considered in this document however.

It is thus difficult to speculate as to what such an indicator set for the local Sugar Industry, may be. However, the issue may be approached from the point of view of:

a) what the core issues are; and

b) what needs to be monitored,

in order to make some assumptions regarding the possible future choice of indicators.

Obviously the issues must be practically measurable within time and budget limits. Given the environmental impact core issues of monocultures and the need to strive towards sustainable production systems, some possible sustainability indicators applicable to the Sugar Industry based on a broad categorisation of *initial* impact site of soil, water, air and habitat are listed in Table 2.1. The indicator set must also reflect the "downstream" or off-site impact of farming activities. Off-site indicators may be used as "surrogate" values to measure in-field processes (Hamblin, 1996). This may be done where it is more feasible to extrapolate values than to measure in the field - for example, sediment loads in streams may be a suitable measure of in-field soil-loss.

Resource	Environmental Impact	Measure rate from
Soil	Salinity/Sodicity	Soil tests Visual appraisal
	Acidification	Soil tests
	Loss of fertility	Organic matter content Nutrient balance
	Compaction	Penetrometer tests
	Soil Erosion	Profile depth tests Stream sediment load Aerial photography (extent of erosion)
Water	Water use	Pump flows Streamflow reduction Water table height
	Water quality	Runoff tests for pesticides, fertilizers, nutrients & salinity
Air	Burning pollution	SO2 Monitors Public complaints
Biodiversity/ Habitat	Loss of wetlands	Time-series - Aerial photography or Satellite imagery
	Habitat fragmentation	Shape indices Habitat fragmentation index
	Loss of specific habitats	Time-series - Aerial photography or Satellite imagery Computer models
	Reduction in species	Surveys

Table 2.1. A speculative sample of environmental indicators applicable to sugarcane monoculture.

It could be argued that measuring surrogate values such as sediment loading in streams is not sufficiently accurate to determine on-site soil loss. In such cases, it would be vital to have detailed spatial information in order to support the validity of using such an indicator. In this case, for example, one would probably need to know the size of the catchment, land-use and the distribution of soil erodibility classes within the catchment in order to make a decision. Differing indicators or different measuring techniques may thus need to be applied in different regions or catchments.

Indicators may be further classified into a pressure-state-response framework (Hamblin, 1998). The classification is developed by initially identifying current conditions (states). A series of pressures that produced these biophysical conditions can then be identified. These changes in biophysical states stimulate biophysical and socio-economic responses. These responses may occur concurrently, as shown in Table 2.2, or sequentially, with each response acting as a pressure producing the next response. This method has the advantage of viewing indicators as part of a system, and monitoring cause, current condition and response to gain a more thorough understanding of the problem.

Land Problem	Indictors of ...		
	Pressure	State	Response
Soil erosion: water erosion on arable land, particularly steep land	• extent of cultivation of sloping land without adequate conservation measures	• rates of erosion (t/ha/year), obtained by field measurement or modelling • loss of topsoil, soil organic matter and nutrients; truncated soil profiles • extent and severity of visible signs of erosion, e.g. thin or rocky soils, soil slips, gullies, areas of abandoned land	• extent of adoption of soil conservation practices, by area or farm • number of farmer associations / local environment committees active in conservation • abandonment of land formerly cultivated

Table 2.2. Example of categorising indicators according to land problems and the pressure-state-response framework (after Pieri *et al.*, 1995).

A substantial volume of information on environmental indicators applicable to sugarcane agriculture is available within the Australian State of the Environment Report available on the Internet at <http://www.environment.gov.au/index.html>. Of particular significance in this report is the sub-report on Land Environmental Indicators which makes extensive reference to the use of GIS as a tool for environmental monitoring (Hamblin, 1998).

2.4 SUSTAINABLE AGRICULTURE: A SPATIAL PERSPECTIVE

A sound spatial information framework is essential, not only for establishing relevant usage of indicators, but also in the measuring and subsequent analysis thereof in many cases:

- Using satellite imagery in geographic information systems is a well-established technique for monitoring change in habitat (Crist, 1997). A wetland monitoring program at a broad scale has been commenced in South Africa (Dini, 1999).
- Catchment analysis to monitor farm pollution has been well supported by GIS for a number of years (Olivieri *et al.*, 1991).
- On-site measurements can be aggregated and displayed in map form to highlight trends. Indicator values for various aspects may be aggregated by a weighted average to arrive at an assessment of their cumulative rating with regard to sustainability (Herweg, Steiner and Slaats, 1999). This aggregation can be carried out spatially and displayed in map form for ease of interpretation.

Environmental indicators provide a crucial measure by which the environmental performance of an industry can be measured. The fact that these indicators are applied at widely differing spatial and temporal scales make GIS a vital tool in assisting in their measurement, aggregation, analysis, archiving and display. The South African Sugar Industry has not yet produced such indicators for its proposed Environmental Management Plans (EMPs). The spatial context in which many of these indicators must be monitored and addressed will be an important consideration for the Industry when formulating EMPs.

Chapter 3
SUGARCANE PRODUCTION: AN OVERVIEW OF ENVIRONMENTAL ISSUES

"Environmental problems are nearly always spatial in nature."
(Fedra, 1994)

3.1 SUGARCANE ENVIRONMENTAL ISSUES: THE INTERNATIONAL SCENE

From a review of available literature, it appears as though sugarcane has not yet attracted the level of environmental pressure that has been applied to timber industries internationally. Of the major world sugarcane producers, most of the scientific literature deals with environmental work in Australia (mostly Queensland) and the USA (particularly Florida). In these industries the combination of environmental and market pressures together with the availability of suitable technology and expertise have resulted in some innovative and effective GIS-assisted methods of achieving environmental standards.

3.1.1 Australia

The Australian Canegrowers' Association called for public tenders to conduct an Environmental Audit of their industry in 1995. An environmental consultancy was then commissioned to conduct an environmental audit of the Queensland sugarcane farms which produce 95% of Australia's sugarcane crop (Gutteridge, Haskins & Davey, 1996). The report was published in August of 1996 and appears to be the only work of this type and scale yet undertaken in a sugar industry. The project entailed 180 stakeholder interviews and 130 carefully selected farm audits along the Queensland coast. The audit essentially involved a risk assessment in three key areas: a pollution and waste audit, an environmental management and compliance audit, and an ecological and social impact audit. The focuses within each of these were to identify the following:

- pollution sources and potential problem areas;

- environmental management issues and the status of compliance with environmental standards; and
- activities that have the most significant ecological and social impact.

The selection procedure for the farms to be audited involved a GIS analysis of soil type, geography and adjacency to any sensitive or protected areas. This emphasises the need to have an industry geographic database in place to enable the efficient planning of such operations.

The majority of those selected to be interviewed thought that the current environmental management practices of cane growing needed improvement. The environmental issues rated of highest concern amongst the various sectors interviewed were the impacts of cane growing on:

- riparian zones;
- indigenous flora and fauna;
- the aquatic environment;
- soils and soil erosion; and
- oceanic life – the Great Barrier Reef.

Amongst conservation groups interviewed, the greatest degree of negativity against the cane farming industry was with regard to water issues; in particular, the effect on river water quality and flows. The need for greater use of Integrated Catchment Management (ICM) techniques was thus seen to be a critical outcome. Other important outcomes with a particular spatial connotation include the perceived need for:

- increased environment monitoring;
- improved land and water management – including irrigation strategies;
- increased protection of indigenous flora and fauna; and
- the adoption of ecologically sustainable farming techniques.

These are strikingly similar sugarcane issues to those being faced at present in South Africa, although not formalised in any auditing operation locally.

A joint research initiative, known as Co-operative Research Centre for Sustainable Sugar Production (CRC) was established in 1995 to respond to the perceived negative environmental impact of sugarcane agriculture by the public. Its initial focus is on the agronomic aspects of the industry, sustainability issues, protection of the environment through minimisation of exports of nutrients, pesticides and sediments into the river systems and enhancing long-term productivity. Key research objectives which have a particular spatial dimension and which will be assisted by their establishment of an industry GIS are the (CRC, 1997):

- assessment of current environmental scenarios and budgets for inputs to and losses from sugarcane production systems at farm and catchment scales;
- development and promotion of production practices consistent with environmental protection and integrated catchment management principles;
- use of computer-based inventories of soil, water and climatic resources to aid industry planning and extrapolation of research results;
- development and promotion of soil conservation practices based on conservation of crop residues; and
- better management of water and nutrient supply to match sugarcane needs and avoid losses to the environment.

One of the most significant aspects of this organisation is its commitment to technology transfer, *i.e.* making its findings and recommendations accessible and understandable to growers. In response to environmental pressure cane burning has been dramatically reduced, particularly in the far north of Queensland where 90 percent of cane is now harvested green (Sugden, 1999). Integrated catchment management is well advanced in certain catchments where sugarcane producers are major land users. Walker and Johnson (1996) describe the establishment of a decision support system in the Herbert Catchment wherein GIS plays a major role.

3.1.2 USA

Only half the sugar grown in the USA is from sugarcane – the remainder is from sugarbeet. Just over half the sugar cane grown in the USA comes from Florida, with the remainder from Louisiana, Hawaii and Texas (Gutteridge, Haskins & Davey, 1996).

The Florida sugarcane growing region is concentrated near the south and eastern shores of Lake Okeechobee. Most of the severe environmental pressures in this region stem from concerns relating to the gradual deterioration of the unique Everglades system and nutrient runoff into Lake Okeechobee (Negahban *et al.*, 1995).

Government policies that once favoured development are now being reversed by policies and regulatory efforts to restore natural ecosystems. The Florida Sugar Industry is adjusting to more stringent environmental standards and policies (Anderson and Rosendahl, 1996). Florida government has responded to these environmental concerns with the initiation of numerous projects aimed at developing control practices to reduce the level of phosphorus (P) in agricultural runoff as part of the Lake Okeechobee SWIM (Surface Water Improvement and Management) plan. A need arose during this work for a comprehensive planning tool that could integrate results for the various classes of P control practices. The Lake Okeechobee Agricultural Decision Support System (LOADSS), a GIS-based decision support system, was developed to assist regional planners in decision making by generating reports and maps on regional land attributes, integrating external hydrological simulation models and by displaying water quality and quantity monitoring station data.

Agriculturists in the Everglades Agricultural Area are required by law to implement comprehensive best management practices (BMP) to reduce P loads. Landowners are required to develop water and nutrient management plans whilst farm managers and technical staff are required to undertake certification programs for the implementation of BMPs. Florida also has strict legislation controlling the intentional burning of sugarcane and permits are required before any burn may be implemented. In order to manage the largest regulated burning program in the USA, and probably the world, a sophisticated GIS-based fire management system has been established (Brenner *et al.*, 1997), discussed further in section 8.4.1.

3.1.3 Other Countries

Similar environmental issues are faced by other cane growing countries, with differing emphases in different situations. Brazil, Colombia and India are encouraging a move to green harvesting (Sugden, 1999); Fiji has major concerns regarding soil deterioration with continuous cane cropping, and Mauritius is concerned with the impacts of sugarcane production on water quality and supply (Ng Kee Kwong, Umrit and Mhr, 1996).

The general trends are:

- soil conservation with minimum tillage as a priority;
- concerns with water usage;
- concerns with degradation and pollution of water bodies and wetlands;
- pressures to reduce cane burning and move toward trashing or green harvesting;
- concerns with reduced soil fertility from continuous sugarcane production;
- the reduction of and more accurate application of fertilizer and pesticides; and
- initiatives to increase or at least prevent further losses of biodiversity (after Hay and McKenzie, 1999).

3.2 SUGARCANE ENVIRONMENTAL ISSUES: THE LOCAL SITUATION

3.2.1 Water use and quality: environmental issues

3.2.1.1 Introduction

Probably the most pressing environmental issues facing the SA sugar growing industry at present are those pertaining to the effect of sugar cane growing on water resources. Being a water scarce country it has been estimated that our current water resources will be fully exploited during the next 50 years (Rowlinson *et al.*, 1999). The pending changes to South Africa's water law will address these issues as well as redressing water allocations, which were skewed during apartheid years. Sugarcane agriculture in this country has thus far escaped the governmental pressures to which the timber industry is subject. The new water policy proposals will change this scenario however, and the sugar growing industry will need to urgently implement new water management standards and associated resource management structures and information systems to address these issues.

3.2.1.2 Irrigated sugarcane

Of the 412 000 hectares of land under sugarcane, 21% is estimated to be irrigated (Schmidt, 1997). In the northern parts of the industry, irrigation is a prerequisite for growing sugarcane, whereas in the KwaZulu-Natal midlands and coastal areas irrigation is generally supplementary to rainfall in order to maximise production and mill throughput in dry years. Irrigation water requirements range from 500 millimetres per annum in the south to up to 1200 millimetres per annum in the north (Lynsky, Schmidt and Sugden, 1997).

River Catchment	Catchment Area (ha)	Sugarcane Irrigation (ha)*	Irrigation % Mean Annual Runoff
Amatikulu	95346	7406	17
Fafa	26101	160	2
Hluhluwe	90997	1513	30
Komati	970229	12389	17
Krokodil	1043818	12491	15
Lomati	147800	6107	30
Lovu	94424	66	<1
Mdloti & Ohlanga	59638	1801	8
Mgeni	443553	857	<1
Mhlali	29000	308	2
Mhlatuzi	387435	11690	16
Mkomazi	438515	285	<1
Mkuzi	480138	2017	9
Mlazi	96889	1269	6
Mpambanyoni	55458	9	<1
Mtwalume	55201	367	3
Mvoti	273444	2700	3
Mzinene	72789	331	13
Nonoti	29746	110	<1
Nyalazi	64718	450	99
Pongola	608525	14592	27
Tongati	42186	2119	11
Tugela	2904600	1127	<1
Umfolosi	999933	4231	4
Umlalazi	49792	1330	4
Umzunduzi	117600	565	16
Umzumbe	54081	0	<1
Total	10 556 021	86 080**	

* based on a broad apportionment of cane into catchments

** excludes some 1200 ha in other minor catchments

Table 3.1. The spatial extent and impact of sugarcane irrigation on mean annual runoff (Lynsky, Schmidt and Sugden, 1997).

GIS was used in the production of Table 3.1 to calculate the proportion of cane area which falls into each catchment and represent this spatially (see section 8.2.2.1). To assess the impact of irrigation more precisely, more accurate details need to be obtained regarding cane area, irrigation applied per unit area and finer detail regarding available water resources within the catchment.

3.2.1.3 Rainfed sugarcane - impact on stream flow

Of the 412 000 hectares of cane in SA, about 68 percent is grown within 30 km of the coast, which has a mean annual rainfall averaging 1000 millimetres. Being thus situated it could be considered to have less of an impact in reducing stream flow than if it were in the headwater of catchments (Schmidt, 1997).

Some workers consider sugarcane to have nearly as severe an effect on reducing runoff as afforestation (Midgley, Pitman and Middleton, 1994). More recent research indicates that contribution to streamflow from sugarcane is well above that of timber, particularly on shallower soils where runoff levels approached those of grassland (Smithers and Schulze, 1996). During periods of low flows however, the contribution of sugarcane to runoff was approximately between that of timber and natural grassland (Schmidt, Smithers, Schulze and Mathews, 1998).

Research that takes into account local soils, climate, topography and management practices and incorporates hydrological models is needed to more reliably evaluate the impact of sugarcane on streamflow (Lynsky, Schmidt and Sugden, 1997).

3.2.1.4 Water quality

Little research has been done on quantifying the impact of sugarcane agriculture on water quality in South Africa. Some of the possible impacts on water quality to be expected from local sugarcane agriculture are:

- increased turbidity through increased sediment load caused by water borne soil erosion;
- enrichment of streams and rivers through leaching of fertilizer chemicals;
- transport of agricultural chemicals leached from the soil; and
- increased salinity in irrigated areas.

Preliminary work by Meyer and van Antwerpen (1995) examined the influence of sugarcane production water quality in selected rivers in the SA Sugar Industry. They found little evidence of excessive wash-off of nutrients or minerals from the catchments, although levels of potassium and acidity were elevated during the drought years between 1991 and 1994. The peak concentrations of these nutrients were within accepted world standards for drinking water.

A survey of water quality for twelve selected rivers in the SA Sugar Industry was undertaken by DWAF between 1983 and 1993. The survey revealed that salinity levels in the lower Crocodile River have more than doubled since the last assessment was made in 1976 (quoted in Cave, Klapwijk and Associates, 1997).

Researchers in Mauritius addressed concerns and pressures regarding the effect of nitrate and herbicide residues from sugarcane production on their surface and groundwater resources. Monitoring and analysis revealed however, that concentrations of these residues were well within internationally accepted standards (Ng Kee Kwong, Umrit and Mhr, 1996). In the local situation, Cave, Klapwijk and Associates (1997) echo this view, although both papers indicate the *possibility* of contamination occurring in certain instances and emphasise the need for sound management practises regarding fertlizers and herbicides.

3.2.2 Soil erosion and soil degradation: environmental issues

3.2.2.1 Introduction

The State of the Environment - South Africa (DEAT, 1999) report notes the following impacts of monocultures on the soil resource based on work by various researchers:

- crusting - reported to be serious and widespread in irrigated areas;
- salinisation / water logging - estimated to be between 10 and 15 percent of irrigated areas;
- acidification - 40 percent of summer rainfall cropped areas; and
- erosion - 300 million tons per annum lost into rivers and associated fertility loss due to loss of nutrients in this soil.

These issues are all prevalent in the sugarcane industry and although much relevant work has been done by various researchers in the Industry, their spatial extents have not been determined.

3.2.2.2 Soil Erosion

Fuggle and Rabie (1992) consider soil erosion to be possibly the greatest environmental threat facing South Africa. Rooseboom (1975) estimates South African sediment loss carried away by rivers to be between 100 and 150 million tons annually. DWA (1986) reports this figure to be 120 million tons, whilst Adler (1985) reports the figure to be 300 million tons per annum.

Maher (1996) estimates soil losses from KwaZulu-Natal agriculture to be in the region of 100 million tons per annum. Estimated average annual soil loss per hectare in South Africa is 2.5 tons per hectare which is well within accepted soil loss standards in the SA Sugar Industry (Platford, 1979). Given that the approximate area of cane in Kwa-Zulu Natal is approximately 383 000 hectares (calculated from Lynsky, Schmidt & Sugden, 1997), a simple calculation of 383 000 hectares at 2.5 tons per hectare per year, results in the Sugar Industry contributing 95 percent of the provinces soil loss! A simple observation of some of the severely degraded communal grazing lands in the province would reveal this to be an unlikely statistic, but emphasises the need to more accurately quantify and classify the extent of such degradation. Given that Scotney (1995) deduced that less than 10 percent of the country comprises high potential land and that soil formation is only in the order of 0.31 tons per hectare per year (van der Merwe and de Villiers, 1997), the situation is clearly unsustainable.

It is worth noting that researchers in Australia measured losses ranging between 47 and 505 tons per hectare per year in sloping, conventionally tilled lands in north-eastern Queensland, with an average annual loss of 148 tons per hectare per year (Prove, Doogan and Truong, 1995). No-tillage practices reduced these losses to less than 15 tons per hectare per year.

Platford (1979) commenced a program of monitoring a set of 7 Universal Soil Loss Equation (USLE) runoff plots and four small catchments in order to attempt to quantify soil and runoff losses resulting from various field management practices. Reporting on this work of Platford (1979) and of Maher (1990), Schmidt *et al.* (1998) noted that:

- soil losses of up to 30 t/ha per simulated storm event on bare fallow runoff plots were recorded;
- plot soil losses under sugarcane cover ranged from 21 t/ha/annum on one site to less than 2 t/ha/annum on three of the five plots;
- soil losses of up to 72 t/ha/annum were recorded on a bare fallow small catchment;
- catchments' soil loss declined markedly with cane establishment;
- soil type and slope have a marked impact on runoff during bare fallow conditions;
- soil loss is affected mainly by crop cover and management practices which reduce the power of falling raindrops;
- strip cropping, minimum tillage and retention of trash play a vital role in reducing soil loss;
- 85 – 90 percent of soil loss occurs during replanting; and
- conservation structures are most important during this replanting phase.

The results from these catchment and plot experiments were used by Platford (1985) to develop standards for the design of field conservation measures.

The research clearly demonstrated that the combination of tilled bare fallow conditions coinciding with heavy rainfall are the major cause of soil erosion in the Sugar Industry and that losses well in excess of acceptable norms could be expected under these conditions (Schmidt *et al.*, 1998). As with the national situation, the spatial extent and severity are considered largely unknown (Cave, Klapwijk & Associates, 1997). Ferrer and Nieuwoudt (1998) found that although many farms had soil conservation plans prepared by SASEX, the implementation rate of these plans was often poor – particularly in certain areas.

3.2.2.3 Salinity and Waterlogging

Salinity and waterlogging occur as a result of poor irrigation practices and/or inherent soil properties which predispose them to this form of degradation (Meyer and Wood, 1990; and Meyer, van Antwerpen and Meyer, 1996). It is considered to be a serious problem in irrigated areas in the Sugar Industry, seriously reducing productivity and sustainability.

3.2.2.4 Soil compaction and crusting

Soil compaction and crusting appears to occur mainly on the red, apedal, loamy and clayey soils of the Hutton form and is a result of inherent soil properties and infield traffic - particularly during wet conditions (Meyer *et al.*, 1990). The full spatial extent in the industry of this phenomenon again is unknown. Crusting is also reported on by Meyer, van Antwerpen and Meyer (1996), and is thought to result from soil properties, drop impact and irrigation water quality. The problem may be temporary, occurring after harvest and before full canopy. Both issues impact negatively on productivity, sustainability and can contribute to soil erosion. Although considered to occur widely in the industry, little work has been done on its spatial dimension.

3.2.2.5 Soil Acidification

Since the early 1980s there has been a general increase in acidification of soils in the Sugar Industry with the proportion of soil samples analysed by SASEX below pH 5.0 increasing from 18 to 43 percent (Schumann, 1998). This is a major concern, since low pH leads to aluminium toxicity which stunts roots and impairs water uptake, as well as causing various other mineral toxicities and deficiencies in the soil. Causes of acidification are:

- excessive nitrogenous fertilization;
- nutrient reduction by removal of crop; and
- acid rain.

SASEX soil samples indicate that the most acid soils occur in the Midlands and South Coast areas (Schumann, 1998). Work by Schroeder, Robinson, Wallace and Turner (1994) explored the spatial dimension of acidification on an estate scale. The ability to link soil sample databases to mapped farm at field level will provide a valuable dimension to further research. Further work in this arena is currently in progress at SASEX as a pilot project (pers. obs.).

3.2.3 Habitat and biodiversity: environmental issues

"The coast district, before it was cleared for the sugar and coffee plantations, was one vast mass of trees and flowering shrubs, mostly with evergreen vegetation, opening out here and there into park-like glades, which were carpeted with luxuriant grass and flowers. In many parts of the coast this beautiful and teeming vegetation is still preserved" (Brooks, 1876, writing about the KwaZulu-Natal coast).

Since habitat loss is considered the primary threat to terrestrial biodiversity (World Bank, 1999), the issues of loss of habitat and diversity may be dealt with as one issue. Biodiversity refers to the total diversity of living organisms and encompasses genetic diversity within species, diversity among species and diversity of assemblages of species into ecosystems (World Bank, 1999). The primary causes of habitat loss in land based ecosystems is the conversion to monoculture agriculture or forestry. Where the remaining natural habitat is insufficient in size, or too fragmented to support its previous ecological functions, effective losses often extend beyond the area of converted land.

South Africa has the third highest level of biological diversity in the world due to its broad range of climatic, geological, soil and landscape forms. Because of the complexity of terrestrial ecosystems, research has only been able to cover a few aspects and the far-reaching impacts of monoculture are not yet fully grasped (DEAT, 1999).

Currently there are 62 South African plant taxa that have become globally extinct, of which ten can be attributed to clearing for crops, and many more are threatened (DEAT, 1999). In fact South Africa has the highest concentration of threatened plant groups in the world (Cowling & Hilton-Taylor, 1994). Although particular "hotspots" of plant diversity occur in the Succulent Karoo and the Fynbos biomes, both KwaZulu-Natal and Mpumalanga rank highly in terms of species richness per province in South Africa as shown in Table 3.2.

Province	Biomes	Plant	Mammal	Bird	Amphibian	Reptile
Eastern Cape	7	6164	156	384	51	57
Free State	3	2984	93	334	29	47
Gauteng	2	3303	125	326	25	53
KwaZulu-Natal	4	6141	177	462	68	86
Mpumalanga	3	4782	160	464	48	82
North-West	2	3025	138	384	27	59
Northern Cape	6	5067	139	302	29	53
Northern Province	3	4236	239	479	44	89
Western Cape	6	8925	153	305	39	52

Table 3.2. Species richness per province of South Africa (DEAT, 1999).

Sugarcane plantations have replaced some 412 000 hectares of vegetation, mostly falling within the Savanna biome (Rutherford and Westfall, 1994). More specifically, Bredenkamp, Granger and van Rooyen, (1996) note that the following vegetation types (Low and Rebelo, 1996) have been specifically impacted on by sugarcane production:

- Coastal Bushveld-Grassland, the plains of which are high in endemic plant species;
- Coast-Hinterland Bushveld;
- Natal Lowveld Bushveld;
- Sweet Lowveld Bushveld; and
- Mixed Lowveld Bushveld.

The spatial extent of eradication of these vegetation types by sugarcane is not recorded, but simple spatial analysis in GIS can determine the proportion of total cane falling into each vegetation class. In Figure 3.1, the SASEX cane area dataset was intersected by the vegetation types according to Low and Rebelo's (1996) map. The result revealed that a substantial portion of cane fell into the following vegetation classes in addition to those mentioned by Bredenkamp, Granger and van Rooyen, (1996):

- Short Mistbelt Grassland; and
- Valley Thicket, which contains a high number of endemics and high species diversity.

With the exception of the Lowveld vegetation types these are all considered poorly conserved by Bredenkamp, Granger and van Rooyen, (1996).

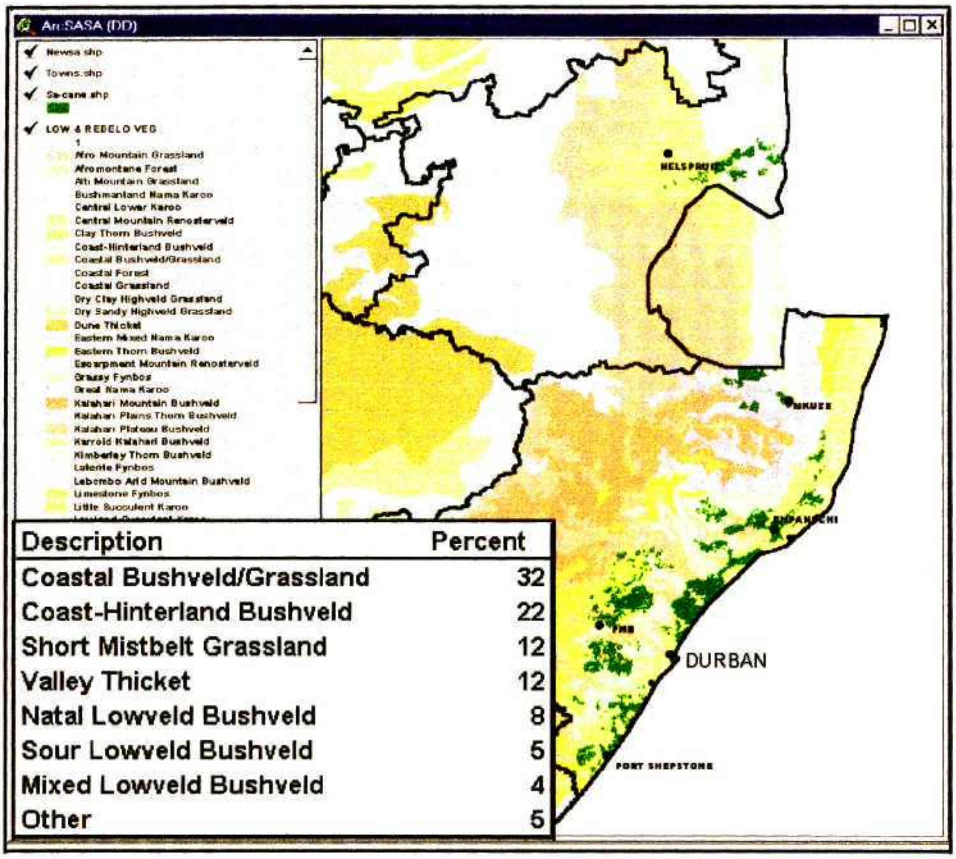

Figure 3.1. GIS analysis of Low and Rebelo (1996) vegetation types in which sugarcane is produced. The inset table shows the proportion of the 412 000 hectares of cane which occurs in the particular vegetation type.

McCracken (1996) contends that it would be a fallacy to assume sugar farming alone was responsible for the obliteration of the local indigenous flora. He describes the gradual colonial expansion from the 1880s and the various crops, such as tea, coffee, arrowroot, cotton, tobacco, cinchona and even rubber which were tried with varying degrees of success in the region. Prior to that, he considers the Nguni slash-and-burn agriculture during pre-colonial times to have had a marked impact on the natural vegetation. He does however, state that the more recent eradication of much watercourse vegetation was at the hands of sugar farmers.

Maddock (1999, pers. comm.)[1] studied animal populations in sugarcane, and although a number of invertebrates, small mammals and reptiles and frogs were found it was not

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[1] Maddock, A. Zoologist, formerly of KZNNCS, Cape Town.

ascertained whether these animals were resident, moving through or in a source or sink population. He considers it clear however, that in sugarcane, as with any monoculture, essential ecosystem function and diversity is lost. Areas presently under cane, were previously covered by several different vegetation types, all undergoing different stages of succession and impacts such as droughts, fires and floods. The consequence of these changes to a monoculture is a major change to the essential functioning of the area. Maddock (1999, pers. comm.) contends that mitigation should be through considered spatial planning of more frequent and abundant strips of natural vegetation within the cane estate, including. riparian, woodland, forest, grassland, and vlei vegetation.

As is the case globally, wetlands (discussed further in the next section) in South Africa provide habitat for a wide range of plant and animal species, many of which are threatened (Kotze and Breen, 1994). The impacts of wetland habitat eradication may be far removed from the site. For example, even though the serval (*Felis leptialis serval*) ranges widely across landscapes, the small mammals which are concentrated in wetlands provide an important food source (Kotze and Breen, 1994). It is suggested that the primary factors in the landscape mosaic influencing biotic diversity are:

- total habitat area;
- size-frequency and quality of habitat patches; and
- the distribution of these patches in relation to each other and to drainage patterns in the landscape (Harris, 1984, quoted in Kotze and Breen, 1994).

The importance of the spatial dimension involved in the study of biodiversity is clearly evident.

3.2.4 Wetlands: environmental issues

3.2.4.1 Sugarcane impacts on wetlands

Many of the adverse impacts of agricultural activities on biodiversity manifest themselves most strongly in wetlands. In terms of the Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention) wetlands are:

"areas of marsh, fen, peatland or water, whether natural or artificial permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water the depth of which does not exceed six metres".

Therefore wetlands include riverine, lake, marsh, estuarine, and marine systems (DEAT, 1997).

Kotze and Breen (1994) cite common functional values of wetlands including:

- water purification through removal of sediment, excess nutrients and toxicants;
- erosion control through trapping, binding and stabilizing sediment;
- dissipating wave & current energy with the ability to recover quickly from flood damage; and
- ecological value through provision of habitat for wetland dependent flora and fauna.

Wetlands also have resource value in terms of opportunities for tourism, recreation (*e.g.*, bird-watching), education, reed harvesting and water purification.

Sugarcane impacts on wetlands may take one or more the following forms:

- complete or partial loss of wetland through drainage and replacement of natural vegetation for the production of cane[1];
- damming of wetlands;
- pollution from agrochemicals;
- over-extraction of water; and
- decrease in regional biodiversity with a corresponding
- increase in invasive species.

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[1] The forestry industry advocates moving forestry areas out of historical wetlands whilst the Sugar Industry contends that legally planted wetland areas can continue to be cultivated under sugar provided that artificial drains are maintained by hand and not with machinery (Kotze, 1999, pers. comm.).

Although there is little documented information regarding to the extent of wetland loss throughout South Africa, Kotze *et al.*, (1995) hypothesized that more than 50 percent of natural wetlands in KwaZulu-Natal have been lost. Isolated examples with particular relevance to sugarcane growing can be quoted:

- the Mfolozi Swamp, forming the largest fluvial plain in South Africa, by 1988 has been reduced through agricultural development to 43 percent of its previous extent; and
- in the Siyaya catchment in northern KwaZulu-Natal, 93 percent of the wetlands had been lost by 1966 (Begg, 1986).

Although both of these are in extensive sugarcane regions, Begg (1988) did not quantify the particular land-use (e.g. sugarcane) causing the losses (Kotze, 1999, pers. comm.)[1].

Based on his observations, Kotze (1999, pers. comm.)[1] contends that in lower altitude (warmer) sugar areas, the destruction of wetlands through artificial drainage and cultivation of sugar has been particularly high. Extensive areas of the Mfolozi Swamps, for example, have been converted to sugar. At higher altitude areas, such destruction of wetlands has been less, possibly owing in part to the fact that at these higher altitudes there is a greater incidence of frost and wetlands are mainly found in valley bottom areas where frost tends to be most severe. He suggest that at both high and low altitudes sugar would have also indirectly impacted on wetlands through altering water quality, quantity and timing, particularly where sugar is irrigated.

3.2.4.2 Sugarcane impacts on estuaries

A review of the syntheses for each lagoon in KwaZulu-Natal in Begg (1978) and Begg (1984) indicates the devastating effect that sugarcane agriculture has had on many estuarine systems in the past. Impacts of sugarcane agriculture quoted in these works include:

- catchment degradation, resulting in altered flow regimes;
- sugarcane encroachment on estuary banks;

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[1] Kotze, D. Wetlands Specialist, University of Natal, Pietermaritzburg.

- siltation and the resulting reed encroachment;
- pollution from agricultural chemicals; and
- organic enrichment where mill effluent water (dunder water) is used for irrigation.

Hay (1999, pers. comm.)[1] considers much of the damage to have been done prior to the advent of chemical minimum tillage in the late 1980s. Conservation efforts by farmers can lead to substantial improvement in the state of the catchment and a resulting improvemnt in estuarine ecology. Two examples of such efforts are the Siyaya (pers. obs.) and Zinkwasi (Hay, 1999, pers. comm.)[1]estuaries.

An initiative is under way to conduct an inventory to map all wetlands (from aerial photography) at 1:50 000 scale with a minimum mapping unit of 0.25 hectares. A database coupled to a Geographical Information System will be used to store and manipulate the data generated by the inventory. The database will be maintained by the DEAT, and most of its contents will be available to anyone requiring inventory information (South African Wetlands Conservation Programme, 1999). This should provide a sound basis for the Sugar Industry to determine which wetlands are impacted by its activities and/or fall under its stewardship. This could serve as baseline data for monitoring and assessment activities in the future.

3.2.5 Air pollution issues

3.2.5.1 Reasons for burning sugarcane

Burning of sugarcane before and after harvesting is common throughout the world. In the last 10 years the practice has being questioned and opposed by communities surrounding cane-growing areas because of its environmental and health consequences. Cane burning has increased from 63 percent of cane harvested to about 90 percent over the last twenty years for the following reasons (Meyer, 1997, pers. comm.)[2]:

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[1] Hay, D. Environmentalist, Institute of Natural Resources, Pietermaritzburg.

[2] Meyer, E. Mechanisation Specialist, SASEX.

- Productivity - between 98 and 99 percent of sugar cane harvesting is done by manual cutting. The removal of the unmarketable stalk tops and the leaves, known as trash, by burning makes it much easier to cut. In some instances labour refuse to harvest unburned cane due to the difficulties in removing this trash by hand.
- Cane quality - sugar mills have stringent requirements for clean cane. The inclusion of trash reduces sucrose production in proportion to mill throughput.
- Transport - higher payloads are achievable with burnt cane.
- *Eldana saccharina* borer is a major pest of sugarcane and annual burning is a means of management of this insect.
- Trash blankets can become fire hazards.
- Germination and regrowth of the cane stool is retarded in cooler areas where a trash blanket limits the penetration of solar energy into the soil.

3.2.5.2 Some environmental impacts of sugarcane burning

3.2.5.2.1 Smut or fly-ash fallout

Smut fallout is generally a result of incomplete combustion during a burn due to damp cane. The ash is lifted initially by the heat of the fire, and due to the size of the fallout, is deposited subject to wind direction. This causes a nuisance in urban areas, often resulting in the anger of the affected community due to soiled washing, swimming pools *etc*. Due to the size of the ash it does not normally pose health risks, being eliminated before reaching the lungs (Echavarria, 1995).

3.2.5.2.2 Visibility and aesthetics

There is potential danger from smoke adjacent to road obscuring traffic visibility. Because of the common occurrence of temperature inversions in KwaZulu-Natal in winter months, under certain circumstances impacts of sugar cane smoke can be widespread in depressions and valleys until sufficient air mixing occurs, usually in the mid-morning (van Zyl, 1995, pers. comm.)[1]. Smoke from cane fires is usually highly visible, considered

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[1] van Zyl, O. Head of Durban Weather Bureau Office (since retired).

unsightly and leads to negative impressions of the industry's environmental ethic. The KwaZulu-Natal coast and Mpumalanga are popular tourism destinations and smoke creates negative perceptions amongst tourists.

3.2.5.2.3 Health

During burning silica fibres are released from the cane stalk. Inconclusive recent studies have raised concerns that these may act like asbestos fibres and be linked to an obscure form of lung cancer called mesothelioma (Echavarria, 1995). Further research is in progress. Hydrocarbons in smoke have also been implicated as causal agents in cancer (Markham, 1995). Cane smoke contains particulate matter and ozone which aggravate allergies and asthma, (Markham, 1995) whilst nose, eye and throat irritation may be caused or exacerbated by smoke. Respiratory problems may result from carbon monoxide which reduces the capacity of blood to carry oxygen (Echavarria, 1995).

3.2.5.2.4 Atmospheric interactions

Studies on the environmental effects of biomass burning have been neglected until fairly recently, but now form part of the International Geosphere - Biosphere program. Sugarcane is recognised to be one of the major contributors to burned agricultural residues (Crutzen and Andreae, 1990). Gaseous and particulate emissions from biomass burning affect the oxidation efficiency of the atmosphere and may contribute to the "greenhouse effect" (Echavarria, 1995).

3.3 SUMMARY

Without exception the key environmental issues in sugarcane production discussed above have a spatial context in which they occur and within which they can be addressed, with the objective of mitigating their environmental impacts. In many cases, the spatial extent of environmental impacts is not known, as a result of gaps in research or a lack of consideration of spatial issues in research. The increase in societal, regulatory and economic environmental pressures discussed in the following chapter will necessitate that the above issues be addressed and managed at various spatial scales and will require more accurate reporting of the extent of the industry's environmental impacts.

Chapter 4
ENVIRONMENTAL LEGISLATION AND PRESSURES AFFECTING SUGARCANE PRODUCTION IN SOUTH AFRICA

"Everyone has the right -

- *to an environment that is not harmful to their health or well-being ;*
- *to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that -*
- *prevent pollution and ecological degradation;*
- *promote conservation; and*
- *secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development."*

(New Constitution of South Africa, May 8, 1996)

4.1 INTRODUCTION

A 1997 environmental survey of South Africa's top 200 companies by global professional advisory company KPMG, found broad consensus (86 percent of respondents) that government policy and legislation would be the most significant pressure driving greater environmental responsibility amongst top companies and their industries. Other important pressures cited by a majority of companies were public opinion, customer demands and international trade (Visser, 1999). Given that sugarcane production in South Africa relies heavily on its international markets for economic sustainability and that its environmental impacts are often very visible to an increasingly discerning public, these same pressures must apply to sugarcane agriculture.

4.2 INTERNATIONAL TREATIES AND CONVENTIONS WITH POSSIBLE RELEVANCE TO SUGARCANE PRODUCTION

4.2.1 Introduction

International law governs relations between states and is primarily concerned with the rights and duties of states. Until recently, international law did not really concern itself with the conservation of the environment (Fuggle and Rabie, 1992). It is now being realised, however, that environmental impacts do not remain within political boundaries and that there is a socio-economic interdependence between nations. International environmental law is that part of international law which deals with the conservation of the environment and with the control of environmental pollution and has developed mainly through international conventions (treaties) - i.e. deliberate international standard setting (Devine and Erasmus, 1992).

4.2.2 International treaties and conventions

The following are some of the international agreements which have relevance to sugarcane agriculture and to which South Africa is a signatory:

4.2.2.1 Convention on Biological Diversity, 1992

(Signed by South Africa in June 1993 and ratified on 2 November 1995)

The Convention has three objectives:

- the conservation of biological diversity;
- the sustainable use of biological resources; and
- the fair and equitable sharing of benefits arising from the use of genetic resources (DEAT, 1995).

South Africa as a signatory of the convention is required to develop or adapt national strategies, plans and programs for the conservation and sustainable use of biodiversity.

Sugarcane farming results in the removal of natural vegetation and the loss of habitat which results in a general reduction in biodiversity. As South Africa is a signatory of the Biodiversity Convention, sugarcane farming will be expected to introduce measures to mitigate the impact it has on biodiversity.

In terms of its responsibilities as a signatory of the convention, South Africa has published a White Paper on the Conservation and Sustainable Use of South Africa's Biological Diversity (DEAT, 1995), which incorporates many aspects of this convention into South African law.

4.2.2.2 The Convention on Wetlands of International Importance, especially as Waterfowl Habitat, 1971 (The Ramsar Convention)

(South Africa ratified the convention in March 1975)

The general purpose of the Ramsar Convention (as it is commonly known) is to promote international wetland conservation. The broad aims of this convention are:

- to stem the further loss of wetlands;
- to provide for the wise use of wetlands in general; and
- to establish a list of wetlands of international importance.

South Africa has sixteen wetlands included on the list. South Africa as a signatory to the convention has special obligations to promote the conservation of its "Ramsar" wetlands. Currently, South Africa has no national legislation implementing the Ramsar Convention, although a Wetlands Conservation Bill is under consideration by government (South African Wetlands Conservation Programme, 1999).

The general responsibility to promote the wise use of wetlands should be noted, as in some cases wetlands are drained and planted over with sugar cane, and impacted upon in a number of other ways.

4.2.2.3 Convention on the Conservation of Migratory Species of Wild Animals (Known as the Bonn Convention)

(South Africa acceded to the Convention in December 1991)

This Convention was a response to the need for nations to co-operate in the conservation of animals that migrate across their borders. These include terrestrial mammals, reptiles, marine species and birds. Special attention is paid to endangered species. South Africa is a major partner in this convention as it is the terminus for many of the migratory species, both to Palaeoarctic and Antarctic species of birds. Sugarcane agriculture could possibly impact on migrations through eradication of habitat.

4.2.2.4 Protocol for the Protection of the Ozone Layer (Montreal Protocol 1987)

(Signed by South Africa in 1990)

The protocol is aimed at ensuring measures to protect the ozone layer. South Africa also ratified the subsequent London Amendments to the protocol designed to restrict the use of chlorofluoro-carbons (CFCs) and halons. Even though the Copenhagen Amendments to the Protocol have not yet been ratified, South Africa has acted in full compliance with these amendments and is in the process of ratifying them. The use of methyl bromide as a soil fumigant will be phased out in response to this treaty and it is possible that sugarcane burning may also be considered a contributing factor to ozone layer depletion (Crutzen and Andreae, 1990).

4.2.2.5 The Convention Concerning the Protection of the World's Cultural and Natural Heritage (UNESCO, 1972)

(South Africa ratified the treaty in 1997)

The convention aims to ensure the international support and protection of sites nominated by countries as natural or cultural heritage sites. Thus far the only site possibly affected by sugarcane production is the Greater St Lucia Wetland Park. The national World Heritage Draft Bill of 1999 will provide for the incorporation of this convention into South African law.

4.2.3 Economic Pressures Relating to International Law

Environmental conservation and pollution control measures are generally costly, in economic terms. These costs make the product more expensive, which in the absence of uniform international standards may diminish the competitiveness of such products, possibly causing distortions of trade and investment. The KPMG environmental survey showed that more than a third of South Africa's top 200 companies budget in excess of R1 million for environmentally related expenditure annually (Visser, 1999).

The existence of different environmental standards in different countries may thus cause a diversion of investment from states where high standards apply, to those where environmental standards are lower and therefore production costs would be reduced.

It is in the economic interest, therefore, of developed countries in which strict environmental protection measures apply, to work towards international acceptance and enforcement of the same standards (via international law), to ensure that their domestic products compete on an equal basis with the foreign market.

4.2.4 Future Trends

International environmental law is still in its formative period and leaves much to be desired (Fuggle and Rabie, 1992). There are still many built-in exceptions and escape clauses, since sovereign states design the law to suit themselves - particularly to accommodate their economic interests. The volume of environmental law is nevertheless steadily growing as conventions are adopted which come into force and receive increasing numbers of ratifications. It appears as though the environmental law will continue to expand, reaching new milestones that in turn set future trends. A convention on factors leading to climate change and global warming may, for instance, be the next important milestone.

The outstanding characteristic of environmental law is that it restrains the permissive traditions of state sovereignty and national autonomy. In increasing measure it is limiting the traditional freedoms of states, particularly the freedom to cause environmental degradation (Fuggle and Rabie, 1992).

4.3 SOUTH AFRICAN ENVIRONMENTAL LEGISLATION

In South Africa, awareness regarding environmental issues has lagged behind Europe and the United States, (Soutter and Mohr, 1993) and developed in a unique way, due to the country's state of socio-economic development and the different priorities perceived by different sectors of society. Whilst many South Africans are concerned with "First World" environmental issues such as global warming and the ozone hole, many more are concerned with environmental problems which have a more immediate and tangible effect on their lives, such as township air pollution, access to potable water, housing and sanitation.

Politically, there has been widespread acknowledgement that an holistic view needs to be taken of the environment and all the major political parties have stated their support for the principle of "sustainable development", *i.e.* improving the quality of human life while living within the carrying capacity of the supporting ecosystems (Anon, 1991).

Until now South Africa's framework of environmental law has not been nearly as strict or as comprehensive as in the USA and some European countries. However, several initiatives have been undertaken during the 1990's with the intention of strengthening and rationalising environmental legislation. Some of these relevant to sugarcane agriculture include (DEAT, 1999):

- the President's Council Report on a National Environmental Management System, published in 1991;
- amendments promulgated in 1991 to the Environment Conservation Act of 1989;
- a series of guidelines on Integrated Environmental Management (IEM) procedure, prepared by the Environmental Evaluation Unit of the University of Cape Town for the Department of Environment Affairs in 1992;
- White Paper on Agricultural Policy, 1995;
- the new SA Consitution (Act 108 of 1996) which addresses environmental rights;
- White Paper on the Conservation and Sustainable Use of South Africa's Biological Diversity 1997;
- Draft White Paper on Integrated Pollution and Waste Management (1999);
- National Environmental Management Act (Act 107 of 1998) preceded by Green and White papers;
- National Water Act (Act 36 of 1998) and the preceding Green and White papers; and
- National Forests Act (Act 84 of 1998).

These are discussed further in the following sections in terms of the pressures that new environmental policy and legislation will bring to bear on the sugarcane growing sector in South Africa.

4.4 ENVIRONMENTAL LEGISLATION AND PRESSURES RELATING TO WATER USAGE AND WATER POLLUTION BY SUGARCANE PRODUCTION IN SA

4.4.1 Introduction

In a water scarce country, it is not surprising that the Government of National Unity in 1994 considered South African water laws a priority for revision (DWAF, 1997). The Minister of Water Affairs and Forestry at that time, Prof. Kader Asmal, implemented a complete revision (through consultative processes) of existing water legislation. As a major water user, the South African Sugar Industry has already come under scrutiny by government and was called on to provide a detailed commodity report in defence of its water use (Lynsky, Schmidt and Sugden, 1997). Agriculture is considered to be the least efficient water user in economic terms (production per m^3) when compared with industry and mining (DEAT, 1999). In the light of this fact it can be expected that pressure on agricultural water use can only intensify with increases in population and competing industries.

4.4.2 Legislation

Some of the key proposals put forward in the Department of Water Affairs and Forestry's (DWAF) White Paper on a National Water Policy for South Africa (DWAF, 1997) particularly pertinent to the sugar growing industry are (summarised):

- All water in the water cycle will be treated as part of the *common resource* and will be subject to common management approaches.
- Only that water required to meet basic human needs and maintain environmental sustainability will be guaranteed as a right. This will be known as the *Reserve*.
- In shared river basins, Government will be empowered to give priority over other uses to ensure that the legitimate requirements of *neighbouring countries* can be met.

- All other water uses will be recognised only if they are beneficial *in the public interest*.
- These other water uses will be subject to a system of allocation that promotes use which is optimal for the achievement of equitable and *sustainable* economic and social development.
- The *riparian system* of allocation, in which the right to use water is tied to the ownership of land along rivers, will eventually be abolished.
- Water use allocations will no longer be permanent, but will be given for a reasonable period, and provision will be made to enable the transfer or *trade of these rights* between users, with ministerial consent.
- *Economic instruments* will be used in making water allocation decisions.
- Infrastructural costs involved in water supply will be recovered through *tariffs*.
- All water use, wherever in the water cycle it occurs, will be subject to a *resource conservation charge* where there are competing beneficial uses or where such use significantly affects other users.
- To promote equitable access to water for *disadvantaged groups* for productive purposes such as agriculture, some or all of these charges may be waived for a determined period where this is necessary for them to be able to begin to use the resource.
- All major water user sectors must develop a *water use, conservation and protection policy*, and regulations will be introduced to ensure compliance with the policy in key areas.
- In the long-term, since water does not recognise political boundaries whether national or international, its management will be carried out in regional or *catchment water management*.
- Provision will be made for the phased establishment of *Catchment Management Agencies* (CMAs), subject to national authority, to undertake water resource management in these water management areas.

The White Paper poses a warning to agriculture. Although agriculture uses well over half the nation's available water, the value added and jobs created by industry far outstrips that of farming. Whilst obviously playing a vital role – particularly in supporting rural communities, it would not be in the interest of the nation to unnecessarily constrain industry's access to water subject to the needs of agriculture and forestry.

When a crop such as sugar cane or timber is planted, the runoff to rivers and streams will decrease and so will the rate of ground water recharge. This in turn will reduce the amount of water that is available for other uses. It is not possible, therefore, to manage water resources without having some influence and control over land use practices (DWAF, 1996). It is also made clear in the White Paper that the costs of impacts of water uses such as sugarcane agriculture must and will eventually be accounted for in assessing the economic benefits of alternative water uses and developments. In other words the pricing of water will reflect its scarcity and will be guided by the efficiency with which it is used, and demand will therefore become market driven. Low-value users will eventually be replaced by high-value users.

The Ministry of Water Affairs and Forestry has repeatedly made reference to the proposed introduction of a rainfall interception levy, which could have a marked effect on dryland sugarcane profitability. The details of this are still under debate and it would be interesting to see how it will be controlled! It is clear, however that *suitably accurate* spatial data regarding areas under sugarcane within catchments will be of vital importance to the Sugar Industry. There is no such database at present of sufficient accuracy (pers. obs.). It is likely that in the allocations of water resources to any land users may ultimately be controlled by a permit system similar to that in operation for forestry at present. Thorough catchment planning and therefore detailed information of a spatial nature will be needed by the Sugar Industry on a catchment basis.

Government agencies responsible for water resource protection will be able to influence or prevent land use decisions that could lead to unacceptable impacts on water resources. It will become critical for catchment stakeholders to have information at hand to argue their case and to have tools in place to conduct water demand audits and strategic environmental assessments. The collection and analysis of data and the circulation of information will also be very important. The White Paper states that the aim should be for all water users to know how well (or badly) they are performing in comparison with their neighbours and other users, and to measure this against their environmental objectives and standards.

4.4.3 Environmental pressures

The proposals contained in the previous section on new national environmental policies and water law represent what is probably the major water-related pressure influencing the Sugar Industry. New policy was formulated through a process of public consultation and participation (van der Merwe, 1996), so it can be considered that the pressures have arisen from the public's negative perception of the way in which water is managed in agriculture – including the Sugar Industry. A recent article in a popular environmental journal suggests that whilst forestry has been receiving most of the governmental attention with regard to water use, inefficient irrigation practices have up until now been overlooked. The author suggests that sugarcane will be affected to a greater extent than forestry, should land use regulation be governed by "hard-nosed resource economics" (Yeld, 1997).

A catchment management plan for the Mgeni River was recently compiled by the DWAF and Umgeni Water (DWAF & Umgeni Water, 1996). As a major land user in the catchment, a number of concerns were expressed regarding the impact of sugar growing on the Mgeni catchment's water resources. Major concerns were the reduction of stream flow and the reduction in water quality due to sediment loss and phosphorus export. The following table (Table 4.1) is extracted from some of the proposed management strategies (for regional water authorities) for the Mgeni catchment, and encapsulates some of the prevailing concerns regarding the impact of sugarcane agriculture on water resources.

Issues	Objectives	Strategies
Midmar Management Unit:		
Phosphorus into Midmar dam	Maintain current mean in-dam concentrations below a specified level	Limit agricultural land use increase in the Midmar dam catchment, particularly afforestation, sugarcane and irrigation through permitting
Albert Falls Management Unit:		
Aquatic env. Health in Mgeni and Karkloof	Maintain health and assimilative capacity	Limit further afforestation and sugarcane production
Reduced water availability	Prevent further reduction in MAR and instream losses	Limit further development of farm dams and irrigation Promote irrigation efficiency
Nagle Management Unit:		
Phosphorus in Nagle dam	Reduce input load to Nagle by 50%	Promote fertiliser and pesticide management programmes on ...sugarcane.
Sediment loss		Promote and enforcesoil conservation guidelines in all agricultural areas Limit further ...sugarcane production
Reduced water availability	Prevent further reduction in MAR and instream losses	Encourage ... rehabilitation of riparian areas
Entire Mgeni Catchment:		
Inefficient use of water	Allocate more efficiently	Support the national initiatives for reassessing water tariffs and apply to irrigation and bulk supply (and possibly forestry and sugarcane)
Inappropriate agricultural practices for water quality	Effective and efficient practices and land use	Evaluate costs and benefits of ... sugarcane in terms of water use and sediment yield Investigate the use of economic instruments to influence agricultural land use, particularly sugarcane and forestry

Table 4.1. Extracts from proposed regional water authority management strategies for the Mgeni River catchment (after DWAF & Umgeni Water, 1996).

Being a catchment under high pressure through industrial, agricultural and social use and containing densely populated areas, the Mgeni is receiving considerable attention at present. In time, however, it can reasonably be expected that similar work will be conducted on other major catchments in which the SA Sugar Growing Industry is a major stakeholder. The DWAF discussion document on water law principles released in April 1996 specifically mentions sugarcane with regard to a proposal to enable government to regulate land use in sensitive catchments (DWAF, 1996).

4.4.4 A note on catchment-scale environmental management

The idea of the "catchment" is important. It is a natural drainage area made up of an inter-linking system of streams and tributaries flowing under the influence of gravity

(DWAF and WRC, 1996). All naturally occurring water in a catchment can, for practical management purposes, be treated as inter-related in terms of both quantity and quality. With the use of storage facilities such as dams and reservoirs, water can be regulated and controlled in a catchment to meet different demands. In most instances surface water catchment boundaries or watersheds coincide with ground water "catchment" boundaries (DWAF, 1996).

A key function of the national Department of Water Affairs will be to promote the establishment, and support the functioning of Catchment Management Agencies (CMAs) as and where conditions permit. Such agencies could have a wider or more restricted range of functions delegated to them, depending on the requirements of the specific catchment/s and systems within their jurisdiction, their capacity to undertake the management tasks, and policy decisions on the overall approach. It would seem that these CMAs would have the responsibility of establishing environmental standards for water users based on the particular status and parameters affecting that catchment.

CMAs will be developmental in nature, and serve the interests of equity, corrective action and optimum use of water. Any functions carried out by a CMA would be done within the parameters of national policy and standards. The governance structure of CMAs will balance the requirement to reflect the interests of various stakeholders with the need to ensure the effective management of the catchment area. As major land users in many of KwaZulu-Natal and Mpumalanga's river basins, it is inevitable that the SA Sugar Industry will be expected to participate in such catchment management initiatives. It will be expected to contribute information necessary to the effective evaluation and management of sugarcane impacts through initiatives such as Integrated Catchment Information Systems (Dent, 1997, pers. comm.)[1].

(Where CMAs are not established, the Department (or a delegate) will carry out the management functions until they can eventually be handed over to such an agency. Where this approach is adopted, a catchment advisory committee will be established to enable water users and those who impact indirectly on water quality or quantity to

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[1] Dent, M. Manager, Computing Centre for Water Research, Pietermaritzburg.

participate in water management. This will provide a focus for the development of local capacity to undertake an increasing range of water management functions.)

The SA Sugar Industry supports the principles of integrated catchment management whereby responsibility for development, apportionment and management of water resources should be devolved to represent catchment based authorities (Lynsky, Schmidt and Sugden, 1997). In order to effectively participate in such joint ventures and achieve specified environmental standards, there will be a critical requirement for:

- accurate spatial information regarding both the natural resources;
- accurate, current data on areas under cane; and
- integrated information (consisting of data and the ability to incorporate models) to assist in catchment decision making and apportionment of responsibility.

4.5 ENVIRONMENTAL LEGISLATION AND PRESSURES RELATING TO SOIL DEGRADATION RESULTING FROM SA SUGARCANE PRODUCTION

4.5.1 Introduction

Soil erosion as has been discussed earlier, is one of the major environmental impacts of sugarcane agriculture. The loss of topsoil and associated reduction in crop production potential, together with the decrease in storage capacity of reservoirs and sediment deposits in reservoirs, wetlands and estuaries, remain one of the major problems facing agricultural and water resources authorities (Schulze and Lorentz, 1995). Soil is a non-renewable resource in terms of time and must be managed as such to ensure sustainable productivity. Management of soil resources must strive to contain soil losses to acceptable levels through strategies that recognise specific conditions, available resources and economic constraints. Monitoring of soil loss and areas of high soil loss potential is necessary from a local to national level to enable mitigating actions to be implemented timeously, as soil damage and loss takes place before visible sign of damage is evident (DEAT and DWAF, 1997).

4.5.2 Legislation

Soil conservation in SA agriculture falls under the jurisdiction of the Conservation of Agricultural Resources Act 43 of 1983. In terms of the new Constitution (Act 108 of 1996), many of the Acts functions are now provincially administered, with the National Department of Agriculture responsible for norms and standards (DEAT and DWAF, 1997). Some of the key measures prescribed by this Act which have direct impact upon soil conservation in the Sugar Industry are:

- Land having a slope greater than 20 percent and in some cases greater than 12 percent may not be cultivated without special permission.
- Permission is needed to cultivate virgin soil.
- Every land user must take measures to protect cultivated land from water and wind erosion through measures prescribed in the legislation.
- Vegetation cultivated in water courses must be removed if it poses a soil loss threat during flooding.
- No land user may plant vegetation within ten metres of the flood area of a watercourse or remove vegetation from vleis and marshes, or drain wetlands.

The Act also provides for the formation of local conservation committees to promote the conservation of natural agricultural resources within their jurisdiction (Hay and McKenzie, 1999).

The National Department of Agriculture is also responsible for controlling the use of potential contamination by pesticides and fertilizers through the Directorate of Agricultural Production Inputs. The regulations are applied in terms of the Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act 36 of 1947. Whilst no regulations appear to specifically address issues of acidification, salinity and compaction (DEAT and DWAF, 1997), the White Paper on Agriculture (NDA, 1995) contains broad principles pertaining to the responsibilities of farmers to ensure that agricultural resources are used in a sustainable manner.

Other Acts having a direct impact on sugarcane production are the National Environment Management Act (Act 107 of 1998) and the Bill of Rights entrenched in the New Constitution. The Environment Act entrenches the "polluter pays" principle in law. Users of resources will be required to minimise or prevent damage to the environment. The Act makes provision for trespassers to be held responsible for rehabilitation of the environment. The Act also provides for any person to undertake private prosecutions in the public interest to protect the environment. The Bill of Rights also bestows on recipients of environmental pollution or degradation the legal right to restitution.

4.5.3 Environmental pressures

Sugarcane producers have been subject to the provisions made in the Conservation of Agricultural Resources Act 43 since 1983. Severe penalties are prescribed in the Act, although persuasion, not coercion has been the main goal until now (DEAT and DWAF, 1997). Prosecutions have been made under this Act but it's implementation is hampered due to the limited capacity of workers in the Directorate of Natural Resources Conservation to "police" the Act (Wyatt, 1999, pers. comm..)[1]. Maher (1996), quoted by Ferrer and Nieuwoudt (1997), drew attention to ongoing erosion in KwaZulu-Natal and contended that sugarcane farmers are not being held accountable for soil erosion on their farms by either the Sugar Industry or government bodies, resulting in too few farmers implementing adequate soil conservation. The following issues will, however, lead to increased pressure on sugarcane producers to meet environmental standards:

- the "polluter pays" principle of a variety of new Acts will broaden the scope for accountability;
- the threat of prosecution by the public made possible by the new Environmental Management Act;
- future markets may require environmental certification;
- environmental audits on sugar growing activities are increasing in the Sugar Industry (Stranack, 1998); and
- research indicates that productivity and therefore profitability is significantly reduced through soil degradation (van Antwerpen and Meyer, 1996 and Schroeder, Robinson, Wallace and Turner, 1994).

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[1] Wyatt, J. Conservator: North Coast, KZNNCS, Durban.

4.6 ENVIRONMENTAL LEGISLATION AND PRESSURES RELATING TO AIR POLLUTION CAUSED BY SUGARCANE BURNING IN SA

4.6.1 Introduction

Because of the highly visible nature of cane fires and the public nuisance impact of smut fallout, the public and government pressures relating to cane burning are currently a major threat to economically sustainable cane production in certain areas (Sugden, 1999, pers. comm.)[1].

4.6.2 Legislation

The principles of the National Environmental Management Act (NEMA)107 of 1998 apply to cane burning in that they:

- place a general obligation on people responsible for significant pollution to take measures to prevent, minimise and rectify such impacts; and
- provide for any person to undertake private prosecutions in the interest of the public or the environment.

More specific to cane burning is the Atmospheric Pollution Prevention Act 45 of 1965, by which local authorities (in gazetted zones only) are empowered to:

- serve an abatement notice on people responsible for smoke causing nuisance;
- make smoke control regulations; and
- establish smoke control zones in consultation with the National Air Pollution Advisory Committee.

The Forestry Act of 1984 restricts burning during specific times and a new White Paper on Integrated Pollution and Waste Management in South Africa (DEAT and DWAF, 1998) will impact on cane burning through its commitment to pollution prevention.

4.6.3 Environmental Pressures

In recent years there has been considerable increase in pressure from the public to prohibit the burning of sugarcane (Tucker, 1995). Numerous letters have appeared in

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[1] Sugden, B. Director, SA Cane Growers Association, Durban.

the press and pressure groups have been formed against burning to pursuade government to introduce legislation to reduce levels of air pollution. The Chief Air Pollution Control Officer of KwaZulu-Natal subsequently warned the sugar growing industry to introduce measures to minimise the undesirable effects of cane burning at harvest, otherwise burning permits may become mandatory before permission is granted for each burn. Sezela growers have received legal threats and there have been numerous public appeals to impose a ban on cane burning. In some areas formal protest groups have been formed to oppose cane burning, such as the registered organisation *Citizens Against the Burning of Sugarcane* (CABS). The organisation has lobbied to attempt to get the practice of cane burning included in the national Anti Pollution Act (1965). In an article in a local newspaper, an attorney stated that in terms of common law a person would have the right of recourse to be reimbursed for any damage subject to being able to identify the source farm and its owner. For legal action to be instituted, a database of facts needs to be collected, and CABS have appealed to residents of Ballito inconvenienced by smut fallout to collect information regarding the date, time, wind direction and quantity of smuts to be made available and kept as a record (Markham, 1995).

On September 1998 the DEAT presented an ultimatum that:

- cane burning would become a scheduled activity under the Atmospheric Pollution Prevention Act;
- a permit would be required for all burns; and
- strict compliance with regulations would be required, enforced by a government inspectorate with the power to impose severe penalties unless the following were established:
  - effective local co-operation;
  - self imposed compliance; and
  - peer pressure coercion (Sugden, 1999).

In Hawaii emission taxes are being considered to curb air pollution from industries - including sugar growing (Echavarria, 1995). In the light of the "polluter-pays" principles in the new environmental policy proposals in South Africa, there may eventually be new direct financial implications facing growers who burn cane in the future.

Whilst much research is still needed in order to quantify global effects of cane burning it is likely to come under increasing pressure resulting from "clean air" international agreements.

4.7 ENVIRONMENTAL LEGISLATION AND PRESSURES RELATING TO IMPACTS ON HABITAT AND BIODIVERSITY BY SA SUGARCANE PRODUCTION

4.7.1 Introduction

As with much environmental legislation the world over, national laws are reactive, not proactive. However, if implemented effectively, the proposed new biodiversity legislation in South Africa will help to prevent further losses and even restore habitat if suitable incentives can be installed.

4.7.2 Legislation

The national government's response to the United Nations Convention on Biological Diversity was to draft the White Paper on the Conservation and Sustainable Use of South Africa's Biological Diversity (DEAT, 1997). The White Paper encapsulates the objectives espoused in the UN Convention. Some of the salient principles relevant to sugarcane production are the government's intentions to:

- identify and wherever possible remove incentives that encourage the loss of biodiversity and the unsustainable, inefficient, and inequitable use of biological resources, taking into consideration social, economic and environmental costs and benefits;
- maintain, adjust, or develop new financial and other incentives that support the conservation and sustainable use of biodiversity, and stimulate local stewardship of terrestrial, aquatic, and marine and coastal areas;
- review the impact of agricultural and commercial forestry practices on biodiversity and seek changes where necessary;

- strongly encourage agricultural producers to incorporate biodiversity considerations in farm management practices and plans;
- promote the optimal use of on-farm inputs, and the minimal use of external inputs such as chemical fertilizers and pesticides;
- support co-ordinated research and development into achieving the ecologically sustainable use of biological resources in agriculture and forestry, and minimising adverse impacts on biodiversity; and
- strengthen delivery of extension and research services related to the management of agricultural, forestry, and pastoral systems to ensure the sustainable use of biological resources and the conservation of biodiversity.

4.7.3 Environmental pressures

The implementation of new policy specifically addressing biodiversity will inevitably lead to increased focus and pressure on those industries impacting negatively on habitat and biodiversity. Conservation bodies, as well as the general public will have increased litigative powers through application of the new Environmental Management Act.

4.8 ENVIRONMENTAL LEGISLATION AND PRESSURES RELATING TO IMPACTS ON WETLANDS AND ESTUARIES BY SA SUGARCANE PRODUCTION

4.8.1 Introduction

Wetland conservation is extremely poor in South Africa and the majority of wetlands fall outside of legally protected areas. Exceptions to this include the 15 Ramsar Sites in the country, which are recognised in terms of the Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention) and afforded legal protection (DEAT, 1997). The degradation of South African wetlands, and their vulnerability to human-induced changes in catchments and in the sea, is a concern recognised by Government as requiring urgent action and co-operation between a diversity of sectors and institutions (DEAT, 1997).

4.8.2 Legislation

Key policy documents relating to wetland issues are:

- White Paper on the Conservation and Sustainable Use of South Africa's Biological Diversity (May 1997);
- White Paper on Environmental Management Policy (July 1997);
- the proposed Wetlands Conservation Act (1995) (not yet passed);
- National Environmental Management Act No. 107 of 1998;
- Conservation of Agricultural Resources Act 107 of 1989;
- National Water Act No. 36 of 1998 and
- the Marine Living Resources Act No.18 of 1998.

Whilst a number of the existing Acts or policy documents address wetland issues, the Wetlands Conservation Bill of 1995 was designed specifically:

"to provide for the application in the Republic of the Convention on Wetlands of International Importance especially as Waterfowl Habitat; ... the prohibition of detrimental activities in wetlands and listed wetlands; and the prohibition of activities detrimental to catchment areas; and to provide for matters connected therewith." (DEAT, 1995).

The Act will give the Minister of Environment Affairs and Tourism extended powers regarding unlawful activities and allows for fines and imprisonment of up to five years for offenders.

4.8.3 Environmental pressures

The reports of Begg (1978, 1984, 1986 and 1988) on the estuaries and wetlands of KwaZulu-Natal helped to focus public attention on their plight. This in turn led to pressure being placed on the Sugar Industry through conservation bodies such as the former Natal Parks Board (now KZNNCS) and the African Wildlife Society - particularly following the floods in 1984 and 1987 where the effect of wetland eradication on flood attenuation was vividly demonstrated (Wyatt, 1999, pers. comm.)[1]. With the co-operation of the Natal Parks Board, wetland working groups were formed

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[1] Wyatt, J. Conservator: North Coast, KZNNCS, Durban.

amongst interested farmers, through the Local Environment Committees, assisted by SASEX extension services and the now defunct SASEX Farm Planning Department. Restructuring of the Natal Parks Board into the KwaZulu-Natal Nature Conservation Service with reductions in field staff, and the cessation of the SASEX Farm Planning service have led to fewer conservation workers in the field and a corresponding slowing down in new wetland initiatives (Wyatt, 1999, pers. comm.)[1].

Again, new legislation will increase accountability for further degradation of wetlands and may result in certain wetland and even catchment activities being prohibited (DEAT, 1995). The pending wetland inventory program (South African Wetland Conservation Program, 1999) will provide a baseline of data against which further wetland deterioration may be compared. It is important that the sugar producers are pro-active in monitoring and mitigating their impact on wetlands before government intervention is required in terms of the new legislation.

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[1] Wyatt, J. Conservator: North Coast, KZNNCS, Durban.

Chapter 5
SUSTAINABLE SUGARCANE PRODUCTION : ENVIRONMENTAL STANDARDS AND MANAGEMENT SYSTEMS

5.1 INTRODUCTION

In recent years, there has been heightened international interest in and commitment to improved environmental management practices by both the public and private sectors. This interest is reflected in the success of collaborative international efforts to address environmental problems, and in the global recognition of trade-related environmental issues. The Montreal Protocol, the environmental agreements of the North American Free Trade Agreement and the mandates resulting from the 1992 Earth Summit of the United National Conference on environment and Development in Rio de Janeiro are some of the successes.

The question may be asked: "Why undertake the expense and effort required to achieve and maintain environmental standards in the Sugar Industry"? Apart from our responsibility in our role as stewards or custodians of the land for future generations, some of the reasons (after Soutter and Mohr, 1993) are:

- to comply with legislation - particularly in the light of the current sweeping changes to national environmental policy;
- to be able to demonstrate self-regulation and thus avoid the need for (and cost of) additional, externally imposed restrictions;
- to avoid causing environmental degradation or disaster;
- to meet the expectations of interested parties, such as customers, employees, local communities, investors, environmental interest groups and the general public;
- to promote acceptability in export markets;
- to take advantage of potential benefits, such as the opening up of new markets, or opportunities;
- to protect and enhance the organisation's image; and

- to overcome the threat of "green tariffs" to be imposed on companies (or individuals) causing environmental damage (DEAT, 1996).

Also, the government strategy in formulating new policy is that those industries who are prepared to take responsibility for their environmental management will be able to have more input into the formation of relevant legislation governing their environmental activities (DEAT, 1996).

5.2 INTERNATIONAL ENVIRONMENTAL STANDARDS

An indication of the widespread interest in improved environmental practices is the emergence of voluntary environmental management standards developed by national standards bodies throughout the world. ISO, the International Organisation for Standardisation, is a private sector, international standards body based in Geneva, Switzerland. Founded in 1947, ISO promotes the international harmonisation and development of manufacturing, product and communications standards (EPA, 1995). ISO has promulgated more than 8000 internationally accepted standards for everything from paper sizes to film speeds. Environmental Management Standards are expected to have a significant impact on trade in the same way that the ISO 9000 series Quality Management Standards have (EPA, 1997).

ISO's Environmental Management Standards are a series of voluntary standards and guideline reference documents which include environmental management systems, eco-labelling, environmental auditing, life cycle assessment, environmental performance evaluation, and environmental aspects in product standards. ISO 14004 provides guidelines on the elements of an Environmental Management System (EMS) and its implementation, and discusses principal issues involved. ISO 14001 specifies the requirements for such an EMS. Fulfilling these requirements demands objective evidence which can be audited to demonstrate that the environmental management system is operating effectively in conformance with the standard. Guidance for the conduct of such audits can be found in ISO 14010, ISO 14011 and ISO 14012 (International Organisation for Standardisation, 1999).

The focus on *management* distinguishes these standards from *performance* standards. EMS help an organisation to establish and meet its own policy goals through objectives and targets, organisational structures and accountability, management controls and review functions all with top management oversight. EMS do not themselves set requirements for environmental compliance nor do these standards establish requirements for specific levels of pollution prevention or performance (Stapleton, 1996). The EMS specification document calls for environmental policies which include a commitment to both compliance with existing environmental laws and standards, and the prevention of pollution. ISO 14001 can also be used for external purposes: to provide information and assurance to interested parties, such as customers, the community, other stakeholders and regulatory agencies. (International Organisation for Standardisation, 1995 and 1999).

5.2.1 Other environmental standards

5.2.1.1 BS 7750 and EMAS

The European Eco-Management and Audit Scheme (EMAS), and British Standard 7750 (BS 7750) are both standards for implementing environmental management systems. BS 7750, developed by the British Standards Institution, was the world's first standard for EMS (Brkic and Douglas, 1997). Unlike the international ISO 14000 standard, EMAS and BS 7750 are regionally developed standards. EMAS only applies across the European Community, whereas BS7750 and ISO 14000 are applied internationally. The ISO 14000 series superseded BS 7750 as of March 1997 (Worthington, 1999). The ISO 14000 series were modelled after BS 7750. The EMAS was developed for the European Union and is also based on BS 7750. Thus all of the standards share the same foundation.

There are more similarities between EMAS and BS 7750 than with ISO 14000. However, since ISO14000 and EMAS are based on BS 7750, all three standards have similar components. The fundamental components of these EMS include:

- commitment from senior management;
- establishment of an environmental policy;
- planning and implementation;
- measurement and evaluation;

- regular audits and review; and
- external environmental communication.

Each of the standards requires organisations to implement an environmental policy. The policy should be fully supported by senior management, and it should emphasise management commitment to continual improvement (see Figure 5.1, page 70). Internal audits and management reviews are essential components of each EMS standard that ensure effectiveness and compliance (Brkic and Douglas, 1997).

5.2.1.2 Forestry Stewardship Council

The Forestry Stewardship Council (FSC) is an international non-profit association spearheaded and supported by major environmental groups. The FSC has developed principles and criteria for sustainable forest management, which producers can use to certify their products on a voluntary basis. Simultaneously, the FSC has formed buyers' groups in a number of countries of companies who pledge to phase out all non-FSC certified wood producers by a certain date. The FSC is thus using business concerns about environmental reputation, risk management and customer loyalty to develop new markets in sustainable timber. Interestingly, one of the most fervent business supporters of the FSC in the UK is B&Q, a do-it-yourself chain targeted in the 1980s by environmental groups for allegedly selling non-sustainably produced timber (Robins and Roberts, 1998). Local timber companies such as Mondi Ltd. strive for FSC certification of their forests (Mondi, 1999).

Should a similar initiative be undertaken within the community of sugar growing countries, those that implement sound EMSs early would have a distinct competitive advantage in certain markets.

5.3 SOUTH AFRICAN ENVIRONMENTAL STANDARDS – LOCAL INDUSTRIES

The implementation of various environmental objectives in the private sector is influenced by the Industrial Environmental Forum (IEF). The IEF was established in 1991, and represents the environmental interests of 30 leading corporations in South

Africa (DEAT, 1999). The IEF in many ways serves as an important barometer of environmental trends and practices within industry and business. While national policy is an important factor of influence, international trends such as changing consumer preferences trade agreements, and environmental conventions have also impacted on the private sector. The nature of these influences varies, but tend to be mainly focused on the introduction of Environmental Management Systems (EMSs) such as the ISO 14000 standards and cleaner production technologies.

The extent to which companies have actually implemented these measures is still open to question. Recently, an assessment of the status of Environmental Management Strategies in South Africa (Sunday Times, April 18, 1999) reviewed 83 local and foreign organisations operating in South Africa. The study showed that South African companies still lag about five years behind their counterparts in terms of Environmental Management Strategy implementation

A national EMS survey by KPMG (Visser and Butcher, 1999), of which agricultural and forestry comprised 12 percent of respondents (included were Tongaat-Hulett Ltd., Mondi Ltd., and TSB), found that ISO 14000 is unequivocally recognised as the environmental management standard of choice. The majority (97 percent) of respondents using or planning to use this system as the basis for their EMS. Of these, 32 percent are already ISO 14001 certified, 41 percent are planning to certify and the remainder intend simply using the guideline informally. Of the agriculture and forestry sector, 12 percent were ISO 14000 certified, whilst 57 percent were planning certification. Both Mondi Ltd. and SAPPI Ltd. (major SA timber companies) have recognised the need to implement ISO 14000 programs (Mondi, 1999; and SAPPI, 1999).

The most commonly perceived advantages of EMS according to this survey were:

- managing risk - ensuring compliance with laws and regulations (95%);
- reducing unforeseen liabilities (88%), demonstrating due diligence (83%) and improving risk management, (80%);
- public relations - improving the company's image (88%) and improving the
- relationship with the public (88%); and

- reducing impacts - improving environmental performance (88%).

Other benefits that were cited include:

- improving understanding of impacts through research;
- increasing environmental awareness of employees and stakeholders; and
- more effective co-ordination within the organisation.

5.4 ENVIRONMENTAL AUDITING AND REPORTING

The demand for reliable environmental information on industries and other enterprises has led to the development of environmental "reviews" or audits as a tool for generating the required information.

An environmental audit is a methodological examination of environmental information about an organisation, facility or site, to verify whether, or to what extent, they conform to specified audit criteria. The criteria may be based on local, national or international standards, national laws, permits and concessions, corporate standards or guidelines of funding organisations such as the World Bank (World Bank, 1995).

Another widely accepted definition is that of the International Chamber of Commerce (ICC) which emphasises the management role in environmental auditing:
"A management tool comprising a systematic, documented, periodic and objective evaluation of how well environmental organisation, management and equipment are performing with the aim of helping to safeguard the environment by: facilitating management control of environmental practices and assessing compliance with company policies, which would include meeting regulatory requirements"
(International Chamber of Commerce, 1991).

It is expected that the results of such audits are made available to government or to the public through publicised reports.

Of themselves, these audits may not be sufficient to provide an organisation with the assurance that its performance not only meets, but will continue to meet, its legal and policy requirements. To be effective, they need to be conducted within a structured management system. The ISO 14000 series provides organisations with the elements of an effective, "auditable" EMS which can be integrated with other management requirements to assist them to achieve environmental and economic goals. They were designed to be applicable to all type and sizes of organisations and to accommodate diverse geographical, cultural and social conditions. The success of the system depends on commitment from all levels and functions, but particularly from top management (International Organisation for Standardisation, 1995).

In South Africa, environmental legislation does not yet require companies to conduct environmental audits. The attitude of government is that environmental auditing should be the responsibility of business and industry themselves (DEAT, 1999). Environmental reporting is growing in South Africa, albeit slowly, with shareholders becoming increasingly interested in companies environmental affairs (Bennett, 1999).

Because of the requirements for spatial information and analysis in environmental auditing and the subsequent reporting of results, the use of GIS is growing in this area. The recently released South African State of the Environment Report (DEAT, 1999) makes extensive use of GIS-produced maps and spatial statistics. The maps are made available to the public both in the published report and via the Internet.

5.5 ENVIRONMENTAL MANAGEMENT STANDARDS AND GIS

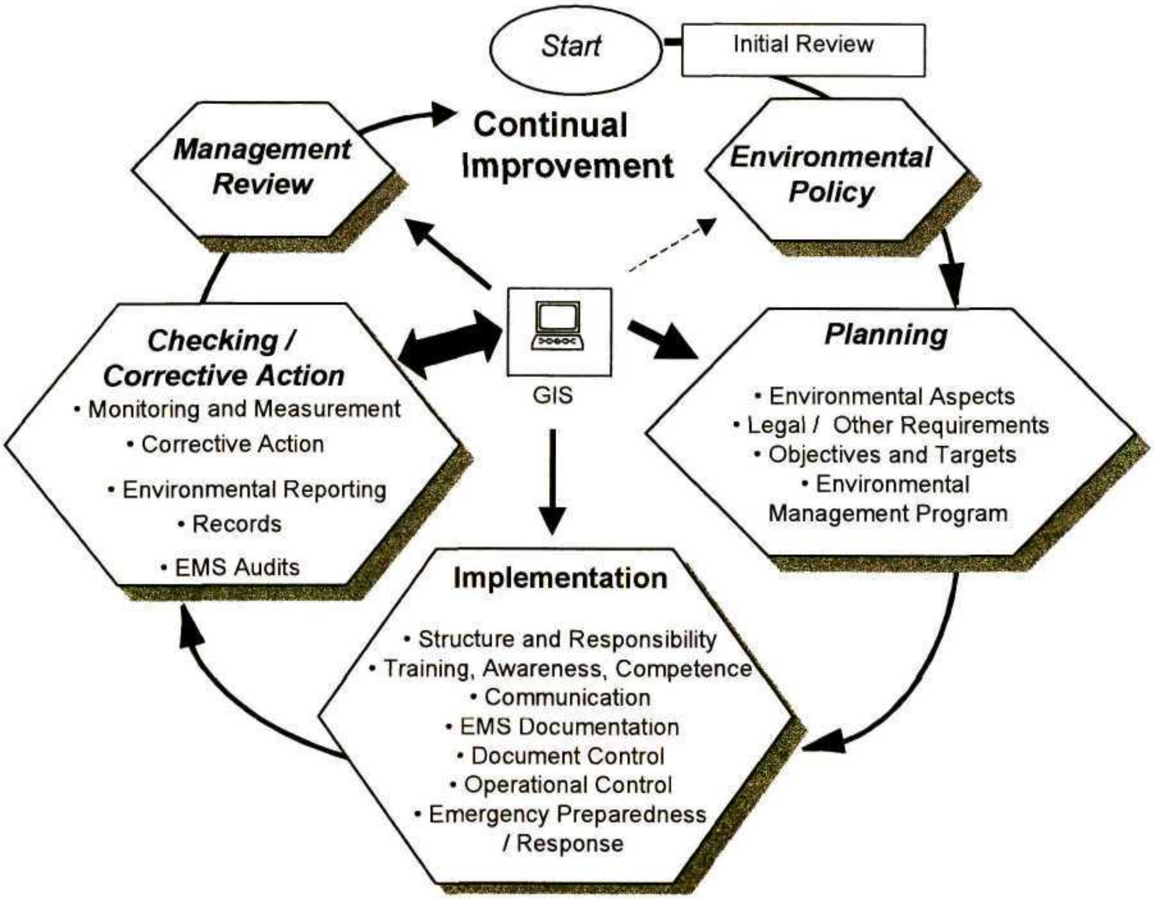

Figure 5.1. A generalised illustration of the role of GIS in supporting an environmental management standard (based on ISO 14001) (after Stapleton, 1996).

To effectively manage a geographically extensive industry such as sugarcane production, the majority of information that needs to be processed is spatial in nature. Figure 5.1 illustrates the potential role of GIS in supporting a hypothetical EMS applicable to the Sugar Industry. The primary role would be in support of the "checking" phase, where GIS and associated technologies can play a major role in monitoring, measuring, reporting and database management or record keeping. Feedback from this phase is important in providing support to all other phases, as one of the objectives of an EMS is to undergo regular self-assessment and strive for continual improvement. Spatial data will inevitably be required at all stages in the cycle at various times, by decision makers. Equally important is the utility of GIS in supporting the public information disclosure requirements of EMSs, through the presentation of maps and spatial statistics.

5.6 THE SOUTH AFRICAN SUGAR INDUSTRY AND ENVIRONMENTAL STANDARDS

5.6.1 SA Sugar Industry's Environmental Policy

The South African Sugar Association (SASA) has an environmental policy statement in which its environmental mission, objectives and key issues are outlined. This consists of a four-page document that was last updated in 1991. At the time of writing, this document is in the process of undergoing substantial revision so it would be premature to discuss the details therein (Tucker, 1997, pers. comm.)[1]. The revision will address changes in South Africa's environmental legislation and international environmental standards, such as ISO 14000.

The SA Sugar Industry has no legislative powers to enforce adherence to the industry's environmental guidelines. The onus will be placed on its constituent members to adhere to the Sugar Industry policy and obviously to the relevant government legislation.

SASA is controlled jointly by members of the miller and the grower community. Due to the widely differing demands on environmental management resources between what is essentially an industrial operation by the millers on the one hand, and widely dispersed agricultural operations by the growers on the other, new independent environmental strategies will be developed. It appears that separate environmental policies may be installed by the large miller-cum-planter companies regarding their agricultural operations as well (Sugden, 1999, pers. comm.)[2].

A proposal was formulated to conduct an environmental audit to attempt to clearly define the impact of sugarcane growing on the environment (Schmidt, 1997, pers. comm.)[3], but this has yet to be approved and implemented. The onus will rest on individual mill groups to implement their own environmental audits. Maher (1999) reports on environmental auditing being carried out in the Noodsburg district.

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[1] Tucker, A.B. Head of Extension Department, SASEX.

[2] Sugden, B. Director, SA Cane Growers Association, Durban.

[3] Schmidt, E.J. Head of Agricultural Engineering Department, SASEX.

It is very likely that in the future certain buyers of sugar on the world and possibly even the local market will require producers of that sugar to be ISO 14000 (or similar) certified. This will require the adherence "from cradle to grave" - or in this case "from field to shop shelf", *i.e.* through the entire sugar production process, to acceptable (and measurable) environmental standards.

5.6.2 Environmental Structures Within the SA Sugar Industry

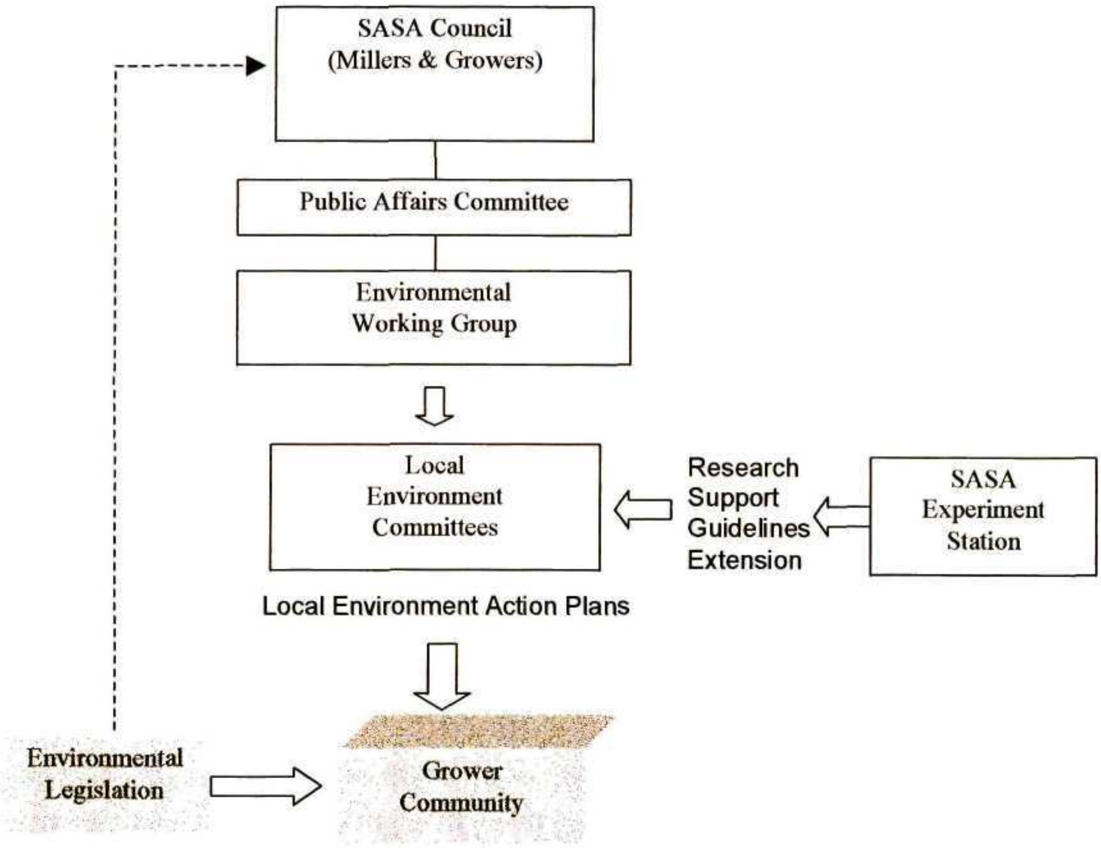

Figure 5.2. Current environmental structures within the SA Sugar Industry (grower sector).

Figure 5.2 illustrates the basic environmental structures currently in place in the SA Sugar Industry. The South African Sugar Association (SASA) is the managing body of the Sugar Industry, controlled jointly by miller and grower representatives from whom the SASA Council is comprised. SASA encourages its members to practice sound environmental management. However the millers and growers associations are ultimately responsible for environmental decisions taken within the Sugar Industry. The Public Affairs Division is tasked with media relations, internal publications, environmental advertising, liaison with environmental organisations and government and public relations functions. An environmental working group (EWG) has been established from representatives of the SASEX, South African Cane Growers Association (SACGA), the SA Sugar Millers Association and the Sugar Milling Research Institute. They are responsible for:

- supporting the activities of the Local Environment Committees (LECs);
- obtaining and disseminating amongst key industry personnel new environmental legislation and relevant environmental standards;
- responding to requests for information from government, industry, media and interest groups; and
- liaison between the millers and growers on environmental issues.

The SASEX Extension Officers play an important role in providing technical support to the LECs. These committees are comprised of representatives from the local miller, local grower groups and environmental interest groups such as the Natal Parks Board. Their functions are:

- to prioritize and address local environmental issues;
- to disseminate environmental developments and requirements to individual growers;
- to establish and maintain lines of communication with local authorities and neighbouring communities;
- to liaise and co-operate with other land users on environmental issues;
- to encourage the grower community to abide by environmental legislation by conducting environmentally acceptable agricultural operations, and to comply with burning codes of practice at harvest; and
- to apply some form of peer pressure to persuade continual offenders to comply with the required environmental standards.

It is these committees then that are entrusted with the task of attempting to ensure implementation of industry environmental standards. Beyond this the industry carries no powers to enforce adherence to environmental standards. It is a function of government resource protection officials to sanction or prosecute those who are found to be contravening various environmental laws.

It is envisaged that SA Cane Growers' "Sustainable Environmental Management Practice" (SEMP) principles for the industry will be completed in 2000 which will incorporate the formalisation of certain *production standards* (Sugden, 1999, pers. comm.)[1]. Some of the environmental management policy statements proposed in the SEMP are (after Hay and McKenzie, 1999):

- Cane Growers will promote compliance with all national legislation and regulations by its constituency that relate to environmental management norms and standards.
- Cane Growers will promote grower accountability for environmental performance and the ethic of custodianship of natural resources under grower control/management.
- Responsibility for ensuring on-farm environmental management performance and compliance will rest with the Local Environmental/Conservation Committees through their Local Grower Councils.
- Local Grower Councils will ensure that environmental management is integrated into an holistic business strategy.
- Cane Growers, in co-operation with SASA, will establish effective mechanisms for supporting, monitoring and evaluating environmental management programmes of Local Grower Councils.
- Cane Growers will commit itself to external assessment of environmental performance by an independent agency.
- Cane Growers will promote the implementation of a recognised environmental management system, which commits growers to continual improvement. (ISO 14000 and/or Environmental Self-Assessment Programme (ESAP)).
- In co-operation with SASA, the Sugar Miller's Research Institute and research/academic institutions Cane Growers will promote that research which is directed towards supporting improved environmental management performance and supporting specific decisions on environmental management issues.

[1] Sugden, B. Director, SA Cane Growers Association, Durban.

- Cane Growers will support local grower leadership in establishing locally appropriate environmental management norms and standards for:
  - soil conservation;
  - surface and groundwater management (including wetlands, riparian areas and estuaries);
  - air emissions; and
  - the management of hazardous materials.
- Cane Growers will promote the sustainable (and preferably non-consumptive) utilisation of natural resources in activities that compliment cane farming, particularly for recreation, tourism and small business development.

5.6.3 SA Sugarcane production environmental standards

"There is scope, however, within the Sugar Industry, as has been done within the forestry industry to develop industry recognised standards (in consultation with key stakeholders) and work to raise the environmental profile of the industry in that way." Karen Ireton - International Society of Sugarcane Technologists Congress, Feb 1999 (Ireton, 1999).

5.6.3.1 Introduction

The local sugarcane industry has yet to produce a set of all-encompassing production *standards*. There is however an existing Code of Practice for cane burning and some environmental guidelines regarding certain processes which have been developed by researchers in the local Sugar Industry over the years - particularly in terms of soil conservation.

For the purposes of this document then, the term "environmental standards" necessarily refers to nationally accepted standards as formalised through a consultative process in new legislation and key national policy proposals, to which Sugar Industry standards will in any case obviously need to conform. Some of the existing guidelines *within* the industry which have a particular spatial connotation for possible monitoring, assessment or analysis in GIS are discussed below. These were mainly extracted from Maher's "Guidelines for Environmental Conservation Management in the South Africa Sugar Industry" (1995). Though generally not true environmental *standards* as such, they illustrate the spatial nature of issues which will need to be formalised into auditable standards. The application of GIS in supporting these standards is discussed further in Chapter 8.

5.6.3.2 Water

Regarding irrigation, some industry norms are:

- surface irrigation should not be practised on slopes steeper than six percent;
- surface irrigation should not be used on soils which have a total available moisture content (TAM) of less than 50 millimetres;
- the application of irrigation must be accurately planned and controlled to prevent waste;
- surface irrigation should not be used on soil less than 0.4 metres deep; and
- dam sites must be carefully chosen and subject to an environmental impact assessment.

Much work is being carried out at SASEX to improve irrigation efficiency through irrigation modelling, scheduling and planning, although this has yet to be formalised into a set of industry environmental standards for irrigation. The role of GIS in this sphere has been recognised, and projects have been initiated to spatially model irrigation scenarios and link GIS to sugarcane growth models (Schmidt, 1998, pers. comm.)[1].

It is clear that the members of SA Sugar Growing Industry will be increasingly under the governmental spotlight in regard to their impact on water resources. A detailed survey will be needed to ascertain more accurately the extent of such impacts and a thorough set of SA Sugar Growing Industry (environmental) irrigation standards will need to be formulated. The alternative to such transparent self-regulation is the likelihood of being prescribed to by government. The spatial nature of all these operations should highlight the eminent suitability of GIS in such tasks.

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[1] Schmidt, E.J. Head of Agricultural Engineering Department, SASEX.

5.6.3.3 Air

The sugar growing industry produced a Code of Practice (SASA, 1996) for growers in respect of sugarcane burning with the key objectives being to reduce where possible:

- atmospheric pollution caused by the burning of cane;
- smuts from fires falling onto sensitive areas;
- smoke from cane fires constituting a hazard to road users and annoyance to the public; and
- the disruption of power supply (caused by arcing to overhead powerlines).

The individual Mill groups have responded to these pressures by the introduction of Codes of Practice for burning, to which their members are urged to abide. Some of the practices agreed to in these Codes include:

- identification of sensitive areas in each region with respect to public roads, residential areas, schools, tourist attractions etc.;
- no-burn days when meteorological conditions are unfavourable;
- no-burn zones, for example adjacent to residential areas;
- restricted burning when wind directions are towards sensitive areas;
- regular contact and liaison with local residents and authorities;
- logging of all fires by growers; and
- mapping areas of farms for burning/trashing according to the agronomic/economic and environmental factors.

In its guidelines, the industry also promotes trashing rather than burning where feasible.

Further guidelines from Maher (1995) include:

- burning should not be practised on steep slopes and erodible soils where trashing should be the norm; and
- on slopes greater than 15 percent, burning should only be practised in the dry season.

It can be expected that the Local Environment Committees will establish differing standards from region to region in accordance with their particular situation regarding proximity of residential areas, tourism sites and other sensitive areas.

5.6.3.4 Soil

- All land on the following soils and slope should be protected by conservation terraces:
  - moderately erodible soils on slopes over 3 %;
  - highly erodible soils over 1.5 %; and
  - all land over 4 % slope.
- Field panel spacing is determined by combinations of slope, soil and management practices.
- Minimum tillage must be practised on the following land:
  - slopes greater than 11 % on erodible soils;
  - slopes greater than 13 % on moderately erodible soils;
  - slopes greater than 16 % on resistant soils.
- On slopes less than 11 % conventional tillage may be carried out provided ploughing follows the contour.
- Cane should not be grown on shallow erodible soils.

5.6.3.5 Biodiversity/Habitat and Wetlands:

- Cane should not be planted closer than 5 metres from a wetland and 10 metres from an indigenous forest.
- Cane should not be planted within the flood area of a watercourse or within 10 metres horizontally outside the flood area of a watercourse.
- No land user may drain or cultivate any wetland.

5.6.3.6 Summary

A thorough and well-designed set of environmental best-management practices and standards is an essential part of an EMS. The industry - or regions within the industry - currently have some excellent environmental guideline documents (Hay and McKenzie, 1999). The guidelines are generally detailed in terms of soil conservation management, burning and to a lesser extent irrigation practices. The issues of biodiversity, habitat and impacts on the aquatic environment are less thoroughly covered, particularly in terms of new legislation. Also, these documents were intended as planning and production guidelines and generally do not provide measurable or formally auditable production standards by which sustainability or the lack thereof may be judged. Cane Growers will support local grower leadership in establishing locally appropriate environmental management standards and they will promote the implementation of a recognised EMS (Hay and McKenzie, 1999). The issue of industry standards will need to be addressed during this process. The establishment of environmental standards for use in an EMS should go hand-in-hand with the selection of environmental indicators (see Section 2.3) which can be monitored over time to ascertain the success or failure of production standards in terms of environmental sustainability. Given the spatial nature of most of the relevant environmental issues, GIS should be a key component in the design, monitoring and management of environmental standards and their associated indicators.

Chapter 6
SUSTAINABLE SUGARCANE PRODUCTION: SPATIAL CONTEXT AND THE NEED FOR A SPATIAL INFORMATION MANAGEMENT SYSTEM

6.1 INTRODUCTION

Sugarcane production inevitably impacts on the environment through various agricultural processes. In an attempt to preserve the sustainability of the environment (and to safeguard international trade) government imposes legislation affecting environmental activities. Most of South Africa's top companies agree that the environment is already a strategic issue in their business and that the significance of environmental issues to their companies will increase in the next five years (Visser, 1999). In order to comply with legislation and meet the expectations of markets and stakeholders, the majority of these companies have implemented various EMSs to assist them in meeting environmental standards (Visser, 1999).

An industry audit as was done in Australia (Gutteridge, Haskins and Davey, 1996) would be required to assess whether current South African sugarcane practises would:

- be considered environmentally sustainable;
- comply with legislation; and would
- satisfy First World "green" standards.

Given the environmental issues facing the South African Sugar Industry, it is likely that members of the industry – particularly in certain regions – would be found wanting in many cases, as was the case in Australia.

In order for the Sugar Industry to achieve and maintain environmental standards, a well-implemented system of environmental management is critical. For decision makers within that system it is equally vital to have sufficient easily-available and appropriate information on which to base their decisions. Since most environmental decisions in agriculture will be in a spatial context, the information system used to support such decision-making must be able to handle such data. This is the reason for the increasing implementation of GIS by organisations tasked with environmental management. Fedra (1994) documented a dramatic increase in the use of GIS in environmental management between 1989 and 1994, whilst an electronic abstract or Internet search on "GIS *and* Environmental Management" provides references in the thousands (pers. obs.).

6.2 SPATIAL DIMENSIONS OF SUGARCANE PRODUCTION ENVIRONMENTAL IMPACTS

All physical resources exist within a spatial context, so all issues impacting on natural resources can best be described in a system equipped to deal with such data. Management decisions need to be taken in the context of various scales in which agricultural processes and their impacts (both on and off-site) occur (Walker and Johnson, 1996a).

This defined area of study needs to be of sufficient size and environmental composition to take into account the main environmental interactions that may be affected by the decision (McCloy, 1995). On examining soil erosion, for example, a farmer or farm planning advisor would require soil erosion potential information at a field or farm scale. A suitable spatial unit in which to analyse the off-site impacts of soil erosion would be at a river catchment or sub-catchment scale downstream of the initial impact site, since soil losses in the sugar belt are mainly water-borne. Were one examining soil erosion through wind, the spatial unit would be quite different. GIS provides the technology to acquire resource information and to partition the information readily into spatial units or regions appropriate for the analysis or management of specific issues and allowing integration between different scales of study. Figure 6.1 illustrates the capacity of GIS to operate at a number of different scales, with the ability to "zoom" into and out of specified scales. This does require, though, that careful consideration be given to data requirements in term of structure and scale. Although one may intuitively want to collect the most detailed and accurate data available, economic considerations usually dictate certain compromises.

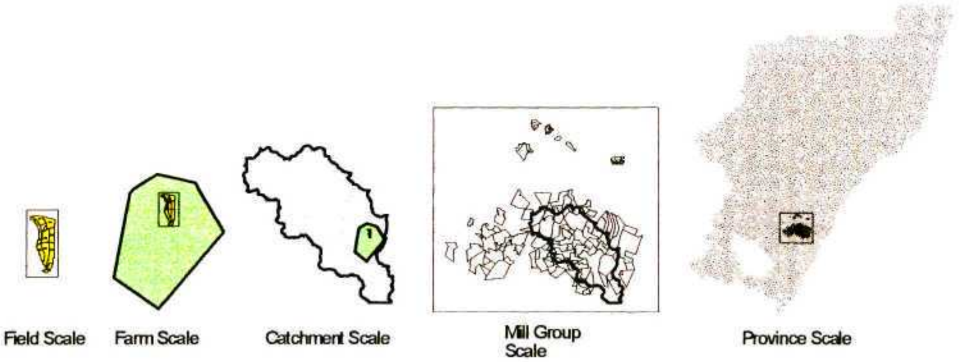

Figure 6.1. An example of the different scales, from field to province, that can be integrated in GIS.

Phenomena such as air pollution from cane fires can clearly operate at spatial scales far larger than the area under the stewardship of members of the Sugar Industry – in this particular case it is feasible to consider that the spatial context of cane burning could be global, owing to particulate transport in high air currents and ozone layer implications (Crutzen and Andreae, 1990). For practical purposes though, the issue would best be handled at a mill-regional scale. Due to katabatic airflow during the night, airflow often follows river valleys, carrying smoke with it during the commonly occurring temperature inversions. Thus in many cases airsheds can conform to watersheds with respect to topographic data requirement.

Issues such as nutrient leaching, water quality and usage, wetlands and estuaries are also most practically dealt with on a catchment or sub-catchment level. The concept of catchment-based resource management has become entrenched in many countries and is particularly suitable in arid countries such as South Africa and Australia where water-related environment issues are critical. Issues pertaining to biodiversity, whilst strictly speaking may be better served by a spatial context based on, say, landscape, biome, vegetation type or land use category, may in certain instances be accommodated in a catchment-based analysis unit. This has other inherent advantages in that the interdependence of various environmental components can be analysed on a common base datum. However this is not a prerequisite given the ability of GIS to integrate disparate data.

Table 6.1 summarises some spatial scales at which, given current technology, it would be feasible to analyse, research or manage some of the major environmental issues impacting upon natural resources of the Sugar Industry. As mentioned, this does not always correspond to the full spatial extent or off-site impacts of the phenomenon itself. Table 6.1 also illustrates the many different environmental management activities carried out by various sectors within the industry that can be supported by GIS input at different scales. Such activities include:

- field and farm-scale planning and record-keeping by farmers themselves, extension officers, soil conservation officers, farm-planning contractors and sugar millers;
- catchment scale activities by researchers, government agencies and CMAs;
- landscape scale activities, usually by ecologists;
- mill region activities, by miller-cum-planters, LECs, extension officers, environmental auditing agencies and researchers; and
- provincial or Sugar Industry-wide activities, by industry management, environmental audit agencies, researchers and government.

	Example GIS Supported Applications at Various Scales					
Issue	**Field**	**Farm**	**Catchment / sub-catchment**	**Landscape**	**Mill region**	**Province / industry**
Soil erosion	Erosion-site Farm plan	Farmer details, Farm plan implemented? Soil types	ICM Soil loss modelling & prediction Downstream impacts	Ecological impacts	Control, prioritise rehabilitation Monitor sites Focus peer pressure	SOE, Env reporting Support & focus research, Spatial statistics
Soil quality	Field manage-ment records, Precision farming	Soil types Mapping degraded zones	Salinity & non-point pollution modelling	Change in ecosystems	Monitor, direct extension & mechanisation advise	
Cane burning	Firebreak plan	Farmer details Sensitive area? Proximity? Altitude	Katabatic flow modelling	Ecological impacts Visual impact	Monitor compliance, Control systems, Recommended burning practices zones	
Habitat / Bio-diversity	Plan field layout for corridors, Layout clear of sensitive areas?	Farmer details, Sensitive area for any species? Record sightings	Alien invasion along watercourses, Riverine vegetation monitoring & rehabilitation	Ecology, shape indices, fragmentation studies, species range and distribution	Monitor indigenous vegetation, plan rehabilitation work & advice	
Wetlands	Fields clear of wetland?	Farmer details, Wetlands on farm?	Hydrology studies, Impact studies, Inventory	Ecosystems impact	Wetland inventory, Monitor changes, Farmer education	
Water use Water quality	Irrigated fields? Fertlizer, pesticide records	Farm details - irrigated? Water control board details.	Cane area, ICM, Hydrology, Impacts on downstream ecology, Non-point source pollution modelling	Impacts on ecology, groundwater impacts	Compliance monitoring, extension focus,	

Abbreviations: SOE = "State of the Environment" reporting, or auditing
ICM = Integrated Catchment Management

Table 6.1. Some practical GIS spatial contexts for the management of Sugar Industry environmental issues.

Chapter 7

GIS AS AN ENVIRONMENTAL MANAGEMENT TOOL

7.1 INTRODUCTION

7.1.1 Definition of terms

A Geographic Information System (GIS) may be defined as:

"A system of hardware, software, personnel and procedures designed to support the capture, management, manipulation, analysis, modelling and display of spatially referenced data for supporting complex planning and management decision-making" (Automated Methods, 1995).

A brief definition of some GIS terms follows[1]:

raster: A geographic data model representing information as an array of equally sized square cells arranged in rows and columns. Each grid cell is referenced by its geographic x,y location. Groups of cells with the same value represent features. Each grid cell has a value that corresponds to the feature or characteristic at that site, such as soil type, rainfall, or vegetation class.

vector: A co-ordinate-based data structure commonly used to represent linear geographic features. Each linear feature is represented as an ordered list of vertices.

point: A single x,y co-ordinate that represents a geographic feature too small to be displayed as a line or area at a particular scale; for example, the location of a mountain peak, nest site, or town (on a small-scale map).

line: A set of ordered co-ordinates that represents the shape of geographic features too narrow to be displayed as an area at the given scale (*e.g.*, contours, street centrelines, or streams), or linear features with no area (*e.g.*, country or province boundary lines).

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[1] Extracted from the ESRI Web site GIS glossary at <http://www.esri.com/library/glossary/glossary.html>.

polygon: A GIS feature class used to represent areas. A polygon is defined by the arcs that make up its boundary and a point inside its boundary for identification. Polygons have attributes that describe the geographic feature they represent.

coverage: A set of thematically associated data considered as a unit. A coverage usually represents a single theme such as soils, streams, roads, or land use.

DEM: Digital Elevation Model. A digital representation of a continuous variable over a two- dimensional surface by a regular array of z values referenced to a common datum. Digital elevation models are typically used to represent terrain relief. Also referred to as 'digital terrain model' (DTM).

topology: The spatial relationships between connecting or adjacent coverage features. Topological relationships are built from simple elements into complex elements: points (simplest elements), arcs (sets of connected points), areas (sets of connected arcs), and routes. Topology is useful in GIS because many spatial modelling operations require topological information.

7.1.2 Organisations using GIS

The last decade has seen an explosive growth in the application of GIS technology by organisations in the fields of: survey; photointerpretation and photogrammetry; image processing; urban and regional planning; real estate; mining; market research; landscape architecture; development; coastal planning; parks and recreation; cartography; water resources; civil engineering; communications; utilities; geoscience; hydrology; land management; ecology; agriculture; forestry; conservation and many others (Dangermond, 1991).

Global revenues for GIS software sales have been growing at an annual rate in excess of 13 percent over the last decade and exceeded $1.3 billion in 1997, according to research company Dataquest (Parsons, 1997).

In South Africa, major GIS users in the field of natural resources management, research and operational planning of possible relevance to the Sugar Industry are (pers. obs.):

- DWAF;
- other water resource management bodies (e.g., Umgeni Water);

- the larger forestry companies, Mondi, SAPPI and SAFCOL and the Institute for Commercial Forestry Research (ICFR);
- National and some of the Provincial Departments of Agriculture;
- CSIR;
- various university departments and institutes;
- CCWR (a service organisation providing GIS facilities to water researchers);
- parastatal research agencies such as Council for Geoscience and the Botanical Research Institute; and the
- KZNNCS.

7.1.3 The elements of a GIS

GIS comprise four basic elements which operate in an institutional context: computer hardware, computer software, data and personnel (Maguire, Goodchild and Rhind, 1991).

7.1.3.1 Hardware

The hardware element may be almost any type of computer platform, from relatively modest personal computers (PCs) to high performance workstations, minicomputers and mainframes. In addition to the standard input, output and storage devices, specialist peripherals are usually required for data input (e.g. scanners, digitizers and tape drives, data output (e.g. large page printers and plotters) and storage (e.g. tape drives and compact disks for data storage and backup) (Maguire, Goodchild and Rhind, 1991).

7.1.3.2 Software

GIS software is generally designed to encompass a wide range of functionality across many disciplines, thus software has developed to sophisticated levels with major packages offering thousands of commands. Software is usually designed for specific platforms, such as UNIX, Windows NT or Windows 95/98, with some vendors offering common functionality across a range of platforms. Some widely used GIS packages in South Africa are (pers. obs.):

- ARC/INFO and ArcView, developed by Environmental Research Systems Institute (ESRI), California;

- Autodesk World;
- MapInfo; and
- Atlas (now owned by ESRI).

7.1.3.3 Data

Data are a crucial and strategic resource in many respects. Establishing a GIS usually entails the collection, verification and storage of large volumes of data. This represents some 70% of the total cost of GIS implementation (Rowley and Gilbert, 1989). Many organisations have specialised data requirements and need to undertake the bulk of the data capture requirements. However, the increasing availability of digital data have enabled GIS users to have access to a wealth of base data (see Section 9.5.2). In this country there is some controversy over the costs imposed by governmental or quasi-governmental agencies for data captured at the taxpayers' expense. These issues have fuelled much debate at GIS conferences and GIS user seminars, without much progress in evidence (pers. obs.).

7.1.3.4 Personnel

With the level of sophistication involved in GIS, specialist GIS staff is required to manage larger GIS installations (World Bank, 1995). It has often been the case that scientists from a wide range of disciplines have migrated into the specialist GIS field (pers. obs.). This is partly due to the previous lack of specialist GIS training at tertiary and post-graduate level and partly due to the manner in which GIS has evolved from small beginnings in a number of organisations. Although desktop GISs have increased the accessibility of GIS to non GIS-specialists, the complexity of the individual system, number of users and sophistication of the applications dictate the number and skill levels of staff required (World Bank, 1995).

7.2 WHY GIS? – UNIQUE ATTRIBUTES

The most obvious unique attribute of GIS is that it is a system designed specifically to manage spatially referenced data. Most decisions made in the management of natural resources and environment require spatial input. GIS has the unique ability to integrate spatial data and related attribute data from many different sources into one framework for manipulation, analysis, modelling, display and storage (Parker, 1988). Coupled to this is the ability of GIS to display results of analyses in the form of graphics – usually topical or thematic maps – which can fundamentally improve the understanding, communication, heuristics and didactics involved in environmental management (Fedra, 1995).

7.3 GIS FUNCTIONS IN AN ENVIRONMENTAL MANAGEMENT CONTEXT

Whilst it is not the intention of this study to provide GIS technical instruction, the following quote by Berry (1996) in his regular GIS World column "Beyond Mapping" is appropriate:

"As a general rule, the confusion surrounding GIS implementation is inversely proportional to the effort spent in assessing what it can do".

Thus, this section explores some of the functionality commonly used in the support of management of environmental issues. It is vital for organisations to know what GIS can do in order to shape thinking to fully benefit from some of its unique capabilities. Rhind (1990) sets out a general classification of the types of generic questions which GIS are frequently used to investigate in Table 7.1.

1	Location	What is at …?
2	Condition	Where are things that fulfil these criteria …?
3	Trend	What has changed …?
4	Routing	Which is the best way?
5	Pattern	What is the distribution..?
6	Modelling	What if …? [Why? How much? Where?]
7	Systems	What effects what? What relationships exist?

Table 7.1. Basic questions that can be investigated using GIS (after Rhind, 1990 and Berry, 1996).

- The *location* question involves querying the geographic database to determine which features occur at an indicated location (*e.g.* who is the owner of an indicated farm?).

- The *condition* question is the converse of this, as it involves finding sites which fulfil certain criteria (e.g. show all farms which encompass environmentally sensitive sites). This type of query often involves more than one type of data and can then be referred to as the 'overlay' or 'intersection' question, as it necessitates finding the intersection of two or more data sets.
- The *trend* question involves monitoring how things change over time (e.g. show cane fields where the pH has decreased since the last inventory).

The remaining questions are more complex, requiring some type of spatial analysis:

- *Routing* involves calculation of the best or fastest route, or 'least cost' routing.
- The *patterns* question allows environmentalists and planners to describe and compare the distribution of phenomena in order to understand the processes which account for their distribution. (*e.g.* an ecologist may use GIS to study how spatial heterogeneity of landscape patterns and shapes influence species distribution).
- The sixth question allows different *models* of real world situations to be evaluated and analysed to provide an understanding of different scenarios, for example:
  - Which areas within a river catchment have soils highly susceptible to erosion according to a soil loss model?
  - What would the effect on potential soil loss be should soil conservation structures be constructed at key locations?
- Finally, GIS can be to integrate information from many different sources to act as a Decision Support *System* (DSS) for decision makers. Good examples of this are found in the increasing number of application of GIS to integrate many systems models and a variety of base data involved in river catchment management (Fedra, 1995).

In order to accomplish these tasks, GISs can use the functionality discussed in the following sections either alone or in combination. This by no means represents the full gamut of GIS functionality, but serves to demonstrate some of the major functionality commonly used in GIS tasks of an environmental nature.

7.3.1 Basic Database Query

This involves simple linkage between point, line or polygon GIS features and a tabular non-spatial or attribute database containing information about the feature. A database field common to both is essential for the link to be made between databases.

E.g. A simple query: *Show and list all farms where soil conservation plans have been implemented in the Eston region.*

Result: A map is returned highlighting these farms in a specified colour. The results could be further classified, say, by ranking the farms by implementation date and assigning different colours to the different years.

Whereas such operations can easily be accomplished by manual means where a small number of farms are involved, the power of GIS data visualisation is evident where a great number of features are involved in the query, and spatial trends can be observed. Such queries can also take into account inherent geographical characteristics of the data, which is beyond the capabilities of conventional alphanumeric information systems:

e.g.: List and show all sugarcane farms without soil conservation plans whose boundaries fall within the Blinkfontein River catchment (Figure 7.1).

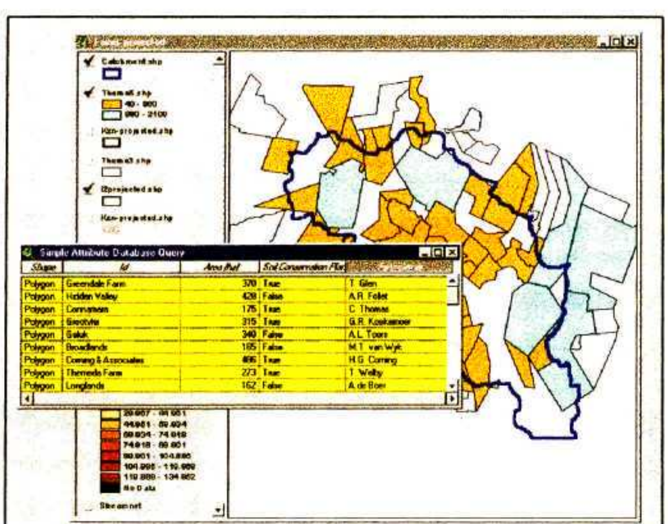

Figure 7.1. Example database query result – farms within a specified catchment without soil conservation plans (in orange).

Further examples of basic spatial database queries are:

- *Show all farms which have undergone environmental audits and classify them according to audit score.*
- *Show all cane fields in the Darnall district where soil pH has decreased over the last five years.*
- *Show all quaternary catchments where sugarcane represents more than 20 % of land use within that catchment.*

7.3.2 Measurement

Because GIS features model the location of those entities in the real world, queries can be made relating to the geographical or spatial attributes of the feature, for example:

- Polygons: *Show the cane and timber plantation distribution in the Mvoti catchment.*
- Points: *Show and list how many sensitive nesting sites occur in the Midlands South region.*
- Lines: *What is the distance from point A to point B or along curvilinear line (e.g. road or river segment)?*
- Volume: *What is the potential dam volume?*
- Area: *What is the area of sugarcane plantations in catchment X?*
- Adjacency: *How many sugarcane farms lie adjacent to areas demarcated as sensitive smoke from sugarcane burning?*
- Proximity: *How many sugarcane farms fall within the Mgeni catchment and within two kilometres of a stream or river?*

7.3.3 Creating a surface from randomly spaced points

Digital elevation models (DEMs) can be constructed from randomly spaced points (Figure 7.2). When the random points represent surface elevation the resulting interpolated topography can be analysed and classified to derive environmental information such as:

- heights between known points;
- slope;
- aspect; and
- curvature (important in soil erosion and deposition modelling).

Secondary information that can be derived from these data include catchment and sub-catchment boundaries, landscape position and flow direction.

There are a large number of environmentally continuous phenomena that lend themselves to modelling and analysis in this way, such as rainfall, temperature, evaporation and many other meteorological statistics, soil physical and chemical properties (Figure 7.3) and in certain cases, species distribution. GIS packages permit the representation of these continuous surfaces through the use of colour (variation and shading), contouring, three-dimensional effects, or a combination of these.

Figure 7.2. A surface created from point data representing elevation.

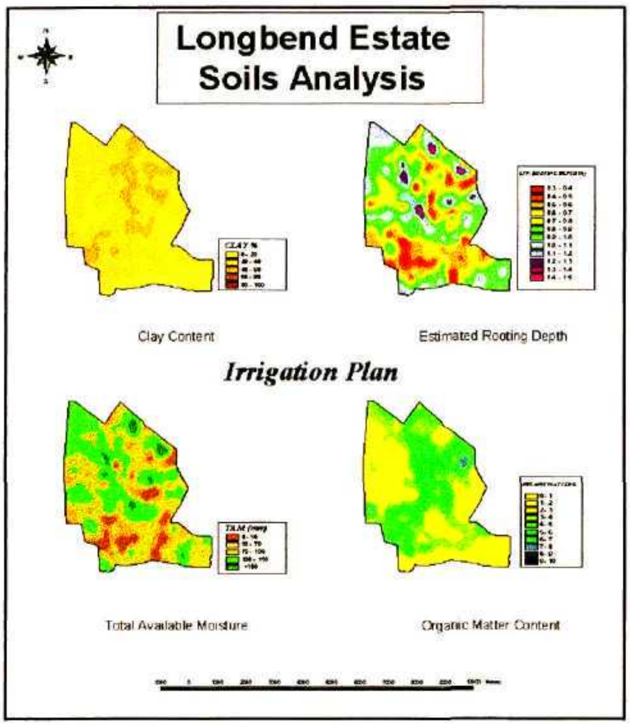

Figure 7.3. Soil properties interpolated from point sampled data to support environmentally sustainable irrigation planning.

7.3.4 Thiessen (or Veroni) polygons

Thiessen polygons are generated from a set of points where the polygons' boundaries define the area that is closest to each point relative to all other points. They are mathematically defined by the perpendicular bisectors of the lines between all points (ESRI, 1996a). This analysis method is used to define a zone of influence for phenomena without interpolating values in between known points as above. Figure 7.4 shows how Thiessen polygons can be used to approximate soil form boundaries from point samples.

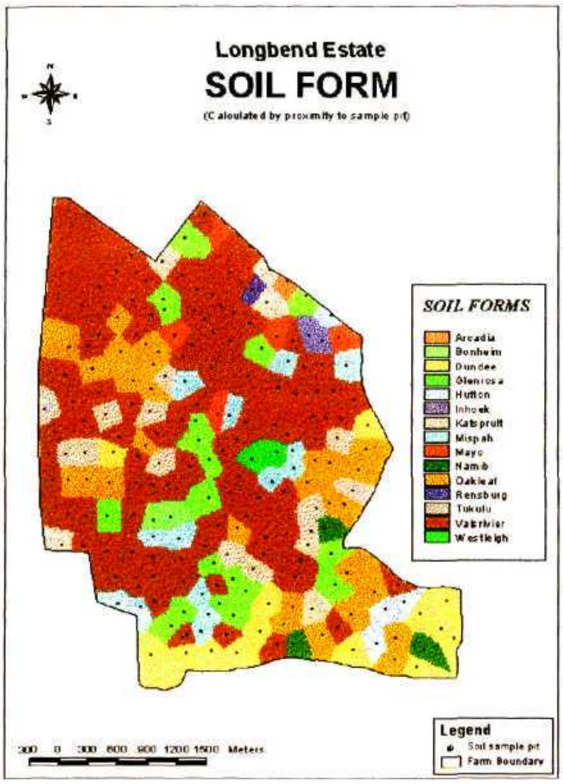

Figure 7.4. An example of Thiessen polygons to allocate soil form properties to the nearest sampled point.

7.3.5 Buffering

Buffers represent zones of specified distance around features. This technique is usually used to define a zone of influence around a feature for various reasons. Buffering of a number of criteria is a commonly used technique in deriving suitable or unsuitable sites for particular operations, *e.g.*:

- To select areas suitable for where sugarcane burning may be carried out without impacting upon sensitive zones, buffer (for example) regions within 500 metres of built-up areas, zones closer than 250 metres to a national roads, zones closer than 200 metres to a school or hospital. The cane areas outside these zones may be freely burnt as required subject to burning regulations.
- Define a buffer around watercourses or wetlands within which, according to law, cane may not be cultivated.
- Define a buffer around a stream within which riparian rehabilitation will be undertaken.

Such buffers need not be strictly linear, but can take into account elevation or changes in elevation for example for flood susceptibility prediction. An example of this (Figure 7.5) may be: *show areas that would be inundated with water given a five metre rise in stream water level.*

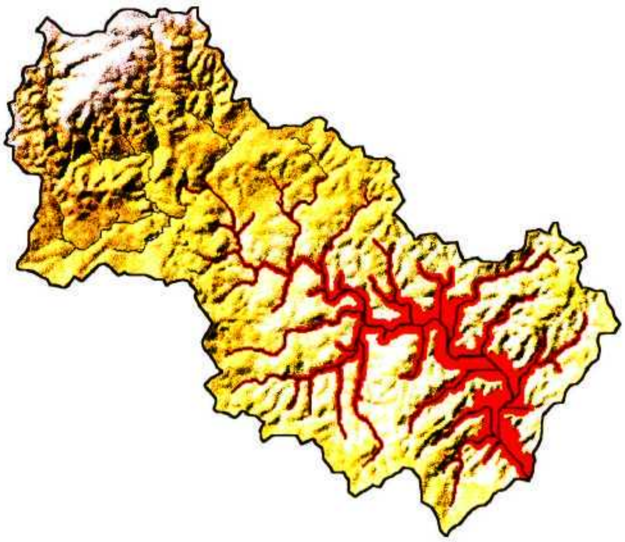

Figure 7.5. Example of non-linear GIS buffering of a watercourse to indicate flood susceptibility (in red).

7.3.6 Reclassification

Reclassify usually refers to the grouping of distributed values into specified classes for ease of visual interpretation. This not only has powerful application in the visual interpretation of data, but also has implications for spatial analysis. For example, slope classes within river catchment X could be reclassified as follows:

- slopes <16% = **1** - suitable for cane growing, low environmental risk (regarding slope only);
- slopes 16 - 22% = **2** - conservation structures / minimum tillage critical, moderate environmental risk; and
- slopes >22% = **3** - too steep for cane growing, high environmental impact risk

Figure 7.6. shows a grid created from reclassification of a slope analysis, given integer values from one to three which can then be used as weighting factors in analysis and modelling. A soil properties grid could be classified from one to three based on

inherent soil erodibility. Multiplied together using cartographic algebra (see section 7.3.8) they yield a very simple sustainability index in terms of erosion susceptibility (see Figure 7.7). This type of modelling is sometimes used by environmentalists or developers to reclassify a wide range of parameters in terms of environmental sensitivity or costs which when multiplied together, yield rankings of development costs or environmental sensitivity (Kuiper, 1999).

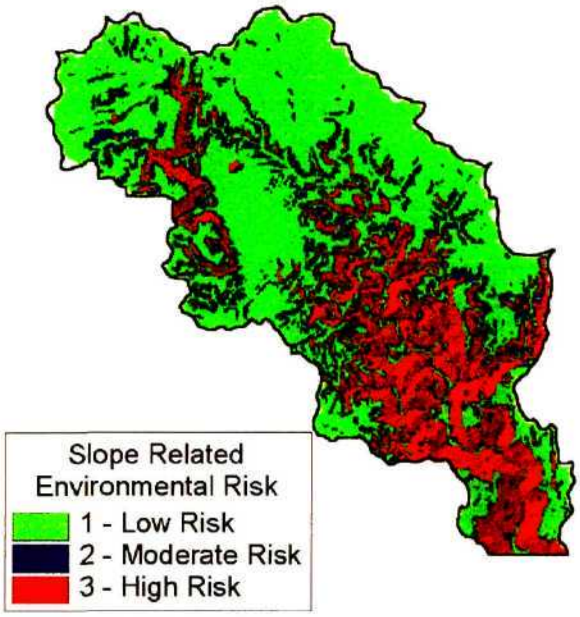

Figure 7.6. An example of GIS reclassification.

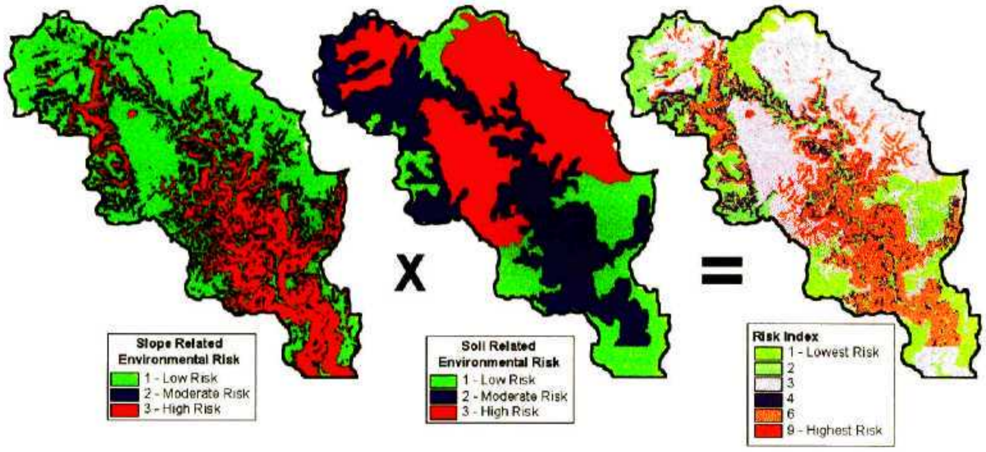

Figure 7.7. Reclassified grids used to derive a simple risk or sustainability index.

7.3.7 Overlay

Overlay is a procedure for predicting the coinciding areas of geographic features, and/or their buffers. This is a powerful GIS function, requiring GIS data to have been created topologically correctly in order for this function to be carried out correctly. Some desktop GISs do not have the capability to do topological overlay (pers. obs.).

Figure 7.8 shows a slope classification coverage overlaid on a coverage showing areas under sugarcane. The resultant coinciding area represents cane areas only, which have taken on the reclassification attributes of the slope coverage, *i.e.*, grouped into three suitability classes. Cane areas on slopes exceeding 22 percent could then be inspected to ensure rigorous soil conservation measures are in place and that no environmental damage is evident.

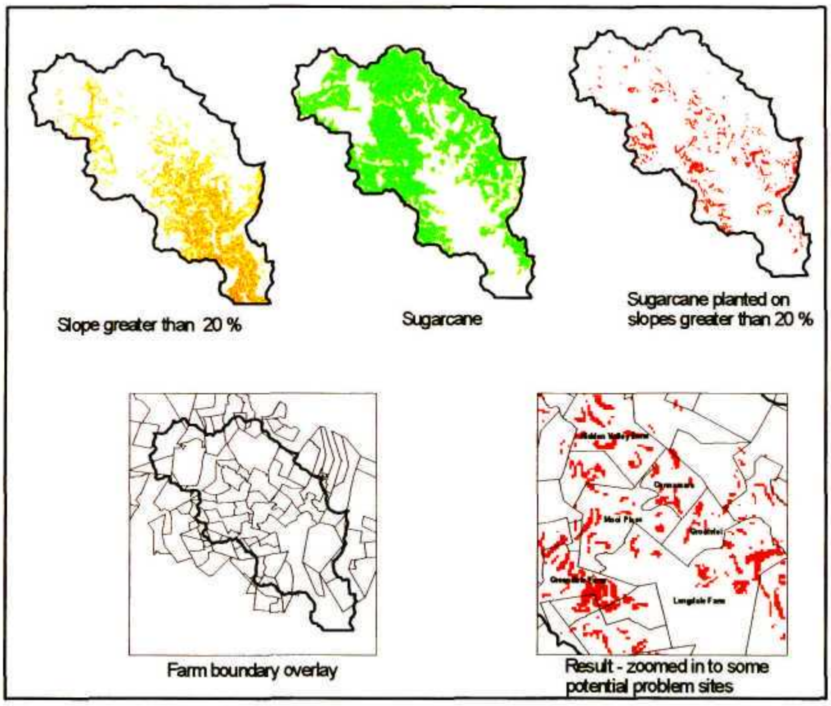

Figure 7.8. Example of overlay of slope classes and cane areas.

7.3.8 Cartographic or map algebra

This involves the use of a spatial "language" that enables sophisticated spatial modelling and analysis to be performed in raster GIS. Using such techniques, mathematical equations or models can be applied directly in GIS, operating on the individual grid cell values. Depending on the software's capabilities, many arithmetic, algebraic, trigonometrical, statistical and logical operators can be used. Operations can be applied at many levels depending on the model requirements. For example new values can be derived:

- on a local grid cell level within one grid;
- within *zones* of a local grid;
- on neighbouring cells; or
- from all of these drawn from separate grids

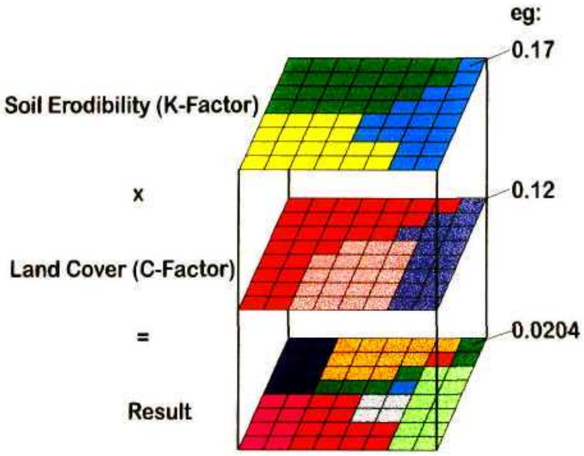

Figure 7.9. A simplified representation of GIS cartographic or map algebra (see also Figure 8.4).

7.3.9 Hydrological functionality within GIS

An increasingly common approach to analysing catchment hydrology using GIS, is to divide the study area into a raster GIS grid with equally sized squares or "cells". The water that enters any cell may flow into as many as eight cells surrounding it. The direction of flow is determined by finding the direction of steepest slope from the centre of that cell to the centre of the ones around it. When the flow direction is determined the output cell is coded with the value representing that direction. If no flow is determined, or if two cells flow into each other, the cell is coded as a "sink". Once these flow directions have been determined, an algorithm can calculate the accumulated flow for the whole study area with a given amount of precipitation. The cells with the most flow are most likely to be stream channels at low elevations and may be identified as such. Cells with no flow accumulation are most likely ridges and may be identified as such. Stream networks are defined by lines of cells through which flow more than a user-defined threshold number of upstream cells. Since the travel path from each cell to the catchment outlet is known, a velocity function of the form:

$$V = aS^b,$$

where S is land surface slope, and and b are land use coefficients, can be used to derive the time of concentration of the watershed (Maidment, 1993), important in the calculation of stream flow hydrographs.

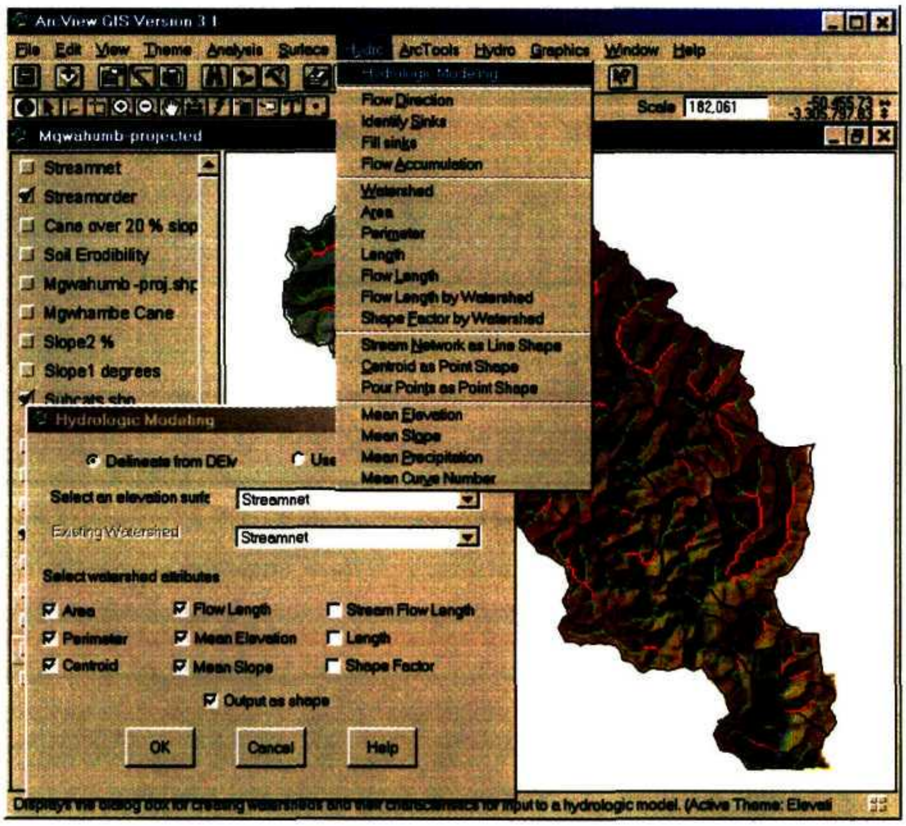

Figure 7.10. Menu-driven hydrology functionality available within ArcView.

Examples of GIS-derived hydrological data for use in GIS or as input to hydrology models are:

- stream lines;
- catchment and sub-catchment definition;
- catchment physiography;
- flow length and direction; and
- curve numbers and shape factors.

7.3.10 Visibility

The visibility function allows one to determine viewsheds from a point on a DEM. This may find application in planning cane development near tourism "hotspots", for example in the Kruger National Park, where tourists have objected to the sight of newly developed plantations and cane fields from certain game viewing sites (pers. obs.) near the Crocodile River.

7.3.11 GIS and image processing functionality

An ability to monitor spatial and temporal changes in land use in cane growing regions is central to the development by government and the Sugar Industry of improved environmental management practises (Johnson and Kinsey-Henderson, 1997). In order to make effective use of the wealth of information contained in the various wavebands of satellite imagery, the use of image processing (IP) software is required. The past decade has seen a progression in the efficiency of links between GIS and IP software (Zhou, 1995) such as ERDAS Imagine and ER Mapper. Basic IP functionality is now available in proprietary GIS packages through the purchase of GIS extensions such as the ArcView Image Analyst. This technology will enhance the ability of non IP-specialists to access information contained in satellite imagery (pers. obs.).

7.3.12 Modelling

Despotakis *et al.* (1993) defined *models* as idealised, presupposed processes and perceptions that are used to approximate the phenomena in the real world. Literature is semantically contradictory in what constitutes a model in the context of GIS. Some workers consider a GIS map to be a form of a model whilst others consider models to be constructions of mathematical processes (Maguire, 1991; FAO, 1999). Semantics aside, the FAO (1999) considers the ultimate use of GIS to lie in its capability for constructing such mathematical models of the real world from digital data which have the ability:

- to simulate the effects of specific processes over time for a given scenario;
- to analyse trends and the identify factors affecting them; and
- to display the possible consequences of planning decisions that affect resource use and management.

Although the objective of any model must be to assist decision making, when models are used in formal decision support structures by a range of users, the term Decision Support System is often applied.

7.3.13 GIS in Decision Support Systems

Decision Support Systems (DSS) can be defined as:

"Analytical tools that can be used to assist the decision maker in assessing the inter-relationships and potential effects of a policy or decision. Analytical results are presented to the user through the visualization and user interface component of the DSS" (van Voris *et al.*, 1993).

Environmental Information Systems, Integrated Information Systems and Resource Management Information Systems are other terms sometimes used to describe similar decision support frameworks (McCloy, 1995). When the tools used include GIS components, the result may be generically termed a Spatial Decision Support System or SDSS (Goodchild, 1993).

Goodchild (1993) states that increasing use is being made of the paradigm of SDSS, in which the technology is made available directly to decision-makers for scenario development, rather than being confined to use by analysts. Fedra (1995) contends that because of the complexity and high dimensionality of decision alternatives that include spatially distributed variables (such as air pollution or soil erosion), a topical GIS map alone is an important component of providing decision support.

Indeed as Maguire (1991) points out, some authors have argued that a GIS in itself *is* a SDSS. Certainly, the incorporation in many GIS products of macro or programming languages, such as Avenue in ArcView or Mapbasic in Mapinfo, enables their use to construct or facilitate the more classically held view of a SDSS. In other cases GIS software itself allows the use of external procedures without the need for additional programming. Such linkages may not be entirely integrated within the GIS, but nevertheless allow the useful combination or linkage of GIS software and models contained in external programs.

The Avenue programming language was used to incorporate a number of external models into a DSS developed by the CCWR in Pietermaritzburg to produce their Integrated Catchment Information System (ICIS) (Dent, 1997, pers. comm.)[1]. The ICIS

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[1] Dent, M. Manager, Computing Centre for Water Research, Pietermaritzburg.

incorporates a number of environmental models, databases – including time-series, graphics and map features into an integrated system which leverages many of the advantages of GIS previously discussed.

Bishr and Mustafa Radwan (1995) identified some limitations and shortcomings in the use of SDSS for watershed management. They contend that watershed management is based not only on spatial analysis and mathematical modelling, but also on experience, preference, intuition, judgement and individual expertise. Whilst these are valid and important issues, it appears that they can be and indeed are addressed in appropriately well-designed SDSS.

Integrated environmental information and decision support systems such as ICIS, with various coupled simulation models, integrated with GIS, feature:

- "transparency" with flexibility and (as far as is practical) user input into design;
- an interactive, menu-driven user interface, that guides the user with messages through the application;
- dynamic colour graphics for the model output and a symbolic representation of major problem components, that allow easy and immediate understanding of basic patterns and relationships (Rather than emphasising the numerical results, symbolic representations and the visualisation of complex patterns support an intuitive understanding of complex systems behaviour. The goal is to translate a model's variables and outputs into readily understood information for the decision making process);
- the incorporation of knowledge and expertise through rule-based models (with the ability to interrogate such rules);
- the linkage between one or several data bases, including GIS and distributed or remote sources of information in local or wide area networks, that provide necessary input information to the models and the user;
- embedded components such as specific knowledge bases allow user specifications in allowable ranges to be checked and constrained, and ensure the consistency of an interactively defined scenario; and

- they are, wherever feasible, built in direct collaboration with the users who are, after all, experts in the problems areas these systems address (after Fedra, 1994; and Dent, 1997).

Walker and Johnson (1996b) provide a detailed overview of a DSS specific to evaluating off-site impacts of sugarcane production. The system addresses land suitability, land use allocation and hydrological impacts of land use change, making extensive use of GIS tools.

Chapter 8
GIS AND THE ACHIEVEMENT OF ENVIRONMENTAL STANDARDS IN SA SUGARCANE PRODUCTION

8.1 INTRODUCTION

Given that:

- land and water resources are a fundamental requirement for sugarcane production;
- land and water resources are variable in space and over time (spatial and temporal variation);
- agricultural processes operate at various spatial scales;
- the major impacts of these processes on soil, water, air and biota occur at various spatial scales; and
- environmental legislation, standards and the monitoring and auditing of these have substantial spatial connotations,

it is obvious that in order to achieve environmental standards and environmental sustainability, the industry needs the capacity to manage vast quantities of spatial information. The requirement for spatial environmental information occurs at many levels and at various scales (see Section 6.2), with differing objectives. Fundamental to all of these objectives, however, should be the need to promote environmental sustainability wherever possible by making the best use of information and technology.

This chapter is not intended as an exhaustive demonstration of GIS applications, but serves to illustrate some of the areas in which GIS could support the Sugar Industry's environmental strategy towards achieving sustainability. The applications discussed are diverse, and include issues of:

- research and understanding of processes and systems in space;
- analysis and measurement of natural resource impacts; and
- general environmental management, planning and monitoring.

8.2 ADDRESSING WATER ISSUES: GIS APPLICATIONS

8.2.1 Introductory review

Most water resources issues have an obvious spatial dimension, and literature, including conventional books, papers and journals as well as Internet World Wide Web pages, abounds with references to the use of GIS in water resources management (Fedra, 1994). The use of computers in water resources planning and management and in design of components of the hydrological cycle is a well developed field with a substantial tradition (Fedra, 1993). Hydrologists van Rensburg and Dent (1997) consider GIS coverages to be fundamental requirements of any water resource analysis concerned with generation of runoff and the use or abuse of water. Developments in the capabilities and speed of affordable computer hardware and appropriate software applications have greatly facilitated the manipulation, processing and display of spatial information using GIS (Tarboton, 1992).

The national Department of Water Affairs and Forestry and regional water authorities such as Umgeni Water have implemented what are possibly the highest investment natural resource management and research GISs in South Africa.

Whilst there are obvious applications for GIS in irrigation planning, with the aim of increasing irrigation efficiencies, there were relatively few references to this type of work in the literature. A wealth of literature, however, was found on the subject of GIS and hydrology. Wolff-Piggott (1995) conducts a detailed review on the linkages between GIS and hydrology modelling.

Hydrological models are usually computerised algorithms which attempt to simplify the characteristics and conditions that influence surface flow over a certain area in reality. These models have day to day practical uses in predicting, for example, runoff and stream flows, erosion rates, sedimentation, the salinisation of soils and non-point source pollution. The construction of a model usually begins with the identification of the most important factors that exert influence over the direction and velocity of surface flow. Every factor affecting surface flow could not realistically be considered, so the model is really only a simplification of the actual conditions present in reality. A GIS is an excellent tool to link physical data describing spatial features of land surfaces with hydrological models, bringing a spatial context lacking in the past (Spence, Dalton and Kite, 1996).

With such simplification comes some limitations which the user must understand when interpreting and evaluating the accuracy of the resulting information (Boyd *et al.*, 1997). Once a model is constructed, varying inputs such as rainfall rate and intensity can be applied to the model to see what the results could be in reality. Such models have applications in areas such as:

- watershed land-use planning and management;
- estimating runoff and stream flows;
- assessing impacts on streamflow of different land use and irrigation strategies;
- erosion management and research; and
- pollutant transport.

In GIS–linked hydrological modelling of the behaviour of surface flow, a critical consideration is topography or, more specifically, slope. One of the first steps is to generate a digital elevation model from which drainage networks (and other physiographic basin parameters) can be derived (Wang and Yin, 1997).

Slope is only one of the many factors influencing surface flow. Spatially variable vegetation cover, soil types, and precipitation over the study area are some factors that are usually considered. As these and other relevant factors are incorporated into the model the more accurate and realistic it becomes. It also becomes more complex and demands more of hardware and software resources. The complexity of the model should be determined according to the needs of the user and the information that will be derived from it (Boyd *et al.*, 1997). In South Africa the availability of DEM data of suitably high resolution data is a often limiting factor in such studies (Howe, 1997, pers. comm.)[1]. Wang and Yin (1997) conducted a detailed comparison of results achieved using different resolutions of DEM data to define basin physiographic parameters in GIS. They found that although high resolution DEMs (e.g. from 5 metre contours) were

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[1] Howe, B. MSc Eng. student, Department of Agricultural Engineering, University of Natal, Pietermaritzburg.

considerably more accurate, certain catchment modelling exercises could be adequately served by broader (50 metre contour) data.

GIS and hydrological models generally operate as separate entities, with varying "degrees" of linkage. A number of papers make reference to this interface (*e.g.* Tarboton, 1992; and Kienzle, 1993) whilst a paper by Stuart and Stocks, (1993) deals specifically with this topic of GIS and hydrological model integration, pointing out the many advantages of a tightly integrated approach where users can conduct all their modelling work within a single environment.

The Department of Agricultural Engineering at the University of Natal in Pietermaritzburg has developed integration between ArcInfo GIS and their ACRU (Agricultural Catchment Research Unit) hydrological model. This link facilitates improved water resources planning and land management decisions to be made with regard to water resources. This system was effectively used in extensive water resources studies of the Mgeni River catchment (Tarboton, 1992 and Kienzle, 1993), and many others.

8.2.2 Potential GIS applications in the environmental management of water use issues in sugarcane production

8.2.2.1 Water use: irrigated sugarcane

In assessing the extent to which irrigation in the SA Sugar Growing Industry achieves or falls short of environmental standards and sustainability, and to help determine the economic contribution of irrigated sugar, a first step would be to determine *accurate* statistics regarding the spatial extent of irrigated sugar. Such information is currently not sufficiently accurately known (pers. obs.). A sugarcane commodity report to DWAF by Lynsky, Schmidt and Sugden (1997) entailed some broad-scale, cursory apportionment of cane into various catchments based on mill estimates and the best available spatial data at that time (Figure 8.1). The estimated water use by irrigation in the various catchments could then be used to give an indication of the percentage of catchment runoff utilised by sugarcane irrigation (see Table 3.1). A considerably quicker and more accurate result could have been obtained had suitable data at a suitable level of accuracy been available in the

SASEX GIS at that time. In the light of the new water legislation it is inevitable that many more tasks of this nature will need to be carried out – either at a catchment, sub-catchment, province or entire industry-scale as in the above case.

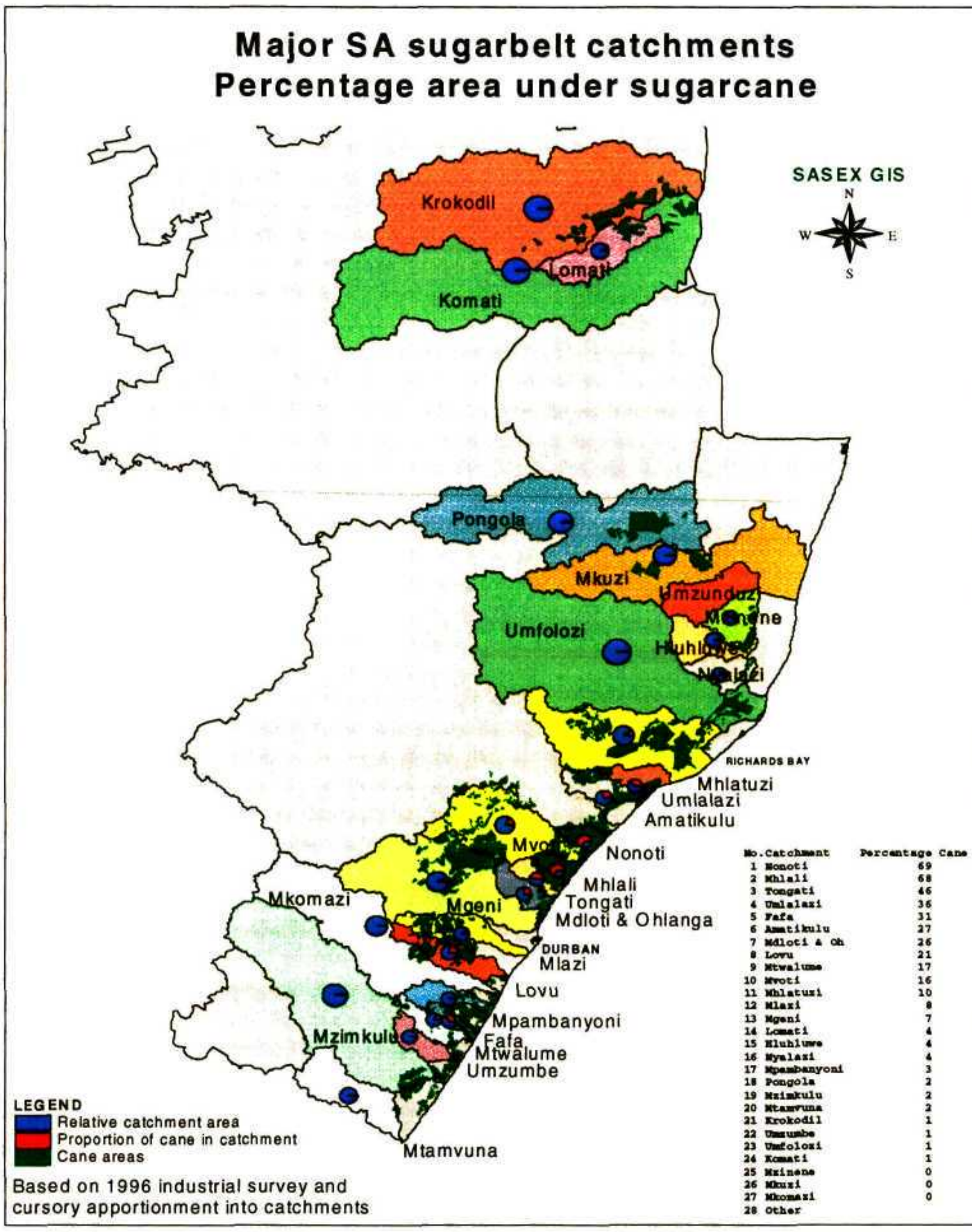

Figure 8.1. Approximate proportion of catchment area under sugarcane (Lynsky, Schmidt and Sugden, 1997).

A detailed regional grower survey could also ascertain the type of irrigation practised: overhead dragline, portable pipe, centre pivot or drip which vary in application efficiency. Such information could be stored at mill group level in the irrigated areas, not necessarily in a GIS, but containing a key identifier that could be accessed by the GIS relational database and linked to the GIS cane area coverage database for spatial query.

The SA Sugar Industry "norms" pertaining to slope restriction, soil depth restrictions and TAM specifications for irrigation have an obvious spatial dimension that lend themselves to spatial analysis and planning supported by GIS.

Using relatively simple GIS techniques one can produce a map at a farm scale, showing total available moisture (TAM) values interpolated from soil sample data. This will indicate irrigation suitability at farm scale for planning and management purposes. GIS slope calculations from a digital elevation model could classify slopes into areas deemed suitable or unsuitable for irrigation. Soil depth data at sample points could be interpolated to demarcate shallow soils for exclusion from irrigation.

On a regional basis (for planning purposes), it is a relatively simple matter to produce a spatially-distributed estimated sugarcane irrigation-demand map using the following GIS-based methodology (Wallace, 1999):

- Obtain the best possible *rainfall* and *potential evaporation* data interpolated as a grid over the study area. (For practical purposes median monthly gridded data is readily available from the Department of Agricultural Engineering, University of Natal. A shorter time-step would produce better results, however.).
- Compute the *runoff* factor (C) as a grid in GIS. The C-factor can be determined in GIS as a function of slope, soil properties, a vegetation factor for sugarcane and average annual rainfall.
- Multiply the rainfall grid by the runoff factor C to determine *effective* rainfall.
- Multiply the evaporation grid by the relevant monthly crop factors for sugarcane to convert evaporation to estimated plant *potential evapotranspiration*.
- Subtracting the effective rainfall grid from the crop evapotranspiration grid gives a resultant grid of estimated monthly nett irrigation required per grid cell.

These values can then be reclassified according to user requirements, and thematic maps produced.

The resulting maps can be used in regional planning to demarcate irrigation requirements through the year. This basic information can be further used in GIS in a number of ways. Sub-catchment boundaries can be overlaid onto this grid. The monthly runoff produced in the sub-catchment can be estimated from recorded flows if it is gauged, or it may be calculated using a linked hydrological model (the suitably accurately mapped cane areas to be irrigated must be available in GIS). From this type of process, the best estimate can be made of the impacts of nett irrigation on the available water resource per sub-catchment, and suitable irrigation strategies can be formulated accordingly, in order to meet environmental standards and sustainability within the catchment.

Obviously sugarcane is unlikely to be the sole land user within the catchment. The presence of the impacts of other land users within the sub-catchment require an integrated approach to catchment management – a requirement entrenched in new water legislation for application in certain catchments (DWAF, 1996). In terms of the new Water Act, the SA Sugar Industry will be required to participate in Catchment Management Agencies in certain cases. The usefulness of GIS in catchment management has been demonstrated in the Australian Sugar Industry (Walker and Johnson, 1996a) and locally by the CCWR (pers. obs. and Dent, 1997, pers. comm.)[1].

A major cause of inefficient irrigation by growers is the rigid adherence to irrigation cycles which do not allow for temporal variations in the soil water balance, and spatial variation in rainfall, evaporation and soil properties. SASEX promotes irrigation scheduling based on scientific principles using evaporation pans and where available, automatic weather stations, soil moisture monitoring and crop growth models (Lynsky, Schmidt and Sugden, 1997).

From the monthly nett irrigation grid described above, a daily nett irrigation requirement can be calculated by using averaged daily data in the calculation. The

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[1] Dent, M. Manager, Computing Centre for Water Research, Pietermaritzburg.

TAM discussed above is a measure of the quantity of water that a soil can hold in millimetres, and as a rule of thumb, water content should not be allowed to drop below 50 percent of the TAM. By simply dividing 50 percent of the soils TAM by the daily nett irrigation required, an optimum irrigation cycle could be derived for planning purposes. It would be a simple process to classify these cycle values and plot a thematic map showing the optimum predicted cycle time for a given location.

Work is in progress at SASEX to develop links between GIS and parts of the CANEGRO model (Schmidt, 1998, pers. comm.)[1]. The combination of the *temporal* capacity of the CANEGRO water-balance algorithm with the *spatial* data handling and display of GIS could produce an excellent product with both commercial and environmental value in terms of improved irrigation efficiency.

8.2.2.2 Water use: rainfed sugarcane

The proposed rainfall interception levy (DWAF, 1997) on major land users such as timber and sugarcane have brought into sharp focus the vital need for accurate spatial data on sugarcane distribution within catchments. The Sugar Industry is strongly opposed to the principles of the levy and argues its case largely on spatial grounds (Lynsky, Schmidt and Sugden, 1997). To attempt to demonstrate that dryland sugarcane does not have a major effect on downstream water supply it will need to show:

- the proportion of cane in catchments/subcatchments;
- the position of the catchment;
- the proximity of the cane and the catchment to the sea – i.e., to show that cane is mostly in the lower reaches of catchments, with correspondingly fewer conflicts with competing water users downstream (Lynsky, Schmidt and Sugden, 1997); and then to
- attempt to demonstrate by means of accepted models that sugarcane consumes considerably less water than competing land uses such as timber plantations (Schmidt *et al.*, 1998).

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[1] Schmidt, E.J. Head of Agricultural Engineering Department, SASEX.

8.2.2.3 Impacts on water quality

Preliminary work would seem to indicate that impacts on water quality resulting from sugarcane production are not widespread. Nonetheless, there is acknowledgement that the subject is not adequately researched (see section 3.2.1.4).

Wolff-Piggott (1995) in a report to the Water Research Commission provides a thorough analysis of linkages between non-point source water pollution models and GIS. His particular point of departure was the increase in stream salinity resulting in areas of high intensity irrigation. GIS applications in this area may be of relevance to the SA Sugar Industry in the northern irrigated areas. This type of application will certainly fall within the scope of Catchment Management Agencies' SDSSs relevant to sugarcane in the future.

The industry may also be proactive by using GIS to analyse monitored water quality data in sensitive catchments under its stewardship. This could be done by forging closer links to water management agencies who routinely sample water quality and assess such data spatially in GIS, such as Umgeni Water (Randall, 1996, pers. comm.)[1].

8.2.2.4 Catchment management

In light of the emphasis placed on integrated catchment management, it can be expected that much of the SA Sugar Growing Industry's GIS input in water management issues in the future will be as participants in catchment based initiatives (DWAF and WRC, 1996). Figure 8.2 illustrates the potential role that can be played by GIS in catchment management. In this example, GIS forms the basis of an information system with:

- decision support capacity through links to environmental models;
- catchment database, inventory and modelling capacity;
- spatial analysis capability and associated inputs to hydrology and crop water use models; and

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[1] Randall, L. GIS Scientist, Umgeni Water, Pietermaritzburg.

- the graphic user interface optimised for simplified data visualisation by a range of users and communication capability for environmental reporting.

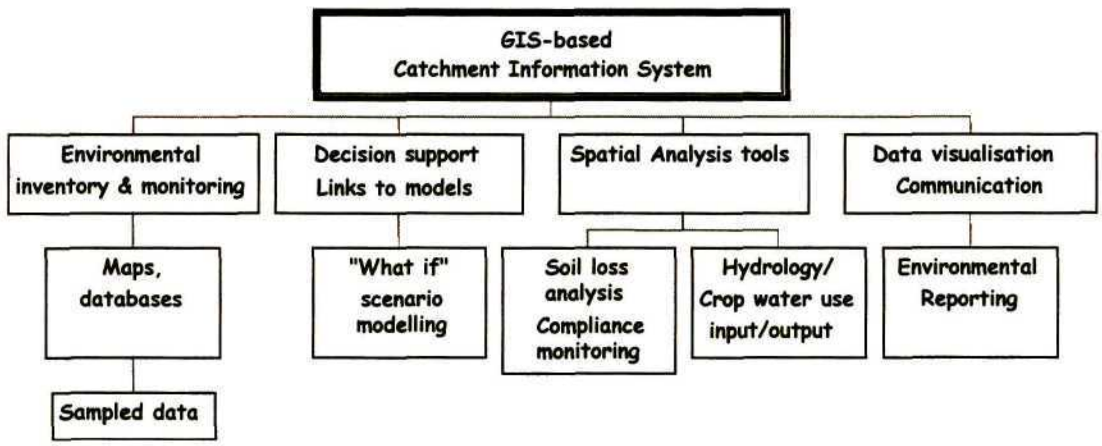

Figure 8.2. An example of a GIS-based information system for catchment management support (Wallace, 1997a).

8.2.3 Summary

Application of GIS in addressing water issues is a well-developed field with a substantial body of literature available. Considerable skills exist in various local universities and water resource management institutions in this field. Table 8.1 summarises examples of some of the key applications areas where GIS can support environmental management decisions in striving for sustainability and acceptable standards in water use issues.

Issue	Scale	Example GIS applications	Decision support to...
Water use: irrigated	Farm	➢ Soil properties – spatial analysis ➢ TAM interpolation & mapping ➢ Slope analysis ➢ GIS-linked water balance model (irrigation scheduling)	Irrigation planners Farmers, Researchers
	Mill supply region or subregion	➢ Regional norm establishment for mean irrigation demand and approximated cycle times	Farmers, Extension officers, regional planners
	Catchment	➢ Irrigation demand analysis ➢ Hydrology modelling ➢ Irrigation feasibility study support ➢ Catchment water use impact assessment	Researchers, Land use planners, CMAs
	Sugar Industry / Provincial	➢ Irrigated areas spatial database ➢ Catchments spatial database ➢ Industry water use statistics database	Industry management, Government
Water use: rainfed	Catchment	➢ Sugarcane areas per catchment database ➢ Crop water use studies, impact assessments. ➢ Rainfall levy "defence" support	CMAs, Industry management, Government
Water quality	Catchment	➢ Non-point source pollution monitoring ➢ Salinity modelling support	Researchers CMA's

Table 8.1. Summary of GIS applications addressing environmental management of water issues in South African sugarcane production.

8.3 ADDRESSING SOIL ISSUES: GIS APPLICATIONS

8.3.1 Introductory review

8.3.1.1 Mapped inventories of soils & soil properties

The importance of a mapped database inventory of soils and soil properties is stressed by a number of workers. Smith and Grundy (1997) report on the perceived importance to the Queensland Sugar Industry of a statewide integrated spatial data infrastructure. They note that soil data in a GIS can be effectively used by both production and environmental applications. Sombroek and Antoine (1994) describe the benefits of GIS soil-based applications as used by the FAO in projects at a range of scales in various land degradation and fertilizer recommendation projects. Locally, the Institute for Soil, Climate and Water has produced an extensive inventory of GIS soils data from the Land Type Survey data, available for purchase by GIS users. This data can be manipulated to produce environmentally vital information on a broad scale, such as erodibility, soil depth and production potential. Such GIS data has been recognised as being strategically vital by the South African *LandCare* program - an initiative to optimise sustainability of natural resources (NDA, 1999b). Matching soil capability to production systems using GIS technology has become a common procedure in development to ensure the system has the capacity to remain sustainable (Antoine, 1997).

Knowledge of spatial dimension of soil types and properties is crucial in addressing many of the problems facing this resource in the SA Sugar Industry. Whilst the industry has considerable soils data on paper maps, the advantages of a digital inventory are numerous and include:

- ease of accessibility - intranets, Internet;
- ease of overlay applications;
- spatial aggregation of data from various sources;
- direct use in spatially distributed models;
- simplified queries;
- simplified spatially monitoring of temporal degradation;
- the ability to relate two-dimensional data with the three-dimensional, e.g. elevation, aspect, curvature, terrain position;
- ability to use in precision farming activities; and
- easier production of State of the Environment report maps and subsequent monitoring.

8.3.1.2 Soil survey and pedology

The advances in soil landscape modelling in GIS improve understanding of soil formation processes and allow improved prediction of soil properties in unsurveyed areas (Gessler, 1996). Qualitative information can also be added to existing soil data using geomorphic and pedological associations with terrain form obtained from DEMs and GIS models (James and Burkart, 1998).

8.3.1.3 Precision Farming

Precision farming, whilst primarily a commercially driven exercise, has as one of its aims, the reduction of inputs to levels within the environmental tolerance (O'Riain and Mills, 1998). Thus environmental impacts arising from over-fertilization, such as soil acidification, may be reduced. Spatial soil data is critical in achieving its aims. Usually a level of accuracy required is such that detailed field surveys need to be undertaken with interpolations between these points carried out in GIS to form a continuous surface. GIS analyses of nutrient levels are used to determine precise fertilizer application rates which are applied variably within a field, as opposed to traditional whole-field "blanket" application rates.

8.3.1.4 Mapping, modelling and monitoring of degraded sites

There is a wealth of literature available dealing with the use of GIS in the mapping, modelling and monitoring of degraded sites. Approaches include:

- using satellite data to identify, model and monitor erosion sites (Randall, 1991 and 1993; Lantieri *et al.*, 1996; and Zhou, 1990). Lantieri *et al.* (1996) included a cost benefit analysis, which estimated benefits of US$75 million (diffused over the regional economy), through implementation of a soil erosion susceptibility monitoring program in Panama. This benefit was made after:
  - improved conservation planning led to greater retention of soil and the nutrients within the soil;
  - costs for clearing silt from state infrastructures were reduced; and
  - productivity increased due to focused land conservation practices;
- linking various soil-loss models to GIS (Howe, 1996, pers. comm.)[1] in an attempt to identify and map sediment sources and simulate sediment yield on a catchment basis (Kienzle and Lorentz, 1993);
- predicting soil erosion by applying the Universal Soil Loss Equation *within* GIS (Wallace, 1997b; McCloy, 1995; and Mander *et al.,* 1993). There is no simple procedure for estimating soil erosion potential in a catchment, but simple empirical methods do, however, meet most of the requirements for initial

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[1] Howe, B. MSc Eng. student, Department of Agricultural Engineering, University of Natal, Pietermaritzburg.

planning and design, and in the absence of gauged data form a suitable basis for soil conservation decisions (Schulze and Lorentz, 1995). The Universal Soil Loss Equation (USLE) or revisions thereof, are widely used estimators of long term average annual soil loss. Much local research has been carried out on components of the equation, making its application relevant to local conditions, and for this reason it was deemed to be a suitable soil loss estimation model for use in estimates of soil erosion susceptibility on a catchment basis (Schulze, 1995; and Mander *et al.*, 1993). The GIS approach entails dividing the catchment into small cells, making the application of field scale models, such as the USLE a practical option. The cells in each theme (*e.g.* slope or soil erodibility) can then be computed as variables in algebraic calculation (see Section 8.3.2.2);

- using GIS to analyse the spatial and temporal extent of acidification over time (Schroeder, Robinson, Wallace and Turner, 1994);
- modelling and mapping salinity sites through interfacing a salinity model and GIS (Corwin, Rhoades and Vaughan, 1998). Researchers in Australia have mapped salinity with great success using GIS and fairly simple spatial modelling techniques (Australian Academy of Science, 1999); and
- predicting salinity through topographic position. Roberts, Dowling and Walker (1997) developed a GIS based salinity model called FLAG, based intensively on topography. Researchers found that salinity and waterlogging could be effectively predicted by modelling position in the landscape in terms of slope, position in relation to surrounds and rate of change of slope (curvature). The model is suited to rapid assessment in places where parameter rich models remain wanting for adequate data.

Hamblin (1998) makes extensive reference to the use of GIS in monitoring and mapping of soil acidity and salinity in Australia for their State of the Environment report.

8.3.2 Potential GIS applications in sugarcane soil erosion management

8.3.2.1 Soil inventory

As a fundamental resource impacted upon by sugarcane production, the best available soil data and tools for managing that data should be readily available to decision makers. Whilst soil specialists within the industry have an enormous knowledge base of soil properties (pers. obs.), the consolidation of this information into a central GIS is imperative for the reasons discussed above. The usefulness of GIS in providing soil specialists with interpolated terrain and rainfall information to help predict soil types has been briefly explored in a project in the Midlands South area (pers. obs.). Using recently developed techniques, GIS can be used to model topographic position (*e.g.*, crest, midslope, footslope or valley bottom) from DEMs (Wallace, 1999) and other geomorphic data important in soil formation processes. Figure 8.3 indicates the results of a GIS model-run to determine terrain position. Such capacity would prove useful in helping to fill gaps in SASA's regional soil database, for example, in newer areas not covered by previous reconnaissance surveys and adding value to existing soils data.

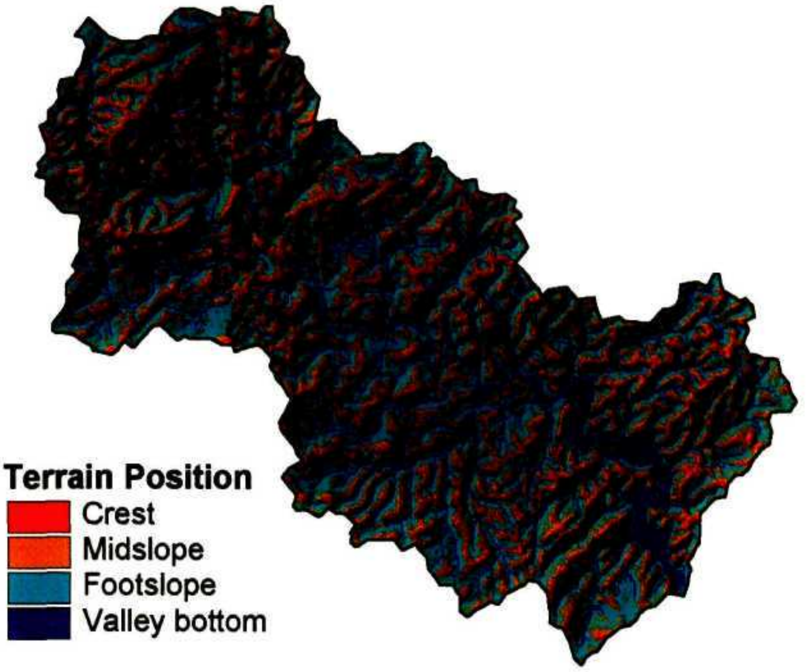

Figure 8.3. Terrain position determined by GIS modelling of DEM data.

8.3.2.2 Soil erosion mapping and modelling

The extent of visible erosion sites can be mapped in GIS using aerial photography, satellite imagery, digital orthophotography or GPS as source data. This information can serve as an inventory of the baseline "State of the Environment" from which future advances (or regressions) can be evaluated (Thurgood, 1996).

Over half the SA Sugar Industry's soils are considered "highly erodible" (Platford and Bond, 1995). Using a soil loss estimator model such as the Universal Soil Loss Equation (USLE) in a GIS environment enables the production of maps (usually on a catchment basis) classified according to predicted erosion potential. GIS provides an ideal environment for combining spatially distributed data such as topography, soil erodibility, land cover, climate data and field management practices which are required in such exercises.

The USLE in its classic form (Wischmeier and Smith, 1978) is:

A = R K L S C P

where

A	= The long term average soil loss per unit area ($t.ha^{-1}.annum^{-1}$)
R	= an index of rainfall erosivity ($MJ.mm.ha^{-1}.\ h^{-1}\cdot annum^{-1}$)
K	= soil erodibilty factor ($t.ha.MJ^{-1}.mm^{-1}$)
LS	= slope length and gradient factor (dimensionless)
C	= cover and management factor (dimensionless)
P	= support practice factor (contour banks, etc.) (dimensionless)

Since all these factors have an explicit spatial dimension, GIS has become widely used as an appropriate framework in which to integrate the disparate data needed to perform the analysis (McCloy, 1995; Bishr and Radwan, 1995; and Kienzle and Lorentz, 1993). Wallace (1997b) describes the implementation of this method to determine soil loss potential in a 20 000 hectare river catchment in the SA Sugar Industry. Input data for this exercise consisted of:

- a DEM constructed from 1:10 000 orthophotos from which slope and the slope length factor, LS, was derived (using the method described in Schulze (1979));
- interpolated rainfall data (sourced from the CCWR);

- rainfall erosivity data, R, computed in GIS from a relationship between mean annual rainfall and altitude;
- soil information derived from GIS Land Type data from the ISCW (ISCW, 1993) from which inherent soil erodibility, K, was estimated;
- LandSat TM satellite data from which the cover and management factor C was estimated; and
- farm maps at field scale from which the support practise factor, P, could be estimated.

Through manipulation of the equation's factors using cartographic algebraic functions, a map was produced showing the potential average annual soil loss spatially distributed over the catchment (Figure 8.4). The GIS model calculated the average expected soil loss to be 6.6 t/ha/year with a range from zero to over 65 t/ha/year. This does not necessarily equate to the amount of sediment transported out of the catchment, but is an indication of soil erosion potential at the indicated position. The USLE was designed to estimate soil loss from rill and inter-rill erosion (McCloy, 1995) and can not take into account factors such as stream bank and gully erosion.

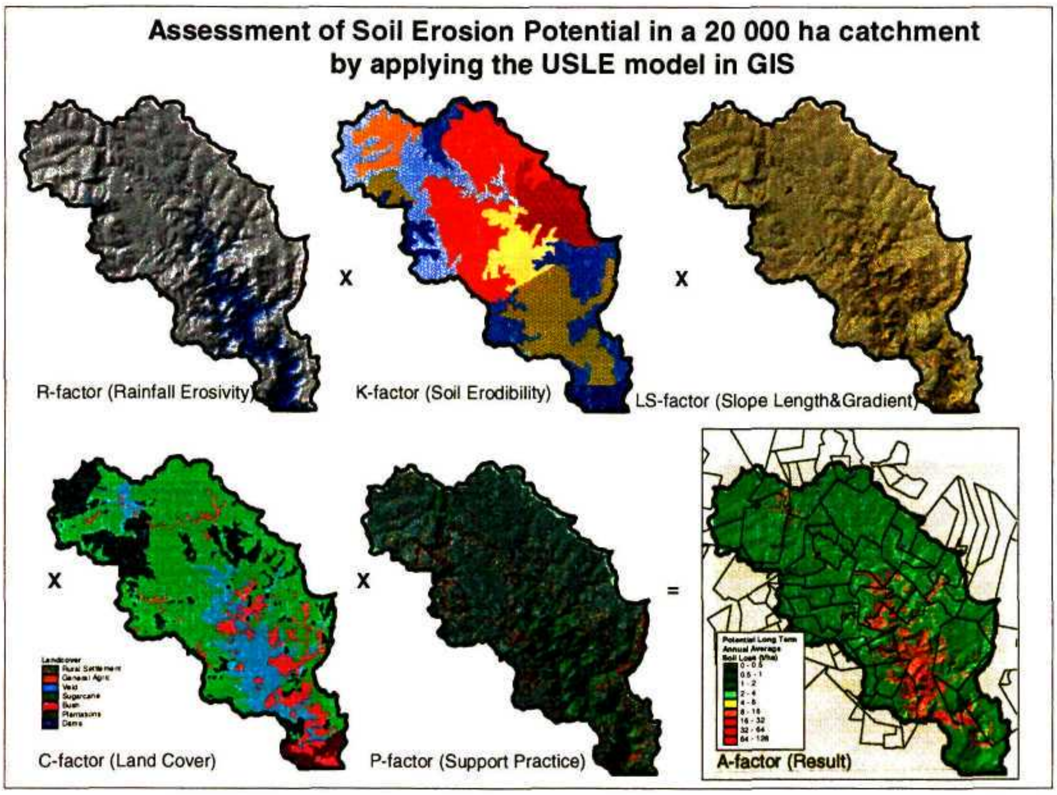

Figure 8.4. Assessment of soil erosion potential on a catchment basis through application of the USLE in GIS.

Other GIS maps such as roads and farm boundaries can then be overlaid on the resultant catchment classification and supplied to field workers to carry out further investigation in order to:

- focus field investigations toward potential problem areas with respect to soil erosion mitigation;
- model the potential effect of temporal changes, such as changes in land cover or management practices on soil erosion potential;
- observe whether agricultural operations in high soil loss potential areas conform to environmental standards;
- reassess standards if they are met and erosion still occurs;
- be used as educational media at environmental meetings e.g. to promote implementation of soil conservation plans to ensure sustainability; and to
- help ascertain whether river sediment loads emanate from sugarcane growing related activities and not from factors such as overgrazing by other catchment land users.

The same objectives are served through various classes of linkages with the many other soil loss or sediment prediction models. As evidenced elsewhere in this document, GIS is becoming routinely used in integrated catchment management. The information derived from soil erosion potential and sediment transport GIS-based models may be integrated in such exercises to demarcate areas of high soil erosion potential to catchment stakeholders, decision makers and other interested or affected parties up or downstream.

8.3.3 Potential GIS applications in managing sugarcane soil quality

It is clear that the spatial extents of many soil degradation processes in the Sugar Industry (as is the case nationally) are unknown. Given a GIS database of field-scale farm maps, it is a potentially simple process to link these to SASEX's field record (FRS or Fieldwatch) and fertilizer advice service (FAS) databases or any other field chemical sampling dataset. Due to a historical lack of co-ordination between the GIS and the other SASEX databases, considerable manual manipulation of FRS or FAS data is usually required in order to link to or import these databases into GIS (pers. obs.). This is due mainly to incompatibility between field numbers in field records and those on maps, due to on-farm changes of numbering, or the common addition of a prefix or suffix to the number by the farmer to identify samples. This reduces the (potentially) automatic one-to-one linkage in the relational database to a tedious manual operation.

The result of this linkage produces thematic maps of a variety of soil properties, such as salinity, pH or aluminium toxicity, with the ability to calculate areas of such phenomena, and changes in these areas over time.

The extent of degraded sites may also be mapped through the use of GPS or aerial photography, where the phenomena or its impacts are clearly visible, or through remotely sensed multi-spectral data where applicable. The power of GIS lies in its ability to analyse entire regions in this way, given appropriate data, and to visually and statistically display temporal changes (Zhou, 1995). Rates of change in intensity and extent may be thematically displayed. Thus one could use the results of such analyses as indicators of a move toward or away from agricultural sustainability.

On a broader scale, GIS linkages to existing models or implementation of GIS spatial models such as the FLAG salinity model can be used to predict the occurrence of soil degradation problems (Roberts, Dowling and Walker, 1997). Usually this is done at landscape scale or at catchment/subcatchment scale in certain cases. It is unlikely that such models could be applied "off-the-shelf" to provide accurate results. Since most are developed under different conditions overseas, they would need to be calibrated and field-verified to local conditions.

The successful implementation of such models would provide the following in terms of soil degradation phenomena:

- valuable input to their research;
- an indication of their spatial dimensions - particularly valuable in areas where field records are not available; and
- an indication of the impacts of management or land use changes.

8.3.4 Summary

Table 8.2 summarises some of the potential application areas for GIS in supporting the environmental management of soil issues.

Issue	Scale	Example GIS applications	Decision support to...
Soils: general	Farm	➢ Soil interpolation from pit samples ➢ Soil maps	Farmer, Farm planners, Irrigation specialists
	Mill supply region / subregion	➢ Soil interpolation and modelling from known points and local knowledge ➢ Site selection for sustainable production	Regional planners, Extension officers, researchers
	Industry	➢ Industry GIS soil database	All levels
Soil erosion	Farm	➢ Slope analysis ➢ Erodible soil mapping ➢ Overlay analysis for (slope restriction) compliance monitoring ➢ USLE-type modelling ➢ Assess compliance	Farmer, Farm planner Extension officers, Researchers
	Catchment	➢ Mapping erosion sites (satellite, GPS, air photo) ➢ Catchment-based soil loss potential models ➢ Monitor spatial changes	LECs, Extension officers, Regional planners, Researchers
	Sugar Industry / Provincial	➢ Spatial analysis of industry erosion statistics ➢ Baseline data for environmental reporting	Industry management, Government
Soil quality	Field - Farm	➢ Database queries on field agrochemical, nutrient and pH records (FAS, FRS, Fieldwatch, individual records)	Farmers, Extension officers, Researchers
	Mill supply region	➢ Spatial mapping and analysis of degradation problem areas	Extension officers, Regional planners, LECs
	Landscape	➢ Salinity modelling (FLAG model) ➢ Spatial analysis	Researchers, LECs
	Catchment	➢ Hydrology-linked soil-quality models	Researchers Planners, CMAs
	Sugar Industry	➢ Soil quality database	Industry management

Table 8.2. Summary of GIS applications addressing environmental management of soil issues in South African sugarcane production.

8.4 ADDRESSING SUGARCANE BURNING: GIS APPLICATIONS

8.4.1 Introductory review

Air pollution, having an obvious spatial dimension, is addressed by a number of spatially distributed models that describe phenomena in one, two or three dimensions. Whilst these models simulate the dynamics of atmospheric pollutants, they cannot, on their own, take into consideration the geographic attributes of the areas under the influence of the pollution. It is when these models are combined with GIS that they can begin to more fully describe environmental impacts of a pollutant and be used in the management and mitigation of air pollution.

A number of industries have found GIS to be a suitable data manager for tracking emissions and for integration with models to estimate downwind impacts. Osborne and Stoogenke (1995) describe a PC-based GIS application called pcAIR. The choice of a GIS platform was made for the following reasons:

- dispersion modelling analyses depend on mapped (spatial) data such as pollution source, receptors (to log pollutant levels), terrain and climatic data sources;
- many of the geographical and analytic functions required are fundamental GIS operations, thus sparing additional programming; and
- GIS is adept at handling and integrating large data sets from many different sources, including input and results from independent dispersion models.

The system was designed with the aim of providing environmental managers with a tool to assist in decision making to maintain regulatory compliance (Osborne and Stoogenke, 1995). Balagopalan (1998) found further advantages to such methodology in that GIS enabled his organisation to provide spatial information to the public and to assist in the development of internal pollution mitigation rules and regulation – important issues for the Sugar Industry to consider.

In Durban a locally developed model and associated data and monitoring infrastructure is used to predict and track pollutant dispersion from the dense industrial area in the south of the city. The GIS functionality in this case was incorporated in the model itself (Coetzee, 1996, pers. comm.)[1]. In Denver, Colorado, an advanced GIS-based system has been developed to predict plume spread and health effects from toxic chemical emergencies. The system can predict plume paths accurately and timeously, even in complex terrain (Hodgin, 1997).

Literature regarding the use of this GIS-linked dispersion modelling technology in planned agricultural burning management seems scarce. Workers in the Department of

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[1] Coetzee, G. Chief Air Pollution Control Officer, Department of Health, Durban.

Forestry (DOF) in Florida, with the help of collaborators, however, have implemented a GIS-based fire management system of particular relevance to the SA Sugar Growing Industry (Brenner, 1996, pers. comm.)[1]. Sugarcane growers in Florida are subject to strict burning restrictions based primarily on wind speed and direction and proximity to populated areas (Runge, 1995). Permits need to be obtained before burning may proceed (Echavarria, 1995). The DOF has implemented a GIS-based system which allows their duty officers to use GIS data and dispersion models, together with current weather information and forecasts to predict if the smoke plume resulting from an open burn is likely to enter any known smoke sensitive areas.

The Florida Fire Management Information System (FFMIS), as this system is known, provides core GIS functionality to support both Florida's wildfire and prescribed fire management programs. The FFMIS uses geographical, meteorological, climatological and informative data in its calculations and products (Brenner *et al.*, 1997). Key to the prediction of plume behaviour is the *Atmospheric Dispersion Index* (ADI). This is an integer greater than one, reflecting the efficiency with which the atmosphere can carry gaseous or small particulate matter away from their source. The ADI uses upper air and surface observations to estimate a mean wind vector and an upper mixing height in which turbulent mixing aids dispersion of pollutants. The source of weather observation data is from 110 weather stations located in and around Florida, extending a few hundred kilometres outside the region of interest. A GIS tool called Spatial Fire Management System (SFMS) is then used to create raster GIS grids from the weather observations to predict fire behaviour. Since weather data is only available at specific locations, it is necessary to obtain values for the grid cells in between using Inverse Distance Weighting interpolation techniques. All other GIS inputs of factors influencing fire behaviour are also in grid format, including fuel type, elevation, latitude, slope and aspect. These maps are also made available to interested parties on the World Wide Web.

Should a sugarcane grower need to burn a field, he makes a call to the DOF duty officer. The duty officer then calls up an electronic authorisation form, into which the grower's details are entered, as well as the location of the burn. A map is then

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[1] Brenner, J. Fire Management Administrator, Florida Division of Forestry, Florida.

presented, showing GIS data such as roads, lakes, landmarks, towns and hospitals. The map is automatically scaled and "zoomed" to the location specified for the burn. The system then integrates the relevant climatic data for the site, and passes the data to a smoke dispersion model. The model is run, and the resulting plume is shown on screen as a set of three isopleths, denoting different smoke concentrations resulting from the burn. The GIS then performs an overlay analysis to determine if any of the isopleths intersect a buffered smoke-sensitive area. If it does so, the system alerts the operator, and the final issue of a permit is subject to approval by a supervisor. If no alert appears, the burn permit is granted. Smoke plume predictions are stored on computer for future reference and validation purposes as well as possible liability issues.

A primary goal of this system is to provide a service to the public – including the growers – with the aim of minimising the harmful effects of smoke from open burning. Application of this innovative GIS-based decision support system will greatly enhance the ability of the Florida Division of Forestry to effectively administer open-burning authorisations throughout the state (as well as wildfire suppression) thus playing a major part in achieving environmental standards in Florida regarding air pollution (Brenner *et al.*, 1997).

8.4.2 Potential GIS application in sugarcane burning management

Preliminary studies at SASEX have demonstrated the potential usefulness of GIS in identifying areas sensitive to burning and assessing spatial impacts of burning restrictions in these areas (pers. obs.). Given suitable base data regarding cane areas, it would be a relatively simple matter to conduct a regional GIS spatial analysis to determine:

- areas where agronomists recommend that cane should be burned, for example, all cane areas above 500 metres, particularly on south-facing slopes and valley bottoms;
- cane areas where the disease ratoon chlorosis is endemic where burning is used as a controlling mechanism; and
- areas currently affected by *eldana* infestation, necessitating regular burning.

This would provide base information for an economic analysis to be made to determine the possible financial and logistical impacts that potential new air pollution legislation could have on the SA Sugar Industry and put into perspective the cost of implementing regional burning management control systems should these become mandatory.

The reason for recommending that cane is burned, not trashed at higher elevations, is primarily due to the thermal regime required for cane germination. The optimum soil temperatures are not reached when a trash blanket intercepts solar radiation in climatically cooler regions. These recommended "no-trashing" areas are estimated traditionally by broad approximation. By using GIS-based solar flux models (Dubayah and Rich, 1995) and readily available interpolated regional temperature and elevation data, the substantial impacts of slope and aspect on incident solar radiation and thus soil temperatures can be more accurately predicted (Knight, 1999, pers. comm.)[1]. This will help narrow the blanket recommendations for no-trash areas in a scientifically determined manner.

Because of the geographic information requirements of any system attempting to manage sugarcane burning impacts, a first step would be to have accurate maps of the region showing farm locations, field layouts and infrastructure such as roads, urban areas, schools, hospitals and powerlines. Whilst this step may not necessarily require the use of GIS, the application thereof even at this simple level would provide considerable advantages, such as:

- using buffering techniques in GIS to demarcate zones sensitive to burning;
- easy updatability of digital spatial data, *e.g.* new urban developments, roads, farm changes;
- updatable links to attribute data, such as grower details;
- terrain modelling in GIS to provide topographic visualisation to determine, for example, which farms' smoke is (intuitively) likely to affect which residential areas down valley under inversion conditions when smoke is prevented from dispersing upwards;
- the facility to electronically log *locations* of fires over time and subsequent complaints in order to assess spatial relationships between cause and complaint; and

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[1] Knight, F. Assistant Director: Resource Utilization Section, Western Cape Agriculture, Elsenburg.

- the easy production of visual media for communication with interested and affected parties.

A valuable result of such a simple GIS based cane fire monitoring system, is that it builds capacity to move relatively easily to a more advanced control system should this be required due to burning permit requirements or more stringent burning regulations with which the SA Sugar Growing Industry may well be faced with in the future.

Taking the simple monitoring and logging scenario a step further would be the introduction of dispersion modelling to more accurately determine the spatial requirements for sensitive or restricted burning zones. Current burning Codes of Practice usually contain an arbitrarily assigned buffer zone around roads and towns and below powerlines. Dispersion modelling using locally developed or locally calibrated models for a range of typical weather condition scenarios could be carried out (either within, or linked to GIS) at specified locations in a region, or point-wise on a grid basis to more accurately predict smoke impacts. A rule-based approach could then be implemented to manage burning conditions on a day-to-day basis in accordance with modelled results. Demarcated sensitive zones in GIS could be adjusted for the day according to predicted meteorological conditions, particularly with regard to wind speed and direction at various levels and the predicted mixing level / temperature inversion scenario. If then, predicted surface and upper air winds were north-easterly at between 20 and 30 knots with an inversion layer at 200 metres, a particular set of previously modelled sensitive zones could be mapped and affected farms "flagged" or highlighted for burning restrictions. This information could be made available to growers in various ways, such as the Internet, by fax or by farm radio networks.

If environmental pressures intensify further, as is likely, and the Sugar Industry is tasked with stricter self-regulation of burning, a system based on real-time integration of meteorological data and modelling of smoke dispersion, such as the FFMIS described above, may need to be implemented in some regions. This could involve the systems and processes described in the following self-explanatory flow diagram, Figure 8.6.

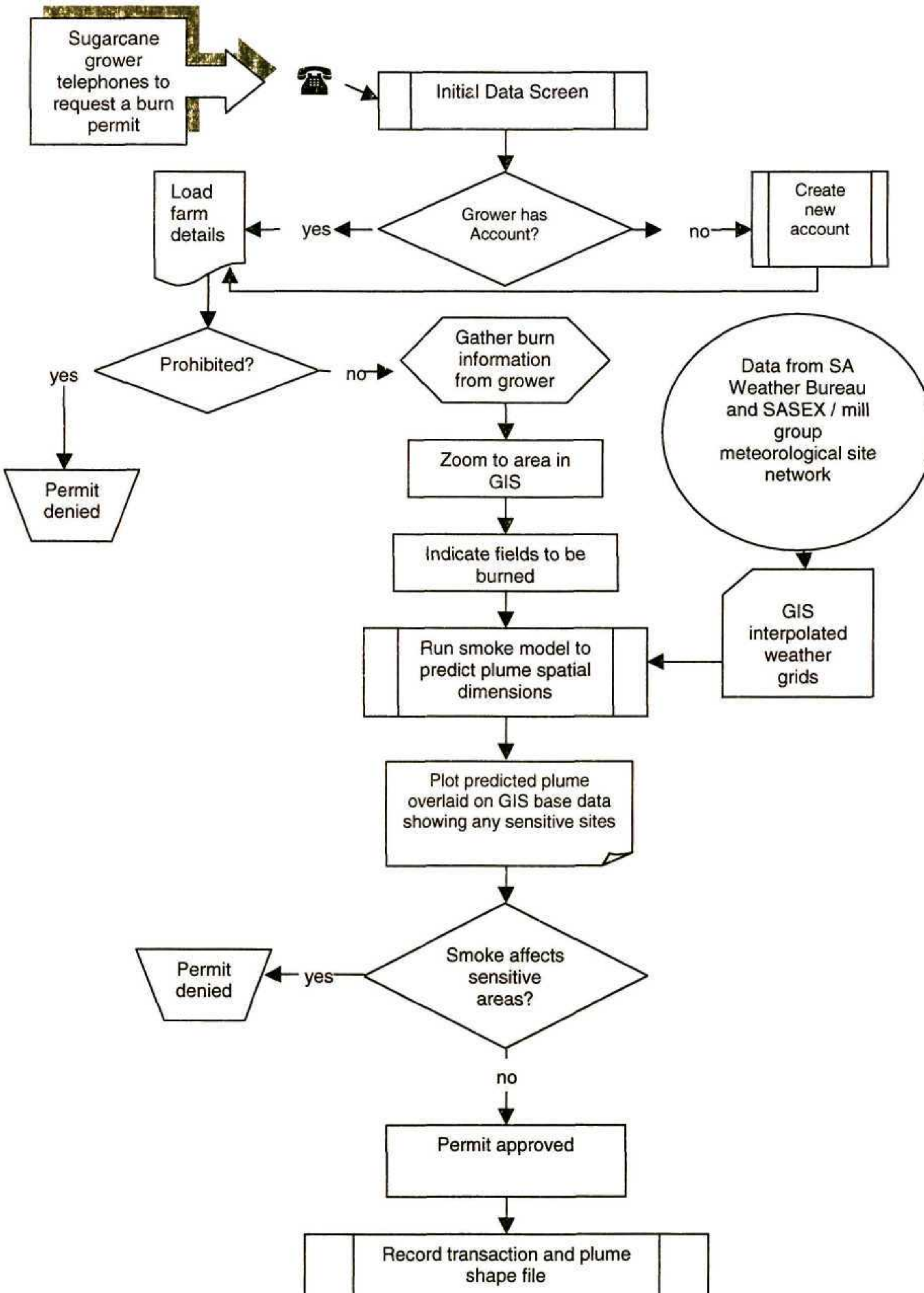

Figure 8.5. Schematic of a proposed regional sugarcane burning management system (after Brenner *et al.*, 1997).

The following steps would be required to implement such a system:

- A GIS database would need to be established in a region, containing detailed spatial information of farm and field layouts, local infrastructure and buffered sensitive areas.
- A database must be established containing grower details linked to the spatial data through a key identifier, being the farm code or name.
- A network of automatic weather stations would need to be accessible to the GIS either through telephone lines or telemetry. It may be possible to include data from weather bureau stations or forestry weather stations in some areas.
- A suitable dispersion model would need to be available. Whilst some smoke dispersion models are available freely (from organisations such as the US Environmental Protection Agency), it is likely that considerable development would need to go into modifying existing models or deriving a suitable model for local conditions and system requirements. The complex topography in parts of the sugar belt would most probably require more sophisticated dispersion modelling techniques than those used in Florida, which is relatively flat. There are GIS - linked dispersion models that claim to operate efficiently even in complex terrain, however (Hodgin, 1997).
- A period of calibration and testing of the system before operational use is a prerequisite.

Ideally, the GIS central database in such a facility would be common to other environmental and production applications (such as agronomic research and mill cane-supply planning) to gain maximum benefit from capital invested and operating costs.

8.4.3 Summary

At the time of writing, a pilot study proposal from Simpson (1999) was under consideration by Sugar Industry management. Interestingly the proposed study (in the Pietermaritzburg region) incorporates a number of the GIS activities discussed above, in order to manage the spatial aspects of smoke dispersion modelling. One of the proposed goals is to develop "more comprehensive and spatially based" codes of practice for sugarcane burning (Simpson, 1999).

The key applications discussed above are summarised in Table 8.3.

Issue	Scale	Example GIS applications	Decision support to...
Formally identify agronomic "no-trashing" areas	Landscape	➢ Spatial analysis to determine from a DEM – Areas above 500 m – South facing slopes – Valley bottoms ➢ Redefine these areas – thermal regime modelling	Farmers, LECs, Extension Officers, Local authorities
Sensitive areas	Mill supply region	➢ Define no-burn buffers according to local Codes of Practice	LEC's, Millers, Extension officers, Local authorities
Burning control or permit management	Mill supply region	➢ Topographic and climatic inputs to smoke dispersion models ➢ GIS plume dispersal modelling to predict scenarios ➢ Farm location and details database ➢ "Real-time" burning control management system decision support	LEC's, Millers, Extension officers, Local authorities
Burning statistics	Sugar Industry	➢ Spatial statistics, such as "no-trashing" areas, areas under specific burning controls, regulated areas. ➢ Changes in industry burning extent	Sugar Industry mnagement, Local authorities, Government

Table 8.3. Summary of GIS applications addressing environmental management of sugarcane burning in South African sugarcane production.

8.5 ADDRESSING BIODIVERSITY AND HABITAT ISSUES: GIS APPLICATIONS

8.5.1 Introductory review

Modern land management practices require increasing levels of information to successfully comply with increasingly strict environmental regulatory restraints (Campbell and Schriever, 1996). To effectively consider the cumulative impacts of various land management decisions on the natural resources, the issues must be addressed at all relevant scales (e.g., catchment, landscape or regional), and over time. Modern GIS and associated environmental models provide new capabilities for analysing this space/time distribution of ecological phenomena and are needed to supplement "traditional" methods of biodiversity inventory (Mackey, 1996). Mackey (1996) describes how various species interact at different scales with their environment. GIS can accommodate the many scales of observation required to fully capture the ecological resources of a region. He considers great strides to have been made in ecological research through the use of GIS, particularly at the "topo" scale (using DEM techniques) - referring to the following processes:

- the role played by topography in redistributing water in the landscape; and
- the effect of slope, aspect and horizon shading in modelling insolation - particularly important in modelling moisture, temperature and light regimes.

He also considers the advances in climatic interpolation and gridding (raster) work in GIS to have provided a hitherto unavailable capacity to generate spatially reliable estimates of what he terms "meso-scaled" inputs to ecological models.

Aspinall, Burton and Landenburger (1998) describe the application of GIS in biodiversity management in various regions, using a framework which combines:

- a simple index of habitat preference;
- a statistical description of the environmental conditions with which the species is associated; and
- a spatial model,

integrated in GIS and readily accessible to decision makers. On a more basic level, August (1998) developed a simple yet effective protocol to estimate areas critical to support regional biodiversity using "off-the-shelf" GIS data. The ultimate product of his analysis was a map showing general regions of high importance in support of biodiversity.

A number of workers have applied GIS in identifying areas of significant biodiversity and attempting to link these with natural linkages or corridors in an attempt to restore functionality to fragmented habitat (Delorme, 1998). Landscape ecologists have a number of specific tools at their disposal in GIS for analysing landscape patterns, computing patterns and shape indices and connectivity of landscape elements (Delorme, 1998).

The use of remote sensing data in GIS in the field of sustainable agriculture allows crude classification and a rapid overall view of large areas (van der Meer *et al.,* 1999). This view can then be used to focus field effort into areas most threatened (ESRI, 1997).

Such imagery also lends itself to change detection monitoring for temporal analysis and monitoring (Campbell and Schriever, 1996).

The USA GAP program is one of the largest and most demanding GIS projects ever launched, involving some 400 institutions. "GAPS" are those elements of biodiversity at risk unless changes in their management status is made. Using many of the techniques discussed above, this project aims to provide the public and decision makers with information regarding the conservation status and stewardship details of animal species and plant communities on lands managed for biodiversity maintenance (Jennings, 1997 and Delorme, 1998).

Riparian vegetation is not only a major contributor to biodiversity, but offers service value in increasing stream bank resistance to erosion and can "filter" nutrients and sediment from agricultural runoff water through both physical and biological processes (Hubbard and Lowrance, 1994). White, Jennings and Harman (1995) consider GIS appropriate in the study of riparian systems and the rehabilitation thereof:

- firstly, because the relationships between land use and aquatic ecology are inherently spatial;
- secondly, because these complex functions require a prohibitively large volume of data that would be impossible to process without the technical aid of a computer; and
- thirdly, GIS and related technologies such as photogrammetry and digital image processing make data and analyses possible that would not be available otherwise.

Additionally, by using spatial analysis techniques, GIS can be used as modelling technology to test hypotheses.

The White Paper on Biodiversity (DEAT, 1997) makes it clear that South African land users will be required to mitigate the impacts of their operations on biodiversity. In order to manage such actions responsibly, a thorough knowledge of relevant ecological processes and systems at various scales is required. Although such research and knowledge is unlikely to be in the domain of the Sugar Industry itself, it is clear that GIS tools have a very important role to play. A Sugar Industry GIS may effectively use products of third party research, such as mapped sensitive areas or areas requiring special consideration.

8.5.2 Potential GIS applications in habitat management in sugarcane regions

In order for the Sugar Industry to begin to manage its impacts on habitats and the corresponding biodiversity, the first step is to map land use and create an inventory of the remaining areas of natural (or rehabilitated) vegetation under its stewardship. This serves as a baseline which:

- allows for strategic planning of critical habitat conservation and rehabilitation, siting of vegetation corridors, riparian vegetation rehabilitation and removal of invader species;
- can help to demarcate sensitive areas with regard to biodiversity;
- can focus efforts to educate growers regarding spatial attributes of species location or ranges; and
- can be used as base data in ecological models.

Although a national land cover GIS database has been made available, the broad scale of mapping and interpretation is not ideally suited to work of this nature (Thompson, 1997, pers. comm.)[1]. In order to identify habitat to the species or even community level, much fieldwork will be needed. It is extremely difficult to distinguish even between some invader species and indigenous species from aerial photography, requiring much in-field, mapping work using GPS (Wood, 1997, pers. comm.)[2]. It is to be expected that such data collection, if not available elsewhere, would be undertaken by a suitably qualified contractor. Close liaison with nature conservation bodies would be vital, given the highly specialised knowledge required, as well as to prevent duplication of efforts. The KwaZulu-Natal Nature Conservation Services are active in GIS and may be able to provide habitat and sensitive area data for certain areas (Benn, 1996, pers. comm.)[3].

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[1] Thompson, M. Remote Sensing Specialist, CSIR.

[2] Wood, J. Agricultural Engineer, formerly of Murray, Biesenbach and Badenhorst, Pietermaritzburg.

[3] Benn, G. Landscape Ecologist, KZNNCS, Pietermaritzburg.

Again this is a specialised field likely to be undertaken outside of the Sugar Industry, yet none the less, an important GIS application in addressing sugarcane biodiversity issues. Proprietary models such as Habitat Analyst and Patch Analyst are available as extensions for ArcView. The former facilitates the development of landscape and habitat suitability models, whilst the latter assists in the spatial analysis of landscape patches. Although easy to use in that they are menu-driven (pers. obs.) the operation of such models is best left to ecologists.

Ideally an industry GIS would maintain habitat and biodiversity GIS data in its final and "user-friendly" form, such as:

- detailed land use map with descriptions of biological communities;
- maps of sensitive areas with regard to threatened species;
- mapped ranges of threatened species; and
- habitat rehabilitation priority zones.

Mander, Quinn and Mander (1993) describe the use of a "decision-tree" model (Figure 8.6) for effective riparian vegetation rehabilitation in the Sugar Industry. A primary objective of rehabilitation is the protection and stabilisation of riverbanks and channels especially at confluences and changes of gradient (nick points). At gradient increases, increased flow velocity may lead to erosion, while gradient decreases lead to reduction of flow and silt deposition where wetlands may be encouraged. Inputs into the decision tree include:

- slope greater than and less than 3 percent;
- gradient increases, gradient decreases and constant gradients;
- confluences; and
- stream order.

These inputs, such as those in Figure 8.7, are simple to derive in GIS, given a suitable DEM (pers. obs.). The guidelines accompanying the decision tree contain many more applications where simple GIS functionality would prove useful. When undertaken on a catchment basis an exercise such as this can serve to assist planners in planning, focus and prioritisation of riparian rehabilitation projects.

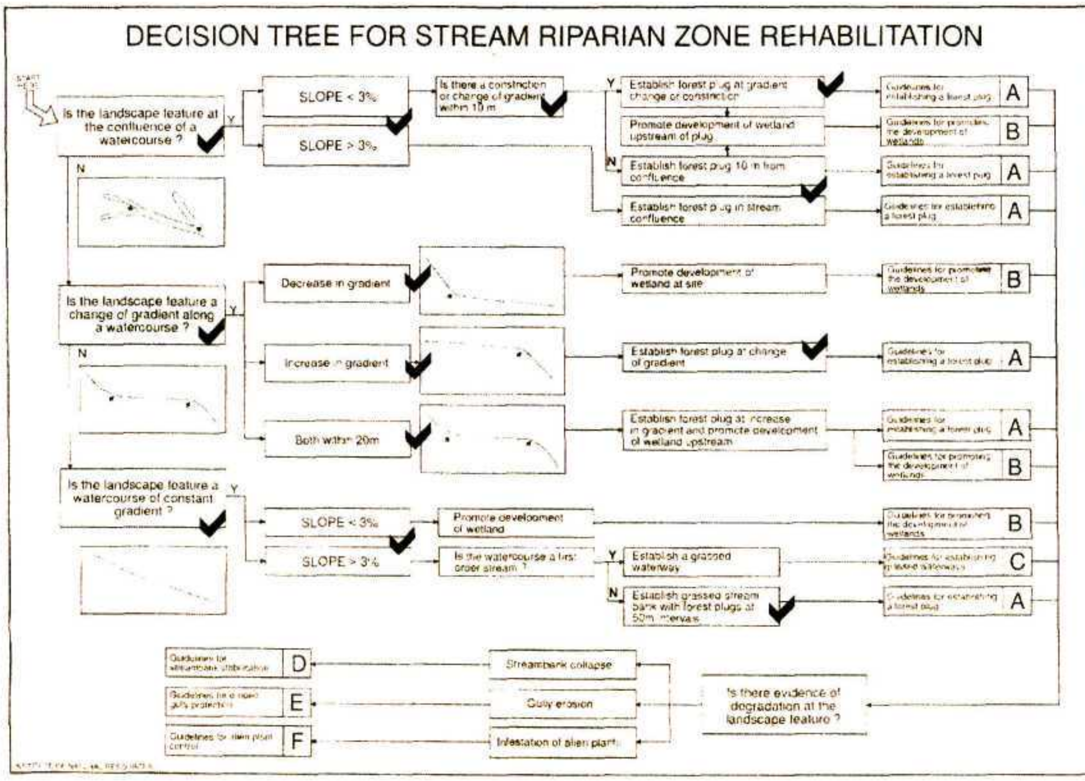

Figure 8.6. The INR Decision-Tree for stream riparian zone rehabilitation. Tick marks indicate potential GIS inputs (after Mander, Quinn and Mander, 1993).

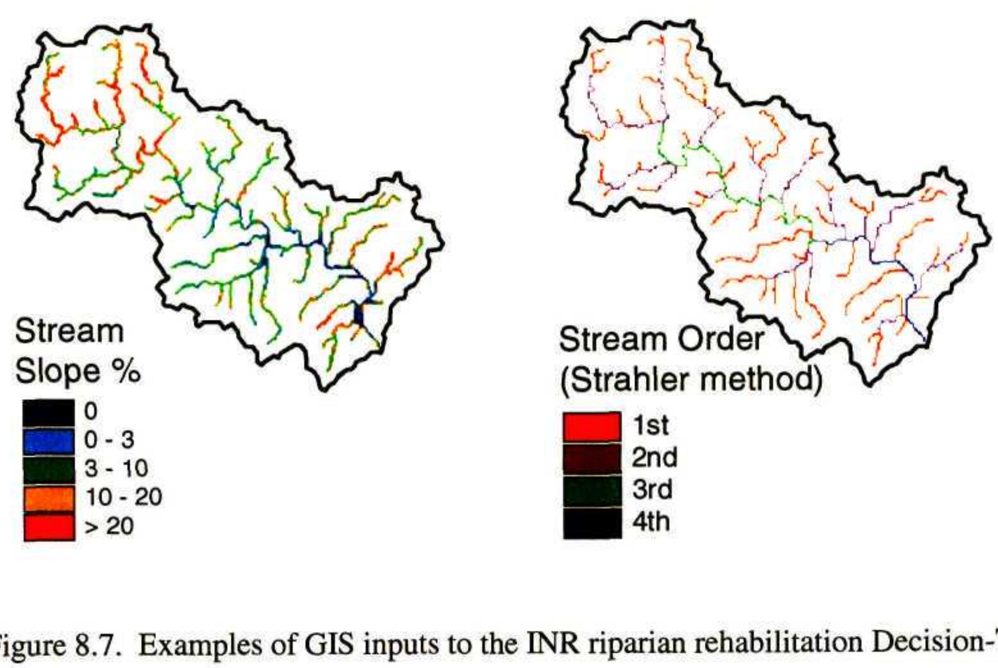

Figure 8.7. Examples of GIS inputs to the INR riparian rehabilitation Decision-Tree.

8.5.3 Summary

Table 8.4 summarises potential applications for GIS in biodiversity management issues. Whilst it is unlikely that the Sugar Industry itself will undertake biodiversity and habitat modelling, the ability to utilise spatial data provided by specialists will be of great value in appropriate projects.

Issue	Scale	Example GIS applications	Decision support to...
Biodiversity inventory	Landscape	➢ Spatial database management ➢ Habitat modelling ➢ Monitor changes in extent of natural areas	LECs' Researchers, Extension officers Regional planners, Developers
Riparian habitat	Catchment	➢ Stream slope analysis ➢ Stream classification ➢ Rehabilitation planning support (decision-tree) ➢ Spatial database of riparian vegetation and alien infestation ➢ Spatial database of riparian rehabilitation progress	LECs' Researchers, Extension officers
Sensitive areas	Landscape, Provincial	➢ Spatial data from conservation bodies ➢ Buffer zones ➢ Monitoring restriction compliance	LECs' Researchers, Extension officers
Industry biodiversity statistics	Sugar Industry, Province	➢ Baseline database – State of Environment ➢ Monitor spatial changes	Sugar Industry management, Researchers, Government

Table 8.4. Summary of GIS applications addressing environmental management of biodiversity issues in South African sugarcane production.

8.6 ADDRESSING WETLAND ISSUES: GIS APPLICATIONS

8.6.1 Introductory review

Wetland inventory and monitoring have become very important for wetland conservation and environmental management (Wang and Shang, 1996). There are numerous references in the literature to the successful use of GIS in wetland inventory in other countries. The US embarked on a major project to create a GIS inventory of its wetlands in the 1980s (Tuggle, 1999). The Department of Environmental Affairs and Forestry has proposed a similar undertaking to be commenced in South Africa. This project will aim to:

- identify where wetlands are and prioritise conservation sites;
- identify functions and values of each site;

- establish a baseline for measuring future changes in wetland area, function and value;
- assist in establishing monitoring programmes; and
- provide a tool for planning and management at various levels and to permit comparisons and information sharing at all levels (South African Wetlands Conservation Programme, 1999).

Fennesy (1997) developed a GIS model to assess the likelihood of success in restoring degraded wetland sites in Ohio, USA. Criteria for restoration potential were categorized into soil, land use and habitat components. Potential restoration areas were identified by the presence of hydric soils, open land cover and hydrological saturation. Weighted combinations of these variables were used in GIS to predict the ability of the degraded site to perform water quality improvement or provide habitat.

In a similar approach, Rudnicky (1999) developed a GIS application to implement a set of preservation protocols to model the relative importance and opportunity for a wetland to perform its functions in the landscape, namely:

- sediment control;
- bank stability;
- water quality improvements;
- habitat; and
- flood control.

The application combined land use cover with the US National Wetlands Inventory information. The model output creates a GIS database to assist land use planners and managers in decision making with regard to wetlands.

Syphard (1999) modelled more complex biological and hydrological aspects of restoring wetland functionality. GIS methodology was used to model surface runoff, in a three-dimensional analysis of stratigraphy, in a water table fluctuation model and to assess biological benchmarks.

8.6.2 Potential GIS applications in the management of wetland affected by sugarcane production

In the SA Sugar Industry's "Environmental Management Plan" (SASA, 1991) stated the following objectives with regard to wetlands:

"*Establish the status of wetlands in the industry and provide guidelines for the preservation and correct utilisation of existing wetlands*"

and

"*Develop a wetland and resource register using a Geographic Information System*".

Maher (1995) proposed some guidelines for wetland management in terms of the Conservation of Agricultural Resources Act of 1983, and the "Wetland Fix" pamphlet series (Wyatt, 1995) have been circulated in the industry. However, there has yet to be an industry-wide assessment of wetlands under its stewardship and no GIS resource register has yet been commenced.

Although the initial sugarcane quota system required a detailed map of each farm, and usually included mapping of wetland areas, this service is no longer required due to the recent abolition of the quota system. At present the spatial extent of wetlands impacted on by sugarcane growing operations is unknown (Wyatt, 1999, pers. comm.)[1]. The proposed GIS based inventory of South African Wetlands by the Wetlands Conservation Programme should provide sound base data to initiate the second objective discussed above of developing an industry wetland register in GIS.

Given a future commitment by the industry to embark on a program of wetland restoration, the GIS could greatly assist in the assessment and prioritisation of wetland initiatives in the manner of Fennesy (1997) and Rudnicky (1999) discussed in the previous section.

The GIS register would also serve as an essential baseline or indicator dataset against which future changes (resulting from sugarcane production) in the state of the wetlands could be judged.

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[1] Wyatt, J. Conservator: North Coast, KZNNCS, Durban.

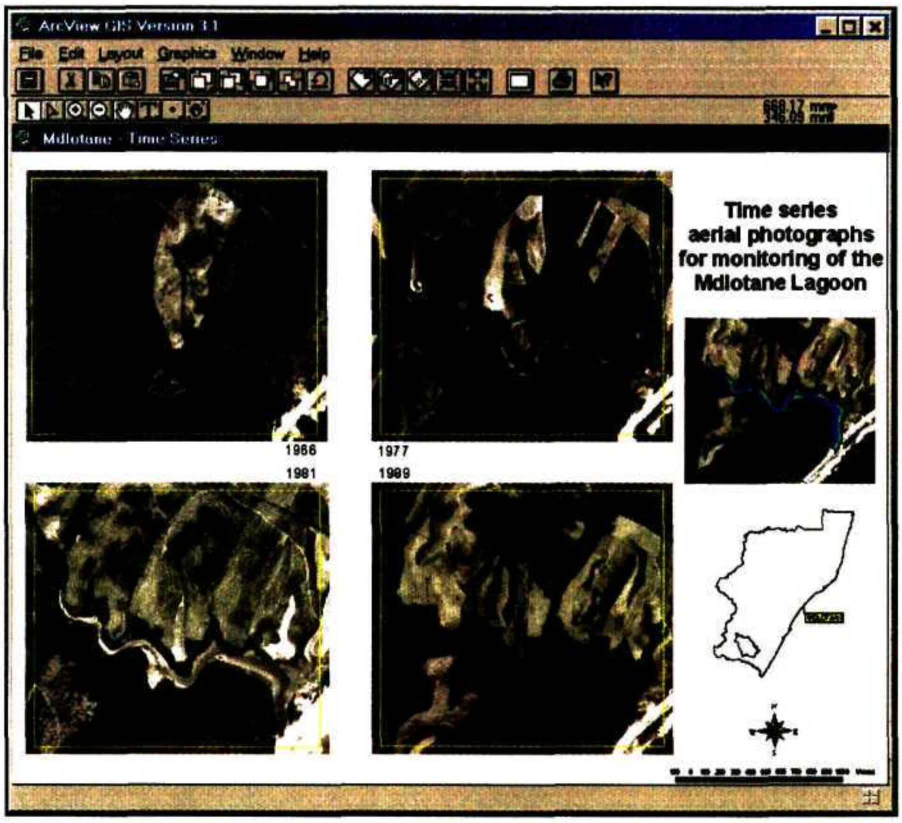

Figure 8.8. Geo-referenced time-series aerial photographs of the Mdlotane catchment.

The photographs of the Mdlotane Estuary (on the KwaZulu-Natal North Coast) in Figure 8.8 depict changes in the surrounding land use and to the lagoon itself over time. Whilst a simple visual appraisal of the images (suitably enlarged) would provide considerable information, the use of GIS offers certain advantages. In an unpublished demonstration the photographs were digitally scanned, imported into GIS, scale-rectified and then analysed (pers. obs.). The use of GIS enabled the following:

- accurate (geo-referenced and to scale) mapping and measurement of the estuary's extent, surrounding land use and changes therein from the photographs;
- buffering distances from streams to assess encroachment of sugarcane;
- assessment of potentially unsound farming practises in the estuary sub-catchments for further investigation, e.g., cane on slopes exceeding 22 percent;
- overlay with other data – e.g., farm boundaries; and
- efficient data storage, retrieval and display.

Information of this nature is useful in programs monitoring the environmental "health" of a wetland and its catchment and supporting environmental rehabilitation work by LECs.

8.6.3 Summary

Table 8.5 summarises potential application areas for a Sugar Industry GIS.

Issue	Scale	Example GIS applications	Decision support to...
Wetland inventory	Landscape	➢ Spatial database management ➢ Use data from National Wetland Inventory ➢ Monitor changes in extent of wetlands ➢ Monitor buffer zones compliance	LECs' Researchers, Extension officers, Regional planners, Developers
Wetland projects	Catchment	➢ Model flow impacts from sugarcane development ➢ Model other land use potential impacts, e.g. sedimentation ➢ Modelling & support for rehabilitation projects ➢ Monitoring restriction compliance	LECs' Researchers, Extension officers
Industry wetland statistics	Sugar Industry, Province	➢ Industry Wetland Database as proposed ➢ Baseline data – State of Environment ➢ Monitor spatial changes	Sugar Industry management, Researchers, Government

Table 8.5. Summary of GIS applications addressing environmental management of wetland issues in South African sugarcane production.

8.7 GENERAL ENVIRONMENTAL TASKS: GIS APPLICATIONS

The World Bank (1995) in the management of environmental data for environmental assessment projects has found GIS especially useful in:

- collating, organising, co-ordinating and analysing spatial data;
- determining baseline environmental conditions; and subsequently in
- analysing alternative scenarios.

Some of the particular advantages in this field offered by GIS include the following:

- the nature of a centralised GIS encourages a more systematic and integrated approach to environmental information collection;
- it can enable or improve the comparability and compatibility of diverse data sets;

- it can assist in making data used in environmental projects accessible to a wider range of decision-makers;
- it encourages the spatial analysis of environmental impacts that would otherwise be ignored due to analytical difficulty or cost (World Bank, 1993).

Many of the GIS applications and functionality discussed previously in this chapter have applications in support of environmental assessment projects such as environmental impact assessment, environmental auditing and in the compilation of environmental reports for companies or industries. Table 8.6 summarises potential applications for a Sugar Industry GIS in this area.

<table>
<tr><th>Issue</th><th>Example GIS applications</th><th>Decision support to...</th></tr>
<tr><td>Environmental Assessment and Audit</td><td>➢ Spatial data support
➢ Mapping
➢ Scenario modelling</td><td rowspan="3">Farmers,
LECs,
Extension officers,
Researchers,
Regional planners,
Developers,
Regional farmer associations,
Local authorities,
Local authorities,
Sugar Industry Management,
Government</td></tr>
<tr><td>Environmental monitoring</td><td>➢ Spatial analysis using remotely sensed imagery and photography
➢ Overlay theses with cane areas, slopes, buffer zones to assess compliance
➢ Monitor disturbance of protected, sensitive or restricted areas</td></tr>
<tr><td>Environmental reporting</td><td>➢ Spatial data support
➢ GIS mapping
➢ GIS supported presentations</td></tr>
</table>

Table 8.6. Summary of some general GIS applications in environmental management.

Chapter 9
IMPLEMENTING A SA SUGAR INDUSTRY GIS

"Indeed, it is hard to see how increasingly demanding objectives in environmental management could be achieved without effective and efficient use of information technology tools."
(Walker and Johnson, 1996)

9.1 INTRODUCTION

The potential applications of GIS discussed in this document, whilst relevant to the SA Sugar Industry's achievement of environmental standards, may not necessarily be carried out solely by the industry's own GIS. Studies pertaining to the industry's impacts on biodiversity and habitat, for example, would most likely be carried out by appropriate external organisations – possibly supported by the Sugar Industry. The industry's GIS would then serve as a portal for integrating, viewing and analysing the data resulting from such studies and making this information available to decision makers. This emphasises the need to determine precisely the level at which the industry's environmental GIS facility will operate.

9.2 INSTITUTIONAL NEEDS ASSESSMENT

The extent of functionality and the scope of environmental management support required are vital considerations. Private consultants or companies – with proven environmental GIS experience – and institutions such as the CSIR can assist the industry in assessing needs and the required scope of application. Although there is certain GIS technological capacity within the industry, such external facilitation is important. Smith and Grundy (1997) consider one of the major problems with the adoption of GIS as a strategic tool for natural resource management to be the direction from which the implementation is being promoted. Often the technical GIS users and developers (usually at a research level) have to promote, demonstrate and prove the worth of GIS to strategic planners and managers. This can result in a "technology-centred" approach to GIS implementation, rather than a goal-oriented approach planned to support specified decisions. However, environmental decision makers are often unaware of the capabilities or advantages that may be offered by GIS in a particular application and may overlook opportunities for its support (per. obs.). The increasing development of simple-to-use and/or customizable GIS interfaces is changing this paradigm by making GIS more accessible for direct use by management (Crossley, 1999).

The many commercial and production-oriented GIS applications of relevance to the Sugar Industry are beyond the ambit of this dissertation but are discussed further in general terms in Wallace (1996), and with particular reference to agronomic and commercial issues in Hellmann, Wallace and Platford, (1995); and Troskie, Vink and Wallace, (1998) respectively. Since much spatial data, GIS expertise and hardware are common to production and environmental management, the implementation of environmental GIS becomes more cost effective when implemented in a common framework (McCloy, 1995).

9.3 INSTITUTIONAL GIS CAPACITY

A personal computer (PC) based GIS was originally established in the Farm Planning Department at SASEX in 1990 (Platford, 1990). The original objective was to establish a computer-based integrated mapping service for farm planning services, combined with the unique spatial analysis and query facilities of GIS. At that stage it was felt that ties between the SASA Central Board Survey Department and SASEX Farm Planning Departments would become closer, and that the former would move to a computer or digital method of mapping. This would allow for easy input of farm base map data into the GIS. However, the Central Board did not move toward digital mapping and was in fact privatised during SASA restructuring. A private company was given custody of the existing SASA "paper" map database which would thenceforth be updated through private initiative.

The Farm Planning Department then concentrated GIS resources on commercial work, using particularly the CAD functions of GIS, in order to generate income as the department was required to predominantly become self-funding.

As a result of reductions in Farm Planning staff and departmental restructuring[1], the role of the GIS was reconsidered, as the limited resources did not accommodate the industry GIS once proposed.

The GIS facility was subsequently restructured and currently falls under the Agricultural Engineering Department of SASEX, where it concentrates on specific research areas and projects where its spatial analysis and mapping capabilities can be best used to benefit the industry (pers. obs.). Due to its limited resources, an important part of its program is to establish and maintain links with other organisations involved in GIS in order to remain abreast with GIS developments, with available data and expertise and to utilize outside data sources where suitable. Importantly, its role is to keep the industry informed and focused on strategic applications and opportunities using GIS (Wallace, 1996).

The SASEX GIS currently consists of a PC-based GIS with two staff members – a GIS specialist and a digitizing clerk. There is additional data capture support available from the SASEX Drawing Office. The facility has some capacity to undertake industry-wide projects, depending largely on the level of detail required and the availability of data. For example, the facility was used to assist in the production of a sugarcane commodity report to the Department of Water Affairs and Forestry towards the formulation of new irrigation policy (Lynsky, Schmidt and Sugden, 1997). Most of the base data used was small-scale, sourced from organisations such as the SA Water Research Commission, CCWR and the Department of Agricultural Engineering, University of Natal, Pietermaritzburg. Similarly, GIS-modelled yield potential maps, cane areas and climatic maps have been produced at a broad industry scale. Further detailed projects have been undertaken at mill supply region level. Specific research projects (both production-based and environmental) are undertaken according to a formal Program of Work.

The current GIS resources in the SA Sugar Industry would be inadequate to facilitate environmental inventory/assessment/monitoring type of GIS operations requiring industry-wide farm scale data and would require either:

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[1] The Farm Planning Department was subsequently closed in August 1997.

- upgrading of the existing GIS facility at SASEX;
- outsourcing most of the data capture and using the SASEX facility to store, manage and analyse the data; or
- outsourcing the whole operation, whilst maintaining access to the databases through the SASEX GIS.

Obviously this is stated in very broad terms and would depend on details of the proposed project and on an industry agreement on whom would be responsible for such activities in the first instance.

SA Sugar Industry management appeared to recognise the desirability of an industry environmental GIS as far back as 1991, when it referred to the need for GIS support in its Environmental Management Plan, for example, in mapping and monitoring wetlands (SASA, 1991). No commitment has subsequently been made in this regard.

9.4 IMPLEMENTATION STRUCTURAL MODEL

Sugden considers SASEX the appropriate institution to accommodate an environmental GIS for the SA Sugar Industry (1999, pers. comm.)[1]. However, in order to support environmental management effectively at field and even farm scale (other than in specific local projects), it is desirable that regional GISs be established. Apart from the advantages offered in regional-scale environmental support as previously discussed, the maintenance of a current spatial database of cane farms, their ownership details and regional environmental conditions is vital.

GIS implementation is being undertaken or investigated in a few of the mill group areas. Mpumalanga Lowveld sugar region has undertaken mapping of their region using GPS and will use this method as base data in a corporate, commercially-driven GIS facility (Gillespie, 1997, pers. comm.)[2]. Such initiatives – even though commercially driven – can potentially provide support to a centralised GIS at SASEX in terms of mill supply region data regarding farm boundaries, farm ownership details, irrigation statistics,

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[1] Sugden, B. Director, SA Cane Growers, Durban.

[2] Gillespie, G. Cane Quality Officer, Transvaal Suiker Beperk, Malelane.

accurate cane areas and any environmental data they may gather. Figure 9.1 illustrates a proposed structure for integrating regional and central GISs in the SA Sugar Industry.

Given the customisability (and increasing simplicity of the user interface) of desktop GIS, it is certainly feasible to install some GIS capacity in SASEX's extension offices to assist in maintaining regional databases. This would ideally be in the form of a GIS tool which has value to the extension officer in agronomic applications as well. The GIS structural model of Mondi Timber, although commercially driven, has distinct relevance in that a central GIS is supported by regular updates from estate level. The estate foresters themselves update their highly customised GISs regarding harvesting progress (as well as certain environmental data), which is then regularly uploaded onto a central GIS facility in Pietermaritzburg (Erasmus, 1997, pers. comm.)[1].

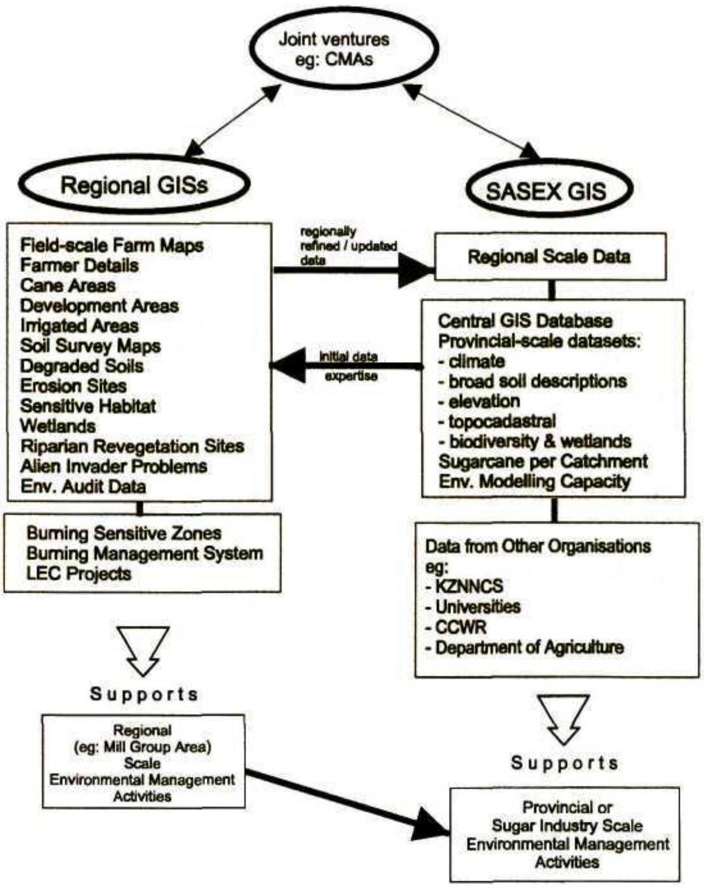

Figure 9.1. A proposed GIS structure for the SA Sugar Industry.

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[1] Erasmus, D. Natural Resources Manager, Mondi Timber, Pietermaritzburg.

9.5 DATA REQUIREMENTS

9.5.1 Introduction

Data is the most critical component of GIS. Output from the most powerful GIS software and hardware available is only as good as the source data. Unfortunately the SA Sugar Industry does not have any legacy of digital CAD mapping as did sectors of the forestry industry, and the industry's existing farm map database exists only as analogue maps (pers. obs.). An aerial survey company routinely produced or updated these maps on an approximately three yearly cycle. With the phasing out of the quota system by the end of 1998, the industry no longer takes responsibility for this mapping. Farm mapping operations are now undertaken by private initiative by the growers and the options implemented thus far have been:

- analogue line mapping as previously;
- mapping derived from digital orthophotography;
- GPS mapping.

Obviously the later two options have the advantage in terms of GIS that they are digitally-based, with the orthophotograph option providing the enormous advantage of a geo-referenced, geometrically correct, digital photograph which can be used as information-rich base data in a GIS (Smith, 1995; and Thurgood, 1996).

9.5.2 Data from external sources

In some developed countries, a wealth of public-domain GIS data is freely available for GIS users, often through Internet access, which allows for the quick establishment of GIS infrastructural, environmental and topographical "general-purpose" databases. This is unfortunately not the case in South Africa where controversy surrounds the practice of government or parastatal organisations charging the public for digital data captured at the taxpayers' expense. The feeling amongst the GIS user community is that base data such as topography, cadaster, soils and geology and infrastructure should be made available either at no charge - preferably via the Internet (as in the USA), or at a charge which simply covers the cost of transfer media and collation. Subsequent addition of value to the base data through analysis or interpretation of some kind could then be traded at market value. This would stimulate the spatial data industry and help to reduce the current situation in this country where the same data sets are often re-captured at great time and expense because the government data is overpriced. An initiative which should help to reduce repeated capture of data sets is the initiative of a private company, Geographic Information Management Services (GIMS) to create a GIS metadatabase on their Internet World Wide Web site. This provides descriptions of databases owned by various organisations, which may be made available either freely or at a cost. Details and links will be provided to obtain the datasets themselves from the organisations involved. This Web site address is: <http://www.gims.com>.

In the light of environmental applications discussed and future possibilities for GIS applications in environmental management systems, there is a requirement for a wide range of data at various scales and resolution. Each application will have its own data requirements, some of which may not be catered for in the general listing which follows. The details to follow in Table 9.1, however, give a broad outline of available data sets at the time of writing which would provide base data to an environmentally-oriented GIS in the SA Sugar Industry.

Data	Ownership	Scale	Cost
Infrastructure and Topography:			
Topo-cadastral maps	The Directorate of Survey and Mapping in Mowbray, Cape Town	1:50 000 1:500 000	Yes
Digital Orthophotos	• The Directorate of Survey and Mapping in Mowbray, Cape Town • Aircraft Operating Company • GIMS	1:40 000 & 1:10 000 1:10 000 1:10 000	Yes
Cadaster	Provincial Surveyor-General	(As per deed diagrams)	Yes
50/200/400 metre grid DEM	The Directorate of Survey and Mapping in Mowbray, Cape Town	(As relevant to grid size)	Yes
Climate:			
	ARC, SAWB CCWR	Various	Yes No
Hydrology:			
	DWAF, Water Research Commission	Various	Nominal
Land Cover/Use:			
Land Cover Project	CSIR/ARC	1:250 000	Yes
Satellite Data	SAC	Various	Yes
Soils & Geology:			
Land Type Data	ARC	1:250 000	Yes
Geology	Council for Geoscience	1:1 000 000	Yes
Broad Soil Patterns	ARC	1:1000 000	Yes
Biodiversity, Habitat & Wetlands:			
Acocks Veld Types of SA	Botanical Research Institute	1:1500 000	Nominal
Low & Rebelo Vegetation Types	DEAT	Various	Yes
Various Catchments' Wetlands	Durban Town and Regional Planning Commission	1:50 000	Nominal
Environmental Potential Atlas	DEAT	1:1 000 000	Nominal
Protected and Sensitive Areas	KZNNCS	Various	No

Table 9.1. A review of available GIS data sources (pers. obs.)

9.6 AGIS

Many of the broader scale data needs of the Sugar Industry will be addresses by a national agricultural initiative known as AGIS - an acronym for *Agricultural*

Information System for South Africa. This is a program initiated by the National Department of Agriculture (NDA) and supported by Provincial Departments of Agriculture and the Agricultural Research Council (ARC) which aims to make GIS data and decision support easily available via the Internet (AGIS Task Team, 1998). The core datasets to be included will ultimately include all of those listed in Table 9.1 with the exception of satellite data. The structure proposed is:

- A *meta-database*, which will be populated as the various spatial databases are added to the system. The meta-data base will supply information on what data is available, the definition of each data element, whether data meets specific needs, how to acquire it, and how to extract it for local use.
- An *orientation or infrastructure database* that will contain national and provincial boundaries; rural land parcels linked to the particular owner; towns and settlements; roads; railways and scanned 1:50 000 cadastral maps.
- A *topography database* containing digital elevation data with applications that can be invoked to produce user defined products, such as slope and terrain morphological maps.
- An Internet based *climate information system* that can be accessed through an interface, which allow the user to define a query for a particular time series. The query may then be submitted to a central processing unit for interpolation and the resultant map will be forwarded to the client.
- A *soil data base and information system* containing soil information, such as land types (Land Type Survey Staff, 1972-1999), soil profiles (with extensive soil profile descriptive and analytical as well as mineralogical data for input in models and various products as needed) and deducted products, such as generalised soil patterns; soil acidity; soil fertility status such as: soil organic matter content, magnesium, nitrogen, pH, potassium, phosphate, sodium, zinc as well as soil crop-production potential.
- Other data such as geology, hydrology, vegetation and land cover will be bought from other data custodians and integrated in the system as needed (Rust, de Munnik, Lindeman and Weir-Smith, 1999).

One of the future goals of the project is to provide easy-to-use decision support tools for interested parties in agricultural and environmental fields where potentially complex models reside behind simple user interfaces (pers. obs.). It was recently proposed during an AGIS meeting to initiate a project to provide farm boundary data on the Internet (pers. obs.). Whilst cadastral subdivisions have been available in digital format for a number of years, the aggregation of subdivisions into actual farming units and the corresponding ownership details have been generally unavailable and would be of great value to the Sugar Industry.

Often, one of the points on which GIS implementations have floundered, has been the limited availability (and/or high cost) of digital data (Clarke, 1999). Whilst costs involved in AGIS access to third party users has yet to be decided, it appears as though the Sugar Industry GIS may benefit from subscription to the service and should monitor developments through liaison with the GIS unit at Cedara.

Chapter 10
DISCUSSION AND CONCLUSIONS

Natural resources are the basis of human welfare in developing as well as in developed countries (Fedra, 1995). Their prudent management has to satisfy an ever-increasing demand, driven by population growth, markets and lifestyle changes, and at the same time meet an increasingly stringent set of constraints and concerns of environmental degradation and depletion. Sugar industries world-wide are coming under increasing pressure to mitigate their environmental impacts, whilst providing an increasingly environmentally-aware public and government with the detailed level of environmental information demanded. South African Sugar Industry policy and planning cannot be expected to achieve legislative and societal goals in the absence of adequate data relating to biophysical processes involved in and affected by resource use.

Sustainable use of the natural resources demands the *informed* action from individual users (cane farmers) to top-level management (Sugar Industry leadership) of these resources (Walker and Johnson, 1996). Walker and Johnson (1996), referring to the Australian situation, state that legislative demands and societal expectations require that environmental planners and managers must demonstrate that decisions are made on the basis of rigorous and systematic consideration of alternatives and their implications, requiring extensive spatial planning and modelling. This scenario will certainly become applicable to the local situation once the increasingly stringent legal requirements and accountability discussed in Chapter 4 are fully implemented and enforced. Already the Industry has been exposed to government pressure through investigation into its activities with regard to water usage (Lynsky, Schmidt and Sugden, 1997), and the demand for such information is expected to increase (Visser, 1999).

In order to address the range of issues encountered in striving to achieve environmentally sustainable resource use, SA Sugar Industry resource managers will need access to tools that:

- are designed to work with the complex and multi-disciplinary spatial nature of data relevant to many environmental processes (Fedra, 1995);

- can integrate the vast quantities of often disparate data required for decision support within a common framework;
- integrate current scientific understanding of the impacts in the form of models;
- provide means of assessing alternative decision scenarios; and that are
- able to operate at scales which are relevant to the context in which environmental decisions are made and which can address cumulative impacts (Walker and Johnson, 1996; Campbell and Schriever, 1996).

GIS has certainly matured to the point where it can feasibly fulfil the above requirements whilst no longer being confined to the enclaves of the "ivory tower" of computing specialists. The advent of desktop GIS and sophisticated graphic user interfaces have made GIS accessible and a realistic option for use – albeit at various levels of customisation – by the (non-GIS specialist) environmental manager. In the same way that spreadsheets have become indispensable general-use *tools* for financial analysts, it can be confidently stated that GIS in its desktop form will become an equally useful and indispensable tool to environmental planners and managers in the next few years.

Whilst possibly lagging in the adoption of spatial information management technology in comparison to similar industries locally and world-wide, the SA Sugar Industry nonetheless has a current advantage in certain respects:

- There exists a foundation of GIS culture and experience within the Agricultural Engineering Department of SASEX which has researched (albeit on a small scale) the application of GIS in a wide spectrum of applications including some environmental work (pers. obs.).
- The need for production-orientated GIS capacity within the industry has been recognised both at a production research level within SASEX, and commercially in certain sectors of the miller-*cum*-planter community. This can potentially provide cross-pollination of data, skills and equipment and thereby lending economies of scale to the implementation of environmentally-oriented GIS.
- It can learn from past mistakes of others in terms of an implementation strategy.
- There is now a substantial and experienced local GIS user community and support group with whom SASEX has forged good relationships during the past decade.

- The volume of available (digital) spatial data has increased and will become readily available through subscription to initiatives such as AGIS.
- There is an international GIS community – particularly strong in environmental applications – available for information and support through the Internet.
- There are a number of reputable companies or private consultants in the business of GIS needs-assessments, design and implementation.

The Sugar Industry, through SACGA, has indicated its intent to implement EMS in the growing sector. The first step in this process was a detailed review of its environmental strategy by Hay and Mackenzie (1999) of the INR. The authors see GIS as playing a key role in EMSs in the industry:
"*An indispensable tool for decision making in environmental management, especially in the agricultural sector, is a Geographic Information System (GIS). The value of such a system has been well demonstrated in the commercial forestry sector where significant investment has been made in its development*" (Hay and Mackenzie, 1999).

The recent surge in environmental awareness and pressure on the Sugar Industry is unlikely to dissipate. Failure to make the best possible use of environmental information and the technology to manage that information will have a detrimental impact in the Industry. The level of GIS technological maturity and the fact that the SA Sugar Industry is entering the planning phase of EMS implementation provide the ideal timing for the Sugar Industry to formally plan and install an Industry-scale GIS as a fundamental component of their proposed environmental management strategy.

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APPENDIX 1 – LIST OF ABBREVIATIONS

BMP	Best Management Practice
CCWR	Computing Centre for Water Research
CIESIN	The Centre for Earth Science Information Network
CMA	Catchment Management Agency
CRC	Centre for Sustainable Sugar Production
CSIR	Council for Scientific and Industrial Research
DEA	Department of Environmental Affairs (became DEAT after 1994
DEAT	Department of Environmental Affairs and Tourism
DSS	Decision Support System
DWAF	Department of Water Affairs and Forestry
EMAS	European Eco-Management and Audit Scheme
EMP	Environmental Management Plan
EMS	Environmental Management System
EPA	United States Environmental Protection Agency
ESRI	Environmental Systems Research Institute
FAO	Food and Agricultural Organisation of the United Nations
FAS	SASEX Fertilizer Advisory Service
FRS	SASEX Field Record Service (no longer in operation)
GIS	Geographic Information System
ICFR	Institute for Commercial Forestry Research
IEF	Industrial Environmental Forum
INR	Institute of Natural Resources
IP	Image Processing
ISCW	Institute for Soil, Climate and Water
ISO	International Organisation for Standardisation
KZNNCS	KwaZulu-Natal Nature Conservation Service
LEC	Local Environment Committee
MAR	Mean Annual Runoff
NDA	National Department of Agriculture
SACGA	South African Cane Growers' Association
SASA	South African Sugar Association

SASEX	South African Sugar Association Experiment Station
SDSS	Spatial Decision Support System
SEMP	Sustainable Environmental Management Practices
SOE	State of the Environment
TAM	Total Available Moisture
UNCED	United Nations Conference on Environment and Development
WRC	Water Research Commission