SOIL AND WATER CRITERIA AND INDICATORS FOR THE SUSTAINABLE MANAGEMENT OF INDUSTRIAL PLANTATIONS

BY

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Submitted in partial fulfilment of the requirements
for the degree of Masters of Science in the
School of Environment and Development,
University of Natal,
Pietermaritzburg
June 1999

This project was carried out within the

Forest Biodiversity Programme

School of Botany and Zoology

University of Natal, Pietermaritzburg

PREFACE

The research presented in this dissertation was conducted in the Forest Biodiversity Programme as part of the requirements for the degree of Master of Science in the School of Environment and Development at the University of Natal, Pietermaritzburg, under the supervision of Professor Mike Lawes.

I hereby certify that the research reported in this dissertation is my own original and unaided work except where specific acknowledgment is given, and that no part of this dissertation has been submitted in any form for any degree or diploma at another university.

Signed

M Wilkinson

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ACKNOWLEDGEMENTS

I would like to express my sincere appreciation for the assistance and advice given by the following people:

- Prof. Mike Lawes (Co-ordinator of the Forest Biodiversity Programme in the Department of Zoology, University of Natal, Pietermaritzburg) for acting as my supervisor;

- Foundation for Research and Development (FRD) for funding;

- Prof. Rob Fincham (Director of the School of Environment and Development);

- Mr Ricki Pott (Environmental Manager for Mondi);

- Dr John Scotcher (Environmental Manager for SAPPI);

- Dr Dave Everard (Environmental Manager for SAPPI);

- All Mondi and SAPPI participants of the C&I workshop;

- Mrs Valerie Wilkinson and Althea Adey for their assistance in editing the document;

- Elizabeth Hunter (Master of Science Student) for assistance in completing the task assigned to us;

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LIST OF ACRONYMS AND ABBREVIATIONS

C&I	Criteria and indicators
CIFOR	Centre for International Forestry Research
DWAF	Department of Water Affairs and Forestry
EMS	Environmental Management Systems
FAO	Food and Agriculture Organization of the United Nations
FMU	Forest Management Unit
FSC	Forest Stewardship Council
ISO	International Organisation for Standardisation
ITTO	International Tropical Timber organisation
NFAP	National Forestry Action Plan
NGO	Non-governmental Organization
SAFCOL	South African Forestry Company Limited
SAPPI	South African Pulp and Paper Industry
SFM	Sustainable Forest Management
SFM	Sustainable Forest Management
UNCED	United Nations Conference on Environment and Development
WWF	World Wide Fund for Nature

EXECUTIVE SUMMARY

South Africa does not have an abundance of indigenous forest resources. Plantations of fast growing exotic tree species are planted and harvested to meet local timber, pulp and paper demands. These plantations significantly alter the ecosystem, at least within the planted area. Growing environmental concerns have required that the forestry industry find links between sustainable economic activity and environmental quality. To prolong tree farming well into the future environmentally sustainable methods of production and plantation management must be developed. A suggested instrument for achieving sustainable plantation management is the development of criteria and indicators, which can be applied and interpreted by non-experts, for measuring the direct and indirect impacts of plantations on the natural resources of an area.

CRITERIA AND INDICATORS

Criteria and indicators (C&I) by definition are *tools which can be used to collect and organise information in a manner that is useful in conceptualising, evaluating and implementing sustainable forest management* (Stork *et al.*, 1997; Boyle *et al.* in press). C&Is can be applied by managers to *assess the progress of plantation management towards sustainability.*

The benefits of C&Is are: (1) internationally they broaden the basis of information and understanding about the quality of forestry practices and sustainable forest management; (2) at a national level they provide a guide to developing and revising legislation, policies, tools and processes and in the formulation and refinement of national forest programmes (see Govt. Gaz. 19408. National Forests Act, 1998, No. 84); and (3) at the forest management unit level they assist in the assessment of the outcome of forest management practices and provide a basis for continuous improvement.

C&Is form part of a hierarchical framework of assessment tools which include; principles, criteria, indicators and verifiers (Lammerts van Bueren & Blom, 1997; Stork *et al.*, 1997). This framework describes both the function of each level, and the characteristics needed to formulate P, C, & Is. The framework also assists in breaking down, level by level, the goal (SFM) into parameters that can be managed or evaluated.

AIMS OF THIS INVESTIGATION

The aims of this investigation were fivefold:

- To investigate the impacts of afforestation on soil and water resources;
- To determine the role of C&Is in the South African situation;
- To supply a critique of the process of developing and implementing C&Is;
- To determine a set of soil and water criteria and indicators which can be applied in the assessment of sustainability of industrial plantations;
- To rank soil and water verifiers for relevance, complexity and cost.

IMPACTS OF AFFORESTATION ON SOIL AND WATER RESOURCES

Environmental impacts of plantation forests are poorly quantified in South Africa, except in the case of water resources (DWAF, 1997a). Afforestation of an area affects both the physical and biochemical properties of the soil (Verster *et al.*, 1992), resulting in increased soil compaction from heavy vehicles (Smith, 1994; Pennock & van Kessel, 1997; Smith, 1997), elevated soil acidification (Musto, 1991; du Toit, 1993; Parifitt *et al.*, 1997), changes in nutrient cycling (Musto, 1991; Parifitt *et al.*, 1997), and adaptation of the soil moisture environment (Musto, 1991; Musto, 1994).

Natural fluctuations in the quality and quantity of water occur as a result of annual and seasonal variation in precipitation and temperature, however, some alterations may also be caused by human activities. Impacts of afforestation on water include changes in water quality (Lemly, 1982; Campbell & Doeg, 1989), alterations in water quantity (Bosch & von Gadow, 1990; Maitre & Versfeld, 1997) and effects on the water biotic component (Campbell & Doeg, 1989).

LEGISLATIVE ROLE OF C&Is IN SOUTH AFRICA

In South Africa, sustainability is a key element underpinning the New Forestry Policy, with the National Forestry Action Plan recommending that this new Act *create enabling legislation to promote and support recognitions of appropriate C&Is for SFM which can be used to guide the formation and revision of policies, legislation and the national forestry programme* (NFAP, 1997). The New Forestry Act empowers the Minister to *set criteria, indicators and standards for assessing and enforcing SFM, and create incentives to manage forests sustainably* (National Forests Act, 1998). The Minister may (1) determine criteria to assess whether forests are being managed sustainably; (2) develop indicators which may be used to measure the state of forest management; (3) select appropriate standards in relation to the indicators; and (4) create or promote certification programmes and other incentives to encourage SFM (National Forests Act, 1998). The forestry industry will have to begin developing and implementing C&Is in the future.

PROBLEM OF IDENTIFYING C&Is

Defining sustainability

The term sustainability is used extensively, particularly in the forestry industry, even though there is still a great deal of uncertainty as to what sustainable forest management is (DWAF. 1997a). Sustainability relies on the spatial and temporal perspective of the observer and is a shifting target which changes through time. How sustainable the plantation industry is in South Africa, will depend to some extent on the definition of sustainability and the description of the forestry management unit that is used. The definition *the stewardship and use of forest and forest lands in a way, and a rate, that maintains their biodiveristy, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national and global levels, and that does not cause damage to other ecosystems,* was accepted and applied to industrial plantations (Everard & Kruger, 1996). Since the establishment of monoculture plantations will alter the ecosystem they are replacing, this definition was modified to read...*and that minimized damage to other ecosystems* (Lawes *et al.*, in press).

Since most environmental indicators have only recently been developed they are still considered as being in an experimental phase. It is therefore, important that indicators selected in this study be tested against the wider phenomena they are intended to represent or summarize so that they can be relied upon. As with any such process, this testing can be expected to lead to modification, refinement, or even the abandoning of some indicators if they are found to be unreliable.

Appropriate scale of application and assessment

One of the difficulties of selecting C&Is for plantation forests is deciding on the scale of assessment. Due to economic and time constraints, it would be impossible for plantation managers to assess plantation sustainability at the regional level. It is therefore, suggested that the FMU be *a clearly demarcated area of land covered predominantly by forest managed to set of explicit objective and according to a long-term management plan* (Prabhu *et al.* 1996). This is the area directly under the control of the plantation manager. However, this is often difficult to apply to water resources which lie outside the FMU, i.e. the impacts of activities outside the FMU will affect the quality of water within the demarcated area. The selection of C&Is had to therefore, address spatial values, concerns and priorities.

Acceptable change

Before evaluating indicators and verifiers it is important to also establish appropriate targets, thresholds and/or benchmarks. Assessment of soil and water resources based on thresholds, will need to acknowledge that there are many destructive events and different dynamics associated with each verifier.

Sustaining everything is not an option for a forest manager, and it is therefore, important to decide what we want to conserve in plantation forests. Before the C&I processes are implemented it will be important to decide what 'acceptable levels of change' implies. One of the major stumbling blocks to the C&I process is the conflict between scientists, decision-makers and forest managers on their perceptions of the levels of acceptable change. A compromise will have to be reached, where thresholds are set at realistically attainable levels for forest managers but which will also be acceptable to scientists and policy-makers. This could perhaps be achieved by making use of Bayesian Inference and requires more research.

Evaluation of C&Is

One of the major concerns of the C&I procedure is the process of evaluation. It is important that the practicality of C&Is be assessed in a clear and rational manner, and the reasons for acceptance or rejection be objectively determined. Expert voting alone will not be adequate for scientific and instructive evaluation, since it is based on a value judgement, preconception and assumptions rather than upon scientific principles. It is therefore, important that the C&I process finds means of linking scientific evaluation with management perceptions during the evaluation process.

THE PROCESS OF DETERMINING SOIL AND WATER C&Is

State of the national framework to support C&Is

In South Africa, forestry legislation which emphasizes sustainability is still in its infancy. As yet, no national framework for C&Is has been developed, but DWAF is currently engaged in rectifying this problem. Confusion also exists over who should be developing C&Is and how the process should be implemented. Since there was no national framework which supported and guided the development of C&Is at the FMU level, the selection of soil and water criteria and indicators had to be based on the international initiatives which focus on natural forests.

International initiatives

There are various intergovernmental initiatives to develop criteria and indicators for sustainable forestry management at the national level e.g. Montreal, Helsinki, Tarapoto Processes, Dry-zone Africa and ITTO. In an attempt to develop C&Is at the FMU level, it was established that the criteria and indicators of the Montreal Process could be best adapted and modified to suit this level of application (Montreal Process, 1995). Soil and water C&Is applicable to the principle were therefore, selected (with slight modifications) from this international initiative.

Verifiers of the individual indicators were then selected from a number other sources.

SELECTION OF SOIL AND WATER C&Is FOR SFM OF PLANTATIONS

Using the hierarchical framework of principles, criteria and indicators, the principle, *the maintenance of ecosystem integrity and environmental capability* was selected for the C&I process of SFM of plantations (Lawes and Eeley, 1998). This principle was chosen as it should be an explicit element of the goal of plantation management i.e. sustainability. The criterion selected for both soil and water was *the conservation and maintenance of soil and water resources* (Montreal Process, 1995; Lammerts van Bueren & Blom, 1997).

After comparing international and national C&I initiatives, four soil indicators were selected for plantation forests, these being; no significant variation in (1) erosion, (2) soil organic matter and chemical characteristics, (3) soil physical properties, and (4) persistent toxic substances. Twenty six verifiers were investigated as sources of information and which related to the measurable element of each indicator. Making use of the same initiative, four indicators were selected for water, namely (1) percent of land managed for its protective functions, (2) no significant deviation in stream flow and timing, (3) no significant change in biological diversity, and (4) no significant variation in physical and chemical properties. Eighteen verifiers were selected to evaluate these indicators. Those verifiers which were believed to be non-essential to the C&I process were discarded during the C&I workshop.

RANKING OF SOIL AND WATER C&Is

A C&I workshop was held with plantation managers and environmentalists from two of the large exotic timber producers in South Africa, i.e SAPPI and Mondi. The original set of twenty six soil and eighteen water verifiers were narrowed down into a subset of eleven each. The participants of the workshop were asked to evaluate the selected indicators and subset of verifies according to nine nominated questions: (1) easy to detect, record and interpret, (2) relevance, (3) unambiguously related to the assessment goal (4) precisely defined, (5) diagnostically specific, (6) reliability, (7) sensitivity, (8) provides a summary or integrated measure, and (9) accountability. The results from the workshop were used to rank the practicality of these indicators and verifiers as measures of progress towards sustainable forestry management (Table A and B). In the scale of ranking, the extent of soil erosion, organic pollutants and bulk density were listed as the most important soil quality verifier, while width of riparian zones and variations in aquatic biological diversity obtained the highest score of the water quality verifiers.

Table A: Ranking of soil verifiers using the results from the C&I workshop

IMPORTANCE	VERIFIER
1	Area and Percent of land with significant soil erosion
2 & 3	Organic pollutants and heavy metals, and Soil Bulk Density
4	Soil water content
5	Aeration
6	Exchangeable base cations
7 & 8	Organic Carbon and Nitrogen, and Available Phosphate
9	Soil Strength
10	Soil pH
11	Mineral nitrate and nitrite

Table B: Ranking of water verifiers using the results from the C&I workshop

IMPORTANCE	VERIFIER
1	Width of riparian zones
2	Biomonitoring of aquatic biological diversity
3	Stream flow rate
4	Organic pollutants
5	Turbidity
6	Phosphate
7	Dissolved oxygen
8	Total alkalinity
9	Nitrogen
10	Electrical conductivity
11	pH

IMPLEMENTATION OF C&Is IN SOUTH AFRICA

The role of C&Is in South Africa was investigated to determine whether they can be incorporated into those certification processes which have already been implemented by forestry companies i.e. ISO 14 0001 and FSC. Criteria and indicators may be used as an adaptive management tool which could be incorporated into the auditing process of certification to measure progress towards sustainable management. Where certification systems assess performance standards and management systems standards, C&Is measure progress toward sustainable forestry management at the level of the forest management unit (FMU) and the state of the industry (Granholm *et al.*, 1996). Although there are many similarities and differences between these two approaches to SFM assessment (i.e objective, scale of operation, relation to standard, level of performance and need for transparency), it is hoped that C&Is might assist in clarifying issues related to certification.

RECOMMENDATIONS

Development of C&Is nationally

- Linkages should be rapidly established between international initiatives on C&Is for SFM and the different processes and policies relating to plantation forestry in South Africa;
- There is a need to address the common understanding of the terms, concepts and processes related to the development and application of C&Is, and to ensure that they are relevant to management;
- Research on the development of C&Is should concentrate on approaches to effectively gathering information relating to soil and water conservation, predicting impacts of human intervention on the natural resources, developing C&Is at the FMU level, developing methodologies for aggregating data from the FMU levels to higher levels, and determining impacts of different forest management systems on SFM;
- Information managers should define the audience to be reached, its level of technical expertise, and its information needs. They should also determine the kinds of data which should be presented through indicators, the number of indicators that are to be presented, the degree to which indicator

information should be aggregated, and the reporting units to be used;

Development of C&Is at the FMU level

- Indicators and verifiers which were accepted at the C&I workshop need to be tested in the field. Information managers should then vet these indicators with individuals representing a sample of the target audience. This will ensure that the indicators effectively answers users' questions;
- Those indicators and verifiers which obtained low scores at the C&I workshop should be further researched to determine whether they form part of an essential suite or whether they may be discarded;
- A relationship needs to be established between management practices, environmental effects and other ecosystems processes;
- The spatial and temporal scale of measurement, and the method and duration of assessment need to be determined.
- Scientists in conjunction with managers and major stakeholders need to determine the acceptable levels of change, and the thresholds, targets and benchmarks against which the C&Is can be measured.
- Methodologies must be determined to locate representative reference/monitoring sites;
- Linkages need to be determine between practical and affordable verifiers which also meet the agreed objectives of the C&I process.
- Linkages must be determined to present indicators already used by forests with those applied in the C&I process.

CONCLUSION

Criteria and indicators are useful tools, designed to support the improvement of the quality of forest management as an integral part of the sustainable development of the nations in which they occur. They accomplish this by providing a measure of the state of forests and their management, and therefore, may be used to assess progress towards the achievement of SFM.

The development and implementation of C&Is is a dynamic process. Indicators and verifiers must be continually refined in response to changing public preferences, new scientific information, growing experience within countries and the exchange of experience between them. Since South Africa lags behind in the development of C&Is for plantation forests, it is important that they concentrate on this process in their attempts to achieve the goal of sustainable forestry management.

CHAPTER ONE

INTRODUCTION

South Africa is not blessed with an overabundance of forest resources, with indigenous forests making up only 0.2 % of the local vegetation (Low and Rebelo, 1996). Purposeful efforts to plant alien tree species began in the1870's, in an attempt to provide an alternative for this fast-disappearing natural resource, (NFAP, 1997). In the last hundred years, the industrial forest sector has emerged as a central element of the local economy, maintaining the livelihoods of thousands of households, mainly in rural areas. The industry has grown to about 1.49 million hectares of planted exotic timber, with efforts being made to manage these plantations for sustained production (NFAP, 1997). A situation analysis of the value of plantation forests in South Africa is shown in Table 1.

Most afforested catchments in South Africa were previously covered by either fynbos or grasslands. The planting of these areas with exotic trees has in many cases led to environmental degradation, and destruction of natural resources.

Table 1: Statistical evaluation of the importance of industrial plantations to the South African economy (Information taken from the NFAP, 1997 and DWAF, 1997a, 1997b).

Contributed 1.8 % of the country's GDP in 1996.
Providing 4.7% of total export earnings in the same year.
Employs 111 550 people, most of whom work in the plantation environment.
Yields about 19 million cubic metres of roundwood, however, this is considerably below potential.
Estimates indicate that about 28 to 30 million cubic metres of roundwood could be yielded annually.
Approximately 1 486 923 hectares of land is under plantations, of which 56 % is pine (*Pinus* spp), 32 % eucalyptus (*Eucalyptus* spp) and 11% wattle (*Acacia* spp).
Industrial plantations are concentrated in Northern Mpumalang (41%), KwaZulu/Natal (37%), Eastern Cape (11%) and Western Cape(6%), where conditions are most suitable for afforestation.
Of the plantations found in South Africa, 30 % are publically owned by SAFCOL, the previous homeland (156 700 ha) or local governments, 47 % are owned by four private forestry companies and the remaining 23 % are controlled by small private companies, individuals and outgrowers (14 000 ha).
Of the roundwood consumed annually by the forestry industry, 69% is used in the pulp and paper industry, 23% as sawn timber and 17% in mining.
In 1995/96, R 12 billion rand was invested in the forestry product industry, 90 % of which was in the pulp and paper industry,

With concern for the sustainability of natural resources gaining momentum, the drive to develop sustainable methods of management for all social, economic and environmental production systems has accelerated. Sustained yield has broadened from basic wood production to the multiple-uses of forests such as the production of products, provision of recreational opportunities and protection of the environment, evoking diverse expectations in relation to sustainability (Granholm *et al.*, 1996; Nambiar 1996a; 1996b). This led to the revision of traditional concepts of sustained yields and has induced the development of concepts such as sustainable forestry and sustainable forest management.

With growing environmental concerns, it is essential for the forestry industry to find a link between sustainable economic activity and environmental quality. To prolong tree farming well into the future it is imperative to develop methods of production which are sustainable. In South Africa, the yield of wood from the current resource base is regarded as sustainable, but threats to this sustainability include soil acidification and declining fertility, future spread of forest pests and diseases, the risks inherent to monoculture forests, increased climatic variability, and an ongoing threat of destructive forest fires (NFAP, 1997). Whether exploitation of the resource as a whole can be sustained will depend on additional social and environmental considerations such as; increased competition for water, the need to ensure higher net economic benefits from the forestry sector than can be derived by other sectors exploiting the same resource, the need to ensure that forest development contributes meaningfully to local rural development, the need to protect biological diversity, and the need to achieve stakeholders agreement on the criteria and indicators of sustainable forest management (NFAP, 1997).

Sustainability relies on the spatial and temporal perspective of the observer and is a shifting target which changes through time. The term is used extensively, particularly in the forestry industry, however there is still a great deal of uncertainty as to what sustainable forest management is (DWAF, 1997a). How sustainable the plantation industry is in South Africa will depend to some extent on the definition of sustainability and the description of the forestry management unit that is used.

SUSTAINABILITY

The term 'sustainability' is a new concept in many sectors, but is one which has been an important component of forest management for some time. Sustainable wood production has existed in one form or another since the 13th and 14th centuries (Granholm *et al.*, 1996). Sustainable yield management which focuses on maximum productive output and economic gain, has proved inadequate to meet the requirements of present day society. Concentration on the production of commodities has led to the disruption of ecosystem processes that balance and cycle energy and matter (Doran *et al.*, 1994). Added to this, is the high growth rate of the human population, which if allowed to continue unchecked, has the potential to further damage and disrupt these processes. Plantation forestry therefore, needs to achieve a balance of environmental and production values (Nambiar, 1996c).

In recent years, much of the debate about ecologically sustainable development has been focussed on forests, their potential to provide multiple benefits over the long term, their critical role in life-supporting processes and their value to the environment. Suggestions have been made that; '*sustainable development (or sustainable forest management) might well be regarded as a ritualistic symbol or icon of some desired but ill-defined future*' (Ferguson, 1996). Ecologically sustainable forestry management as yet, has no discrete interpretation or shared understanding, however, due to public expectations and political pressures on scientists, managers and policy makers, the momentum to provide criteria and indicators for assessing sustainability has accelerated.

The lack of a clear definition for ecological sustainable forestry management is a potential problem when developing criteria and indicators, it is for this reason that the popular definition of sustainable forestry proposed by UNCED was accepted and applied to industrial plantations. The definition states that: *"the stewardship and use of forests and forest lands in a way, and a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local,* *national, and global levels, and that does not cause damage to other ecosystems"* (Everard & Kruger, 1996). Since the establishment of monoculture plantations will alter the ecosystem it is replacing, this definition should be modified to read "....*and that minimized damage to other ecosystems*" (Lawes *et al.*, in press).

The central theme to sustainable forestry management is therefore, that the potential of the forest to meet the present and future needs and aspirations of society should not be diminished and might even be increased (Granholm *et al.*, 1996). This concept includes four elements, i.e. ecological, social, institutional and economic aspects. Today, forest managers are initiating policies and practices which encompass the maintenance and enhancement of the ecosystem as a whole. The multiple functions of forests, which include social, cultural and spiritual functions, and the maintenance and enhancement of the health and vitality of biological diversity of forests are widely recognised elements of forest policies and management.

In developing sustainable management practices it is necessary to have a basic understanding of the processes that determine the biological productivity of plant communities in specific soils and the impacts of management practices on ecosystem processes and productivity, e.g. sites should be prepared to increase water and nutrient availability, fertilizer application and weed control should minimise competition for site resources, and the frequency and nature of harvesting should limit impacts on the soil, the biophysical environment and on growth (Nambiar and Brown, 1997). Of many key properties and processes that are changed by forest operations, the most critical ones include the physical state of the soil, levels of organic matter, nutrients and nutrient dynamics and competition for site resources between different component of the vegetation. Sustainable land use practices and tree farming systems should enhance and maintain the economic viability of wood production for a variety of end products, the natural resource base, especially soil and water, and other production systems that may be integrated with tree farming (Nambiar and Brown, 1997).

The New South African forest policy requires that the industry not only be internally efficient and profitable, but also rational in its use of resources, equitable in its development, and environmentally sustainable. There is increased consideration and commitment to developing improved and effective ways of managing and mitigating the effects of industrial forest on soil and water resources in South Africa. However, the rapid change and dynamic nature of ownership of plantations, and the economic motives and imperatives that drive plantation expansions, will enhance the view that the basic reward is remuneration and that plantation management is principally an exercise of property rights within a broader framework of environmental care and social responsibility (Nambiar and Brown, 1997).

Assessing sustainable forestry management with the use of criteria and indicators provides systematic and objective information about the state and trends of the forests and forest management practices (Granholm *et al.,* 1996). A number of countries have already included elements of sustainable forest management as recognised in C&Is, in their national policies. In South Africa, sustainability is a key element underpinning the New Forestry Policy. The National Forestry Action Plan (NFAP) also recommends that the New South African Forest Act, *create enabling legislation to promote and support recognition of appropriate C&Is for sustainable forest management which can be used to guide the formation and revision of policies, legislation and the national forestry programme.* The National Forestry Act passed in 1998, empowers the Minister to *set criteria, indicators and standards for assessing and enforcing SFM, and create incentives to manage forests sustainably* (National Forests Act, 1998). The Minister may (1) determine criteria to assess whether forests are being managed sustainably; (2) develop indicators which may be used to measure the state of forest management; (3) select appropriate standards in relation to the indicators; and (4) create or promote certification programmes and other incentives to encourage SFM. Sustainable management should therefore be a process of continuous improvement in forest practices, towards achieving desired standards.

CRITERIA AND INDICATORS

Criteria and indicators (C&I) by definition are *tools which can be used to collect and organise information in a manner that is useful in conceptualising, evaluating and implementing sustainable forest management* (Boyle *et al.*, in press; Stork *et al.*, 1997). One of the goals of sustainable plantation management should be the maintenance of the environmental capability of the forestry management unit. A suggested instrument in achieving this, is the development of a set of criteria and indicators, which could be applied and interpreted by non-experts as a rapid method of measuring the impacts of the plantation on the natural resources of the area. C&Is for sustainable forest management are not an end in themselves, but should be viewed as a tool which can be applied by managers to *assess the progress of the plantation towards sustainability.* Criteria and indicators are designed to be used as an instrument to determine trends and changes in conditions of forests in the economic, social or political context within which those forests are managed (Granholm *et al.*, 1996). They serve as an 'early warning' system which help to identify gaps, threats and new opportunities facing forests and their managers (Granholm *et al.*, 1996). A number of C&Is measured over time will reflect the trends towards sustainable forest management. This will lead to the development of a 'tool box' for sustainable assessment which can guide developers to a set of C&Is containing the minimum number sufficient to adequately assess sustainable forestry management. However, this may lead to the further problem of deciding what the minimum number of C&Is are, and what the linkages are between those selected.

C&Is form part of a hierarchy of assessment tools. Stork *et al.* (1997), lists four hierarchical levels to C&Is, which include; principles, criteria, indicators and verifiers. Principles, criteria and indicators have already been developed for sustainable management of indigenous forests (Stork *et al.,* 1997; Boyle *et al.*, in press). However, since South Africa focuses on tree farming rather than logging, C&Is applicable to indigenous forests may not necessarily be appropriate for the sustainable management of commercial forests. The research of C&Is for sustainable management of commercial forests has only reached the point of determining the possible impact and effects on the biodiversity of the area. With the rapid growth of South Africa's population, it is imperative to further develop C&Is for sustainable management of plantations to ensure and maximise wood production for future generations.

The functions of C&Is are to achieve a mutual understanding of sustainable forest management, facilitate improvement of the description and appraisal of forestry progress, to operate as a guide to policy, tools and processes, and further comparisons with other countries (DWAF, 1997a). They should improve the quality of information about forests and impacts of forestry management practices. The proposed operators of C&Is would be certification bodies, governmental officials for policy making, donors as a tool for the assessment of the sustainability of a project, forest managers, project managers as a planning tool, and scientists (Stork *et al.,* 1997). Criteria and indicators should be practical, rapid and cost-effective methods for determining sustainable management practices. They should also be easy to understand, simple to apply and provide relevant information to the manager and the policy makers (Stork *et al.,* 1997).

SCALE OF APPLICATION OF C&Is

Criteria and indicators have been developed to assess sustainability at a range of spatial scales, e.g. international, regional, national and forestry management units (FMU). Although C&I initiatives recognise these levels, it is often difficult to decide whether development should begin at national or FMU levels. Criteria and indicators which have been developed for use at the international and national levels are aimed at facilitating, monitoring and reporting of observed trends in the state or conditions of forests and forest management (Lammerts van Bueren and Blom, 1997).

When developing C&Is, it has been discovered that sustainable forestry management will not be accomplished through only understanding the structure and functions of the forests, but will include the establishment and implementation of appropriate forest policies. National forestry policies for sustainable forest management build a framework for the adaptation of regional and international criteria and indicators which can be applied at a national scale (Granholm *et al.*, 1996). National-level C&Is, which assess the status of forest management over the entire country's forested area, are usually based on a number of international initiatives, such as the Helsinki, Montreal and Tarapoto Processes. Regardless of the reporting method and whether done individually or as a process, any interpretation of the reported results of individual countries should be done with great caution since ecological and socio-economic conditions, terms and definitions, and ways and means of forest policy as well as practising forest management, vary from one country to another (Granholm *et al.*, 1996). Sets of C&Is developed for different levels may not be fully compatible without adjustments. The adjustments may be based on differences of relevance of certain issues, or on different degrees of detail by which parameters should be described. At the national level the forest base must be secured to sustain the forest at the level of the FMU. This is a condition of sustainable management of the FMU.(Lammerts van Bueren and Blom, 1997).

It is essential that sustainability of forest management be measured at both the national and local scales. The issues of concern of international and national level C&Is have been discussed in a more generic way than in a smaller spatial scale such as the FMU (Lammerts van Bueren and Blom, 1997). However, there is a strong relationship between sustainable forestry management (SFM) at the national level and at the FMU level. SFM for the FMU is ultimately dependent on a national forest policy. The policy is reflected in laws, land use procedures and guidelines for sustainability. In South Africa, forestry legislation which emphasizes sustainability is still in its infancy. As yet, no national framework for C&Is has been developed, but DWAF is currently engaged in rectifying this problem. This framework is essential as a legal basis for the implementation of C&Is at both the local and FMU levels. While local-scale assessment is needed, it is the management decision made in individual FMU's which will determine the sustainability of forestry management practices. However, it is only national scale C&Is which can measure the sustainability of certain large scale management practices such as the establishment of a system of "protected areas" for conservation purposes. (Boyle *et al.*, in press). Therefore, satisfactory assessment of forest management at the FMU level should take into account any crucial aspects at the national level.

SCALE OF APPLICATION OF C&Is WITHIN THE FORESTRY MANAGEMENT UNIT.

Environmental changes caused by plantations vary temporally and spatially, the plantation landscape becoming the effective forestry management unit which is used in the assessment of sustainability. However, due to economic and time constraints, it would be impossible for plantation managers to assess plantation sustainability at the landscape level. Prabhu *et al.* (1996) suggests that the forestry management unit in indigenous forests be defined as "*a clearly demarcated area of land covered predominantly by forests managed to a set of explicit objectives and according to a long-term management plan*". This is the area directly under the control of the plantation manager. It is an area small enough to monitor and manage but large enough to take into account the processes which are being assessed. However, this is difficult to apply to water resources which often lie outside the FMU, e.g. water quality can be employed as a tool to assess progress towards SFM, however the measurement of this characteristic may reveal that management practices of the FMU are not sustainable when negative impacts may have originated from water usage higher up in the catchment area.

Since the structure, composition and function of plantations at the FMU level are dynamic in both space and time, identifying an appropriate scale of management may become a challenge to forestry managers. In some cases the appropriate spatial scale for management may be the plantation stand, in others the plantation compartment or the landscape of which the plantations form a part (Spellerberg and Sawyer, 1996). Suggestions have been made that the issue of plantation management at the FMU level be separated into plantation stands and the natural areas, although the two are interlinked. Accordingly, it has been proposed that plantation stands (making up 60 % of the South Africa FMU), be managed for sustainable production of wood using introduced species, and the natural areas (40 % of the FMU) consisting of a variety of natural ecosystems, be managed for conservation (DWAF, 1997a). However, management of the plantation stands purely for wood production negates any possible ecological value.

Natural processes also occur at many scales in the FMU, it is therefore important to determine at which level (e.g. plantation stand, plantation compartment, ecosystem, habitat or niche) the C&Is are applicable. A good example of this problem is that of soil quality, where measurement at any one of these levels may yield vastly different results due to the diversity of soils characteristics within the FMU.

SYNTHESIS

The route to sustainable plantation management is neither easy nor rapid. With South Africa in the situation of having to plant exotic timber to meet present and future wood requirements, it is imperative that sustainable methods of wood production be developed which link maximum economic gain with the maintenance of social and environmental capability. Many countries and organisations seek practical means and ways too sustainably manage all types of forests. These efforts include, the development and implementation of guidelines and criteria and indicators (C&Is) for sustainable forest management.

Criteria and indicators have been developed to assess sustainability at a range of spatial scales, e.g. international, regional, national and forestry management units (FMU). Although C&I initiatives recognise these levels, it is often difficult to decide whether development should begin at national or FMU levels. National forestry policies for sustainable forest management build a framework for the adaptation of regional and international criteria and indicators which can be applied at a national scale. A strong relationship exists between sustainable forestry management (SFM) at the national level and at the FMU levels. SFM for the FMU is ultimately dependent on a national forest policy, but it is the management decision made in individual FMU's which will determine the sustainability of forestry management practices.

Since the structure, composition and function of plantations at the FMU level are dynamic in both space and time, identifying an appropriate scale of management may become a challenge to forestry managers. Suggestions have been made that the issue of plantation management at the FMU level be separated into plantation stands and the natural areas, although the two are interlinked. Since natural processes also occur at many scales in the FMU, it is important to determine at which level the C&Is are applicable.

In South Africa, forestry legislation which emphasizes sustainability is still in its infancy. As yet, no national framework for C&Is has been developed, but DWAF is currently engaged in rectifying this problem. This framework is essential as a legal basis for the implementation of C&Is at both the local and FMU levels. Since South Africa lags behind in the development of C&Is for plantation forests, it is important that they concentrate on this process in their attempts to achieving the goal of sustainable forestry management.

CHAPTER TWO

IMPACTS OF AFFORESTATION ON SOIL AND WATER RESOURCES

Despite their contribution to the national economy, the establishment of exotic tree species on land which was previously covered by grassland, and the management of these plantations for timber production, results in extensive impacts on the indigenous vegetation and ecosystems. These impacts include effects on soil, biological diversity, atmosphere, visual landscape and water resources (quantity and quality) (Everard and Kruger, 1996). Impacts are usually concentrated on the afforested area, with the actions on surrounding areas being smaller (DWAF, 1997b). The quality of the land and the management practices of growers dictate the nature and scale of impacts.

From a land management and silvicultural perspective, plantation forests are closer to farms than native forests, and wood harvests can be considered as another farm product (Nambiar and Brown, 1997). Although industrial timber production is based on the management of transformed ecosystems, it differs from crop agriculture in the relatively high average annual removal of biomass, the relatively low input costs, long intervals between major site disturbances, and the mosaic, spread-out nature of afforestation on an average of 60 % of the estate (DWAF, 1997a). On the unafforested land (40 % of the estate), impacts include vegetation change and weed invasion arising from altered fire regimes. This is the area of the estate where the most positive influences can be achieved, largely by the protection of the indigenous habitats (DWAF, 1997a).

The sustainability of plantations is more likely if there is maximum alignment between interdependent variables such as the ecological capability of the site, the intensity of management, and soil, water, and other environmental values (Nambiar and Brown, 1997). The measure of ecological capability is bound by the inherent soil and biophysical constraints, and their responsiveness to management inputs to increase productivity. The intensity of management at a site should take into account the resistance, resilience and productive capacity of soil and water resources, as well as impacts on adjacent ecosystems.

Environmental impacts of plantation forests are poorly quantified in South Africa, except in the case of water resources (DWAF, 1997a). Although this country has a competitive advantage of producing quality wood fibre at relatively low cost, how well this advantage can be sustained without clearly understanding the environmental implications of the productive process and management practices, remains to be seen.

ENVIRONMENTAL IMPACTS OF AFFORESTATION

Due to environmental concerns, attention is being focussed on the potential impacts of timber extraction and intensive agricultural practices carried out during commercial forestry operations in South Africa. Replacement of natural grassland with industrial plantations may lead to either negative or positive repercussions, or sometimes both simultaneously. Some of these advantageous and disadvantageous environmental impacts are shown in Table 2. It is obvious from the table that the negative environmental consequences of industrial plantations out-weigh the advantages.

Table 2: Advantages and Disadvantages associated with industrial plantations (Modified from Erskine, J.M., 1990)

Advantages	Disadvantages
Improved water quality	Change in water flow regime
Arrested soil erosion	Pollution of soil and water
Flood amelioration	Acidification of soil and groundwater due to the accumulation of litter form acidifying tree species
Decline in the pressure on indigenous forests	Increased erosion, sediment and organic matter loads due to clearing of land
Firewood production	Lowering of groundwater level reducing water availability
Oxygen production	Soil compaction
	Spread of exotics
	Loss of wetlands
	Spread of invader weeds
	Wildlife impacts
	Loss of key habitats

IMPACTS OF AFFORESTATION ON SOUTH AFRICAN SOIL RESOURCES

Afforestation of an area may cause major changes in the environment both at the landscape and ecological process levels. Even so, timber farming is still considered a renewable resource if practiced in a sustainable manner (Forestry White Paper, 1996). It is essential to balance the finite soil resources with ever-increasing population numbers and the soils vulnerability to degradation (Karlen and Stott,1994). Principal causes of soil degradation are deforestation, overgrazing, agricultural activities, over-exploitation and bio-industrial activities. Degradation of the soil endangers agricultural sustainability and environmental quality (Lal, 1997).

Transformation of soil biology in plantations may result in variation in the microclimate and the chemistry of the litter, impacting on the nutrient cycle and soil-forming processes (Everard and Kruger, 1996). The intensification of production methods can lead to the degradation of soils. To ascertain the impacts of production practices on soils, it is important to first understand the soils function. Soil is the medium for plant growth, it regulates and partitions water flow and it serves as an environmental buffer in the generation, decline and degradation of environmentally hazardous compounds (Larson and Pierce, 1991). Disruption of any of these functions may impact directly on the soil quality, which determines the suitability of a soil for sustainable plant growth and biological activities.

Impact of afforestation on the physical and biochemical properties of the soil

The physical properties of a soil play an important role in relation to its resilience and degradation. Soil resilience is defined as the soils ability to recover and restore life support processes and environmental regulatory functions, while soil degradation is brought about by a variety of human actions (Verster *et al.*,1992) Afforestation may lead to degradation of the soil in three categories; physical degradation (soil erosion, compaction and crusting), chemical degradation (loss of fertility, acidification, salinization, soil pollution) or biological degradation (invasive biotas, eelworms and plant pathogens) (Verster *et al.*, 1992)

PHYSICAL DEGRADATION

The key soil physical properties which facilitate sustainable use are soil structure, bulk density, total porosity and pore size distribution, water retention characteristics and available water holding capacity and water transmission properties including infiltration capacity (Lal, 1997). The long-term effect of physical damage to soil on stand productivity has not been properly assessed. Given the increasing degree of mechanisation and the expansion of plantation areas to marginal and degraded soils, the knowledge from such studies would have considerable long-term benefits (Gonçalves *et al.*, 1997).

Soil Compaction

In South Africa, concern has been expressed that the widespread use of heavy wheeled and tracked vehicles during timber extraction may result in a considerable decline in future site productivity (Smith, 1994). Afforestation impacts are primary concentrated in heavy use areas within the harvest block e.g. skidder trails, roads and landings (Pennock and van Kessel, 1997). The impact acts directly on the soil surface and subsoils resulting in compaction or destruction of the surface soil structure, decline in nutrients due to erosion or biomass removal, and increased sedimentation yields (Pennock and van Kessel, 1997).

Compaction of the soil results in the reduction of pores which are the main pathways for water and air movement. An increase in bulk density and soil strength culminates in the decline in the infiltration capacity of the soil, which would affect the partition of water at the soil-atmosphere interface (Pennock and van Kessel, 1997). Therefore, high soil compaction is likely to have greater effect on tree growth during drought periods because it reduces water availability. Tree growth can be impaired in soils with high bulk density because high soil strength restricts root growth (Smith, 1993; Gonçalves *et al.*, 1997).

In South African forestry soils, soil strength is related to bulk density, water content, clay content and organic carbon. Smith *et al.* (1997) found that soil strength increased with an increment in the bulk density and a decline in the soil water content, except where the soil became very dry. This relationship between soil strength, bulk density and water content was affected by the clay content of the soil and the levels of organic carbon present (Smith *et al.*, 1997).

Smith *et al.* (1996) found that different soils exhibited various compaction behavior at different water contents e.g. sandy loam soils showed an increase in compaction independent of the soil water content at certain applied pressures, while sandy clay loam soils were sensitive to water content at the time of compaction. It is therefore, important that the soil indicators chosen to assess soil sustainability include such measures as soil texture, water content and soil bulk density.

CHEMICAL DEGRADATION

Soil Acidification

The acidification of soils under plantations may result from either natural or anthropogenic origin (du Toit, 1993). Soil acidification is usually attributed to the addition of acid, usually of atmospheric origin, or the removal of bases by leaching and biomass accumulation (du Toit, 1993). Clays, the active mineral portion of soils, have a net negative charge which will result in the soil holding cations such as potassium (K^+), sodium (Na^+), ammonium (NH_4^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), and aluminum (Al^{3+}) (Miller and Donahue, 1995). Removal of these exchangeable cations may occur due to absorption by plant roots or replacement with hydrogen (H^+) and aluminum dihydroxide during the leaching process. Since hydrogen and aluminum dihydroxide are acidic cations, replacement will cause toxicity in the soil solutions.

It is estimated that many of the South African plantations are situated on soils where leaching has already occurred or which have already undergone some degree of acidification (du Toit, 1993). The planting of exotic trees on this land may lead to rapid environmental degradation of the area. Pines, wattles and eucalypt plantations all show a definite tendency to acidify the soil (Musto, 1991). Parifitt *et al.* (1997) recorded soil acidification by pines in the upper 20 cm of silt loam soil despite the high levels of carbon, moderate levels of bases and base rich parent material. Pines may amplify soil acidification through the production of organic acids, biomass storage of cation in excess of anions and canopy capture of acid pollution (De Vries *et al.*, 1995). du Toit's (1993) results suggest that the acidification effect of pine, eucalypt and *Acacia* tree species is similar, however, *Acacias* exhibited slightly higher degrees of soil acidification.

du Plessis (1996) reports that, although there is little reliable data on the extent of the problem of soil acidification in South Africa, some soil scientist regard it as one of the greatest threats facing commercial agricultural. It is therefore, important to include this indicator as a measure of sustainability since the effects of this problem can be widely spread across a plantation.

Nutrient Cycling

Plantations are exposed to loss of nutrients through direct and indirect processes. Direct loss results from the quantitative removal of biomass during the harvesting process. The extent of nutrient loss due to direct process is dependent on the circumstances, species involved, nature and frequency of the harvest and the rotation age of the crop (Shepard, 1986). Indirect loss of nutrients is a consequence of poor management practices which culminates in leaching, erosion and physical disturbance of the site (Shepard, 1986).

In South Africa, the percentage of organic carbon in top soils showed little change between grassveld and stands of eucalypts and wattle. However, consistently lower levels of organic carbon were found under pines when compared with grassveld (Musto, 1991). Parifitt *et al.* (1997) also found that soils which were affected by conversion of pasture to pines showed a redistribution of soil organic carbons, a decrease in total nitrogen, soil acidification and an increase in pools of exchangeable magnesium, potassium and sodium. The organic carbon concentration and pools in the upper 20 cm of the soil decreased after conversion, but if the litter layer was included, no difference was observed (Parifitt *et al.*, 1997). This led them to conclude that although the vegetation type had been changed, the decreases of soil organic matter from the mineral soil which had resulted from the conversion, had been balanced by gains in the litter layer under the pine. This demonstrated that the change in soil nutrients may be due to difference in the above ground biomass. In the early stage of stand development, little production of detrital material will arise, as a result the residual organic carbon will decrease. The increase in the exchangeable cation pool could be due to nutrient cycling which results in the absorption of nutrients from the lower soil horizon, which are subsequently returned to the soil surface via rainfall and canopy through fall.

A decline in total nitrogen in soils under afforestation could be attributed to the removal of nitrogen fixing clover, the accumulation of nitrogen in the vegetation biomass or due to leaching (Parfitt *et al.*, 1997). Nitrogen is a major plant nutrient which is a commonly limiting factor in plant growth and, therefore, together with potassium is a primary component of most fertilizers. The availability of these nutrients in the soil, are not only affected by gross levels of nitrogen, but by factors such as soil acidity and micro-organisms activity (Musto, 1991). Soil mineralization can be a rate-limiting step in the supply of N to plants due to insufficient quantities available for growth or a lack of synchronisation between supply and demand of N. Mineralisation of the soil depends on a number of factors i.e. quality of organic matter (C:N ratio, lignin and phenolic content), environmental conditions and microbial factors (Fölster and Khanna, 1997). Other properties such as soil pH, soil texture and mineralogy are also fundamental.

In South Africa, Musto (1991) found little change in the total nitrogen levels in the topsoil of grassveld and tree stands of eucalypt and wattle. However, it is known that many eucalypts tend to take up greater amount of nitrogen in the form of ammonium cation as opposed to nitrate anions (Attwill and Leeper, 1987). This may result in greater amounts of hydrogen ions being removed from the roots and will add to the acidity of the soil. Wattle roots also produce their own source of nitrogen and as a result, trees do not take up nitrate ion from the soil. To maintain electrical neutrality of roots, a greater proportion of hydrogen ions will therefore, have to be released into the soil.

By maintaining or increasing soil organic matter levels and labile carbon and nitrogen stocks, the nutrient supplying potential of soils will be improved, and in the long-term ecological sustainability may be economically achieved (Gupta, *et al.*, 1994). Since these soil properties impact directly on sustainability, one would expect them to be carefully managed and monitored, and to form part of those indicators which are developed to assess the sustainability of industrial plantations.

Soil Moisture

Soil profile hydrological properties are modified by plantation forestry (Musto, 1994). The profile becomes drier, with the effect most pronounced in the topsoil. Three interacting factors (e.g. high water demand of trees, deep rooting system of trees and presence of strong water repellence in eucalypt topsoil) all contribute to the drier characteristics of soils under plantations. Water content is consistently lower in soils under plantations compared to adjacent grassland soils (Musto, 1991). The difference in topsoil water content between grassland and eucalypt is generally greater than the difference in subsoil water content.

Pine, wattle and eucalypt trees showed distinct water repellence over a wide range of soil types, although only observed in the topsoil (Musto, 1991). Water repellence has a marked effect on soil water retention characteristics, infiltration rates and hydraulic conductivity of unsaturated soils. Top soils under eucalypts do not wet-up effectively in some instances, which could have an effect on the pattern of water movement in internal drainage of the soil and could aggravate the relative dryness of eucalypt topsoil relative to grassland topsoil. However, trends indicate that infiltration rate is substantially increased in soils under wattle and pine relative to grassland (Musto, 1991).

Since there will be a marked difference in the moisture content of soil under plantations, it is questionable whether this will be a useful indicator of sustainability. However, changes in certain soil moisture characteristics may give indirect indications of changes in other soil properties, e.g. a decline in the water infiltration capacity of a soil may indicate variation in soil bulk density or increased soil compaction. It is perhaps for these indirect measures that these soil characteristics could be included in the assessment of sustainability.

IMPACTS OF AFFORESTATION ON SOUTH AFRICAN WATER RESOURCES

The water catchment areas of South Africa are situated on the escarpment of the interior plateau and along the southern and south western coastal mountain ranges. Since these regions are high rainfall areas (800mm to 1 000mm per annum), they are well suited for the planting of exotic timber (Bosch and von Gadow, 1990). This places severe demands on South Africa's water supply, and produces conflict between afforestation and downstream water users. It has been estimated that the total reduction in surface water resources in South Africa as a consequence of afforestation was 1 284 million m^3/annum for 1980 and is likely to increase to 1 700 million m^3/annum by the year 2010 (DWAF, 1996a).

Water is a major component which restricts expansion of the forestry industry in South Africa (Maitre and Versfeld, 1997). The growth of the industry is controlled by the afforestation permit system, the procedure of which is explained by the rule: *if afforestation will reduce the mean annual runoff of a catchment beyond a specified minimum level, a permit is not granted. Otherwise planting is permitted, provided that streams, vleis and other open bodies of water are not afforested.* Therefore, the key data required when considering the issuing of an afforestation permit in South Africa are:

- a minimum flow requirement for the catchment; and
- the expected decrease in the mean annual rainfall (MAR) from the catchment after afforestation (Bosch and von Gadow, 1990).

Catchments in South Africa have been divided into three separate categories in terms of acceptable decline in MAR. Class 1 catchments are those where no further reduction may occur, Class 2 where a reduction in the MAR of 5 % is allowed, and Class 3 where a 10 % reduction will be accepted (Bosch and von Gadow, 1990). Most hydrological research into the impacts of afforestation on South African water resources has been aimed entirely at important data for policies and legislation for regulation of the industry (Maitre and Versfeld, 1997). Little research has been carried out on how plantations can be managed as to conserve and utilise water resources efficiently and effectively. Afforestation may have a threefold impact on water, namely; changes in water quality, alterations in water quantity and effects on the water biotic component.

Water Quantity

The effect of forest harvesting operations on stream flows is probably the most widely and intensively studied environmental aspect of forestry practices (Campbell and Doeg, 1989). In the high rainfall areas of South Africa, the natural river flow would amount to 150 to 170mm rainfall equivalent per annum. Afforestation of the region is estimated to reduce this flow to about 50 to 70 mm per annum (NFAP, 1997). An investigation carried out recently by Environmentek, CSIR (1997), indicated that the total reduction in average natural river flow by the 1.49 million hectares of plantation forests grown locally is 1.42 billion m^3/annum, a reduction of 2.8 % of the total annual natural river flow (NFAP, 1997). Plantation forestry's reduction in runoff was equal to 7 % of the total water use in South Africa in 1996, the impacts of which were most acutely felt at the provincial and local (catchment) levels (NFAP, 1997). Spatially, reduction in flow may be concentrated to specific river systems which are situated in areas more suited to the planting of exotics.

There is a general shift in South African afforestation and reforestation to replace pines with *Eucalyptus* species, however, less is known about the effects of this species on the water balance (Bosch and von Gadow, 1990). Evidence from studies done on the Mokobulaan A catchment in Mpumalanga, suggests that Eucalypts were accessing and depleting ground water stores more rapidly then other exotic timber species (Bosch and Von Gadow, 1990; Maitre and Versfeld,1997). Pines were also found to use water in excess of that supplied by rainfall (Maitre and Versfeld, 1997). Usually an increase in stream flow following harvesting depends on the amount of timber removed and the proportion of catchment harvested (Campbell and Doeg, 1989). Stream-flow was perceived to decline over the years following harvesting, except where regrowth was discouraged (Campbell and Doeg, 1989).

Bosch (1979) demonstrated that the effect on stream-flow of afforestation on areas which were previously grassland, was proportionately greater during the low flow months. This is due to the fact that grasses are dormant during the dry period. However, similar results were not obtained in areas which had been converted from indigenous forest and fynbos, which may be a result of these vegetation types being evergreen. In an investigation carried out at four sites in South Africa (i.e. Westfalia Estate in the Northen Province, Mokobulaan in Mpumalanga, Cathedral Peak in KwaZulu/Natal and Jonkershoek in the Western Cape), afforestation with both pines and eucalypts caused highly significant reductions in annual low flows, supporting the hypothesis that afforestation causes a significant decline in seasonal low flows (Smith and Scott, 1992). The effect on low flows appears to be more marked for eucalypts (90-100% reduction) than pines (40-60% reductions) in the first eight or so years after treatment, but this variation declined as the stand of trees became well established (Smith and Scott, 1992).

Transpiration losses from riparian vegetation would have the greatest effect on dry period water flow because streams are believed to derive their water from adjacent saturated zones during dry periods (Bosch and von Gadow, 1990). Although there is much evidence to demonstrate the impacts of afforestation on water flow, it is also important to remember that in many instances, investigations in areas where trees were said to have influenced water supplies detrimentally it was found that other factors were largely responsible (Nänni, 1970)

Change in the flow regime of rivers and streams as a result of afforestation of an area will impact not only on the in-stream biota but also on the fauna and flora that surround the water body, and the down-stream water users. It is therefore, important to manage and monitor this water property in attempts to sustainably manage a plantation. It is an indicator which can be directly linked to management practices and activities. However, the selection of this property as an indicator does lead to a number of problems, i.e. flow regime varies seasonally, variation may not be due to management activities but to natural processes such as drought, and activities outside the plantation will also impact on this water property.

Water Quality

Generally, plantation forestry tends to have a positive effect on water quality by reducing surface runoff and loss of topsoil. However, this will not hold true for all stages of the forestry process e.g. clear-felling. The impacts of afforestation on water quality can manifest itself in many ways. In an Australian study, Campbell & Doeg (1989), showed that timber harvesting impacted on a number of water quality characteristic, particularly levels of suspended solids, deposited sediment, nutrient and dissolved solids, dissolved oxygen, organic material, light availability and temperature.

Campbell and Doeg (1989) found that poor forest management practices during road construction and maintenance, timber extraction and site preparation can release large quantities of suspended sediments into river systems. The removal of vegetation cover and compaction of soils during the harvesting process results in decreased permeability of soils and increased erosive soil runoff, which increased the risk of elevated stream turbidity. Most sediment is transported during periods of high flow, often with the largest proportion of the total annual sediment load being transported in three or four floods (Crickmay, 1974). The amount of sedimentation lost from the catchment due to runoff depended on site factors such as slope, soil type and intensity of the harvesting operation. The major sources of the increased sediment appear to be roading and land slips (Campbell and Doeg, 1989).

Campbell and Doeg (1989) suggested that deposited sediment are likely to have far greater significance to stream biota than suspended sediments. Increased bedloads of sediments have been noted in streams which are draining logged catchments (Lemly, 1982). Even after sediment inputs to a stream have returned to normal as a result of forest regrowth, redistribution and transport of deposited sediment within the stream may continue for many years, continuing to disturb the in-stream communities (Campbell and Doeg, 1989).

Dissolved oxygen in turbulent upland streams is nearly always in saturation equilibrium with the air. Therefore, this water quality characteristic may not be useful as an indicator of sustainable plantation management. However, decomposition of organic material which requires oxygen, large scale logging operations, and low flow periods may produce significant reductions in levels of dissolved oxygen in streams (Campbell and Doeg, 1989).

Catchments which have been disturbed by human activities tend to 'leak' nutrients, the levels in the streams draining them are therefore, inclined to be higher. The quantities of dissolved nutrients leached from organic debris into soils and streams after timber harvesting, may increase. Additional nutrients may also be absorbed onto inorganic particulate materials or be contained in organic particulate material which is washed into the stream, further increasing nutrient inputs (Campbell and Doeg, 1989). Invariably, significant increases in dissolved nutrients have been reported when catchments have been deforested or harvested. In the immediate area of timber harvesting the most significant factor influencing the in-stream community will be the actual concentrations of nutrients, but it is the total nutrient load which is most crucial for the downstream users. It may therefore, be important to include this water quality characteristic as a measure of sustainability since it may be directly linked to plantation management activities.

Afforestation may result in a number of other water quality impacts, some example of which are; effects on temperature and light regimes, pollution through the application of pesticides and herbicides, and changes in the vegetation surrounding the river system. The literature on these impacts is as yet very sparse, making it impossible to have a lengthy discussion on each.

Biotic Impacts

It is generally agreed that measuring only the physical and chemical attributes of water cannot provide the sole assessment of the health of an aquatic system (Dallas and Day, 1993). The reasons for this are that chemical monitoring does not account for many man-induced perturbations such as; habitat degradation, which impair biological health; and physical and chemical information is biased towards the momentary conditions that exist at the time the sample is collected (Roux *et al.,* 1993). However, there is far less information on the impacts of timber harvesting activities on the biota of streams than on their physical and chemical characteristics. The long-term biological impacts develop mostly from the removal of riparian vegetation, while short-term effects arise from the influences of suspended and deposited sediments (Campbell and Doeg, 1989). Some areas where these impacts may be observed would be the periphyton, macro-invertebrates and fish.

Assessing stream biota is a valuable indicator of sustainability since individual organisms have been subjected to the totality of conditions in the stream from one measuring period to the next. They therefore, reflect some idea of ecosystem integrity since biological communities reflect the cumulative effects of fluctuation in water quality, and any change in water quality will be reflected by a disruption of community structure (Dallas and Day, 1993).

MEASUREMENT AND MANAGEMENT OF SOIL AND WATER RESOURCES

Soils

With increasing awareness of the complexity of forestry site dynamics it is becoming evident that more refined soil survey information is required, and that it should be presented in a more accessible form to land-users (Musto, 1992). Soil survey information should be upgraded to emphasise the present condition of the soil of a particular type, include mitigation of negative impacts in management practices, emphasise increased understanding of those soil parameters that characterise the resilience or sensitivity of a soil, and heighten the need to make this additional information available to land-users to assist them in refining decision-making and improve their understanding of important site dynamics (Musto, 1992).

The major limitation of the present system of soil-site surveys is that a single class index cannot describe adequately the different aspects of soil quality. The information commonly used in soil survey codes are listed in Table 3. To optimise sustainable forestry management, separate assessment of different aspects of site quality are required. The survey should include parameters that best describe the different attributes of site quality, major components of site quality should be rated separately, and these ratings presented in an easily assimilated form (Musto, 1992).

Table 3 : Soil survey codes commonly used in the forestry industry (Musto, 1992).

Wetness hazard	Effective soil depth/ effective rooting depth
Cultivation limitations	Depth of topsoil
Nature and depth limits of root restricting layers	Type of topsoil
Nature and depth of root limiting horizons	Colour of topsoil and subsoil
Soil classification	Strength of structure in subsoil
Slope % and landscape position	Clay %, topsoil and subsoil
Parent material	Sand grade, topsoil and subsoil
Permeability, topsoil and subsoil	

Musto (1992) suggests that the parameters which should be included in the site survey are:

- topsoil colour - this is an essential indicator of organic matter status, soil drainage and parent material type;
- topsoil structure - this provides basic and essential information about the physical condition of the soil, may be a useful indicator of soil moisture status since it reflects to some degree the extent of weathering, can indicate the vigour of a soil in terms of biological activity and has an important influence on the "rootability" of the soil;
- topsoil consistence - it is a good indicator of the "rootability" of a soil in terms of soil strength limitations, and is used to determine compaction, hardsetting and ploughpans.
- topsoil organic matter status - supplies information on the resistance of a

soil to drying our, resilience of soil to structural degradation, compaction and erosion, buffering capacity, and biological vigour of topsoil;

- topsoil particle size distribution - a useful indicator of the soil's susceptibility to degradation by compaction, hard-setting and erosion;
- topsoil water repellencey - supplies important information on possible water moisture problems;
- subsoils - all the above parameters should be measured;
- subsoils effective cation exchange capacity (E. CEC) - a good indicator of effective rainfall of an area;
- erosion - extent, severity and type of erosion should be emphasised in forestry soil surveys;
- surface compaction, smearing and rutting - damage caused by machinery which should be thoroughly assessed; and
- crusting and capping of surface - usually indicates that either the soil is to some extent dispersive or has been excessively exposed to direct rainfall.

It is possible if all these parameters are included, to replace or improve the present soil survey indices with a 'toolbox' of criteria and indicators. These C&Is would measure those soil quality parameters which impact on sustainability and at the same time supply information to the forest manager on the soil capability with reference to plantations. One of the major advantages of the C&I process, is that it is possible to link it with management practices and processes which are already in place.

Water

Long-term water planning and management requires the incorporation of principles such as sustainability and equity. Among these principles are guaranteed access to a minimum amount of water necessary to maintain and sustain ecosystems (Gleick, 1998). The incorporation of characteristics of sustainability in water planning and policy has become a major policy priority in South Africa, and requires placing a high value on maintaining the integrity of water resources and the flora and fauna which exist around them (Gleick, 1998).

Increasing awareness of the need to protect South Africa's water quality and water resources from degradation, has resulted in a growing awareness of the need to also control non-point pollution. In the past, the forestry industry has emphasised water yield in its water resource management, but due to pressure from external environmental groups, the trend has now shifted to include the quality of the water emanating from afforested areas (Lesch, 1995). The management of water quality is therefore, becoming a critically important issue. However, not all forms of river management are necessarily good administration of the river system in question. Ideally, the purpose and objectives of river management should be the following: balancing user's interests; optimizing the use of the resource; inclusion of environmental interests and those of the general public when exploiting the resource; and cleaning up after "old sins" (Boon *et al.*, 1993). The purpose of resource management is to balance the use of the resource without deterioration of the natural basis. The prescription is sustainable development based on controlled use of resources, cutting back on consumption, and intensive measures to lessen damage where necessary (Boon *et al.*, 1993).

There are five possible scenarios for the management and conservation of rivers, based primarily on how degraded the system is. In natural or semi-natural systems, management should be focussed on preservation. However, the challenge to conservationists using this scenario is to distinguish between natural, acceptable change and anthropogenic, undesirable change (Boon, 1993). The other four scenarios are concerned with conservation management to a greater or lesser extent. For rivers of high quality, emphasis should be placed on limitation of catchment development. In lower quality rivers, the case essentially becomes one of mitigation, where the need for river regulation, abstraction, or waste disposal is accepted and where attempts are made to salvage the best deal possible for aquatic habitats and organisms. The final scenario of river management is that of restoration in which attempts are made to enhance the process of recovery by manipulating some combination of water quality, hydrology, aquatic habitat structure, and riparian zones (Boon, 1993).

To understand which of these water resource management process will be most adequate for a plantation estate it is essential to assess the conservation status of the river. Assessment of the conservation status and sustainability of maintaining this status may be done using a number of indicators and verifiers selected during the C&I development process. It is therefore, important to select C&Is which can be applicable to all rivers, no matter what the conservation status, and that those parameters selected measure important attributes such as the quality and quantity of the resource.

SYNTHESIS

Planting exotic timber on land which was previously covered by fynbos and grassland results in a large number of soil and water impacts. Impacts on soil resources include physical, chemical and biological degradation. Physical degradation of the soil includes soil erosion, compaction and crusting. Concern has been expressed that the widespread use of heavy wheeled and tracked vehicles during timber extraction may result in a considerable decline in future site productivity. Impacts of machinery result in compaction or destruction of the soil surface structure, decline in nutrients due to erosion of biomass, and increased sedimentation yields. It is therefore, important that the soil indicators chosen to assess soil sustainability include such measure as soil texture, water content and soil bulk density. Chemical degradation of the soil as a result of planting of exotic species include increased soil acidification, changes in nutrient cycling and modification of the soil profiles hydrological properties. Since these soil properties impact directly on sustainability, one would expect them to be carefully managed and monitored, and to form part of those indicators which are developed to assess the progress towards sustainability in industrial plantations. Since there will be a marked difference in the moisture content of soils under plantations, it is questionable whether this will be a useful indicator of sustainability. However, it is perhaps for the indirect measures which this soil characteristic may provide that it should be included in the assessment of sustainability.

The effects of industrial plantations on water include variation in water quality and quantity. Changes in the flow regime of a water body as a result of planting of exotic timber species will be influenced by the particular species which is cultivated, the type of vegetation which previously covered the area, the levels of low flow of the river or stream, and the season of the year. Change in flow will impact not only on the in-stream biota but also on the fauna and flora that surround the water body, and the down-stream water users. It is therefore, important to manage and monitor this water property in attempts to sustainably manage a plantation. However, the selection of this property as an indicator of progress to sustainability leads to a number of problems, e.g. seasonal variations in flow, influences of non-anthropogenic activities, effects of activities outside the plantation. Changes in water quality due to afforestation of an area included increase sediment levels due to bad management practices, changes in dissolved oxygen levels and loss of nutrients. Since dissolved oxygen in turbulent upland streams is nearly always in saturation equilibrium it is questionable whether this water quality characteristic will be an useful indicator of progress toward sustainability. Invariably, significant increases in dissolved nutrients have been reported when catchments have been harvested but it may be the total nutrient load which is most crucial for the downstream users and it is therefore, important to include this water quality characteristic as a measure of progress towards sustainability.

It is generally agreed that measuring only the physical and chemical attributes of water cannot provide the soul assessment of the health of an aquatic system. Assessing stream biota is a valuable indicator of sustainability since individual organisms have been subjected to the totality of conditions in the stream from one measuring period to the next. They therefore, reflect some idea of ecosystem integrity since biological communities reflect the cumulative effects of fluctuations in water quality. Afforestation may result in a number of other water quality impacts, however, literature on these impacts is as yet very sparse, making it impossible to have a lengthy discussion of each. The magnitude and intensity of these impacts will determine those soil and water parameters which are vital to the C&I process, i.e. those which can best indicate progress toward sustainable plantation management.

CHAPTER THREE

FRAMEWORK AND ROLE OF CRITERIA AND INDICATORS

Currently, there are numerous groups involved in the development of standards to conceptualize and evaluate sustainable forest management (SFM) at international, regional, national or forestry management unit level. The concept of C&Is has been broadly adopted in the forest sector as the common approach to conceptualize and evaluate SFM. Criteria and indicators are to a large extent outcome-oriented approaches in the sense that the state and dynamics of the forest are the central focus. There are however, a number of process-orientated assessment strategies related to sustainable forestry, notably the appraisal of environmental management systems. There is growing consensus that the two approaches complement the assessment of sustainable forestry management (Lammerts van Bueren and Blom, 1997).

HIERARCHICAL FRAMEWORK TO C&Is

Principles, criteria and indicators (P, C & I) are a set of hierarchical standards that serve as a tool to promote SFM. They serve as a basis for monitoring and reporting, or as a reference for assessment of actual forest management. However, since hierarchical standards have not yet been well developed, there is still a great deal of investigation required before an elaborated framework with a common base of standards can be developed (Lammerts van Bueren and Blom, 1997).

A hierarchical framework serves as guidance for the formulation of sets of P, C, &I or at least some combination of these hierarchical levels. The hierarchical framework describes both the function of each level, and the characteristics needed to formulate P, C, &I. The framework also assists in breaking down, level by level, the goal (eg. SFM) into parameters that can be managed or evaluated. The challenge of developing a set of P, C & I for sustainable forestry management is that it fully covers, as conclusively and operationally as possible, all aspects of SFM to be monitored and assessed (Lammerts van Bueren and

Blom, 1997). The potential value of a hierarchical framework is that it avoids redundancy since it limits the set of P, C & I to a minimum and results in a transparent relation between the parameter that it measured and the compliance with the principle it refers to. The following definition for a hierarchical framework is suggested: *A hierarchical framework describes hierarchical levels (P, C & I) to facilitate the formulation of a set of parameters in a consistent and coherent way. It describes the function of each level as well as the common characteristic of the parameters appearing on a particular level* (Lammerts von Bueren and Blom, 1997).

The first hierarchical level which splits the goal (SFM) into separate components is referred to as the principle. A principle is defined as *a fundamental truth or law used as the basis of reasoning or action* (Lammerts von Bueren and Blom, 1997; Stork *et al.,* 1997; Boyle *et al.*, in press). They have the character of an objective or attitude concerning the function of the forest ecosystem (Lammerts von Bueren and Blom, 1997). Principles are explicit elements of a goal (e.g. SFM) which is formulated as an ideal and requires further elaboration to make it meaningful to forest policy, management and assessment. To obtain satisfactory results, the principle should be selected after consultation between all the parties involved or interested in the ecosystem.

In the hierarchical framework, principles are followed by criteria. A criterion is *a principle or standard that a thing is judged by* (Lowe, 1995; Stork *et al.*, 1997; Lammerts van Bueren and Blom, 1997). They are intermediate points to which the information provided by indicators can be integrated (Stork *et al.*, 1997). The function of a criterion is therefore to give rise to a verdict on the degree of compliance with a principle in relation to the forest ecosystem. Criteria will define the state of the ecosystem that results if the principles are adhered to. They do not explicitly or implicitly add new requirements which do not originate as a logical consequence from the principle. They also focus current weaknesses in management and therefore, help identify achievable improvements in management practices. The formulation of criteria also requires a process of compromise and negotiation by interested and affected parties.

The list of criteria selected should cover all major aspects, but should also be short enough so that a set of indicators can in itself provide a clear picture of the extent to which the guidelines are being applied (Lowe, 1995). No single criterion or indicator will comprise a measure of sustainability, but each needs to be considered in the context of other C&Is (Montreal Process, 1995).

The third level in the P, C & I hierarchical framework, is that of indicators. An indicators is *any variable or component of the forest ecosystem or the relevant management systems used to infer attributes of the sustainability of the resource and its utilisation* (Stork *et al.*, 1997). It is a descriptive, quantitative or qualitative variable which is assessed in relation to a specific criterion and describes features of the ecosystem in an object and unambiguous way (Lowe, 1995). Indicators simplify the communication process by reducing the number of measurements, parameters and their aggregate information required to describe the state of the ecosystem. They will simplify the communication process between all interested parties (Granholm *et al.*, 1996). Changes in values of indicators which reflect the impact of policies, measures and practices should be supplied in the data provided through appraising and monitoring of indicators. This should supply information on the state of forests and forest management which could contribute to better decision-making and ultimately a reduction in the risk of unsustainable policies and forestry management practices. Indicators must be assessable parameters, based on sound scientific research (Lammerts van Bueren and Blom, 1997). How realistic it is to perform this research has yet to be established. This may also lead to the other problem i.e. promoting indicator research at the national level may place too much emphasis on the development of criteria leading to the thought that indicators are criteria. Indicators should not be subject to different interpretations according to social groups but should provide information without bias (Lammerts van Bueren and Blom, 1997).

Indicators can be categorized and distinguished according to their type. They can be input/process/outcome indicators or quantitative/qualitative indicators (Lammerts van Bueren and Blom, 1997). Outcome-orientated indicators that are derived directly from criteria, must be formulated in such a way that the assessment results are unambiguous. If formulated in an open-ended form such as 'damage is minimized", the usefulness of the indicator is diminished, however this is dependent on the type and quality of the research which is undertaken. An outcome indicator does not always offer the ability to give a verdict. Instead, it often describes actual conditions of an element of the forest ecosystem in quantitative or relative terms, in which case a verdict can only be given when a norm is linked to it.

Process or input indicators refer to a human process or intervention which is to be executed (Lammerts van Bueren and Blom, 1997). These types of indicators are indirect indicators since they reflect elements of the management and policy system. Quantitative indicators are expressed and assessed in terms of a quantifiable number or figure, whereas qualitative indicators are expressed as situation, object, or process. Indicators which can be quantitatively measured are preferred because they are less ambiguous. However, quantitative indicators are meaningless without a reference value. Assessment of management performance should be based on a comparison between the actual value of the indicators and its reference value or norm. The norm or threshold value would be the minimum (or maximum) allowable value of an indicator. A reference value which is aspired to is the target value (Lammerts van Bueren and Blom, 1997).

The fourth hierarchical level, below that of indicators, are the verifiers. The definition of a verifier is *the source of information for the indicator or for the reference value for the indicator* (Lammerts van Bueren and Blom, 1997). Verifiers refer to the measurable elements of the indicators, and clarify the way that indicators are measured in the field (Stork *et al.*, 1997). The verifiers which are selected to assess sustainable forest management must be practical since assessment of C&Is can be a potentially costly exercise with the more complex and expensive verifiers being less likely to be adopted (Boyle *et al.*, in press). Verifiers will be far more powerful if used by forest managers, allowing them to assess the consequences of management interventions on an on-going basis and modifying activities accordingly (Boyle *et al.*, in press). Selected verifiers should possibly be included in normal forest inventory processes.

The intention is to present a hierarchical framework that is consistent both horizontally and vertically. In the hierarchical framework a principle is followed by a criterion. To avoid duplication at both levels, either an integral principle or a set of more narrowly focussed principles should be selected. In doing so, horizontal consistency at the level of principle is achieved. Vertical consistency refers to the relation between parameters appearing at adjacent levels. Figure 1 and 2 show the correct and incorrect model of a hierarchal standard.

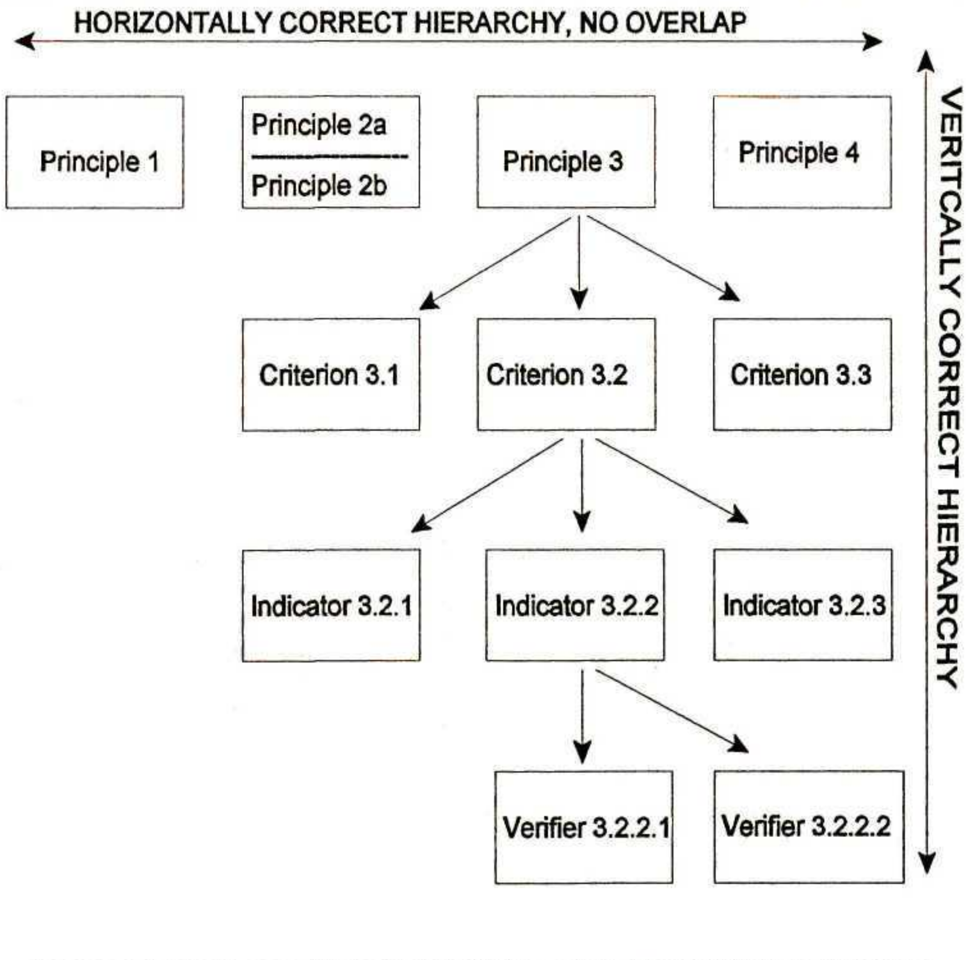
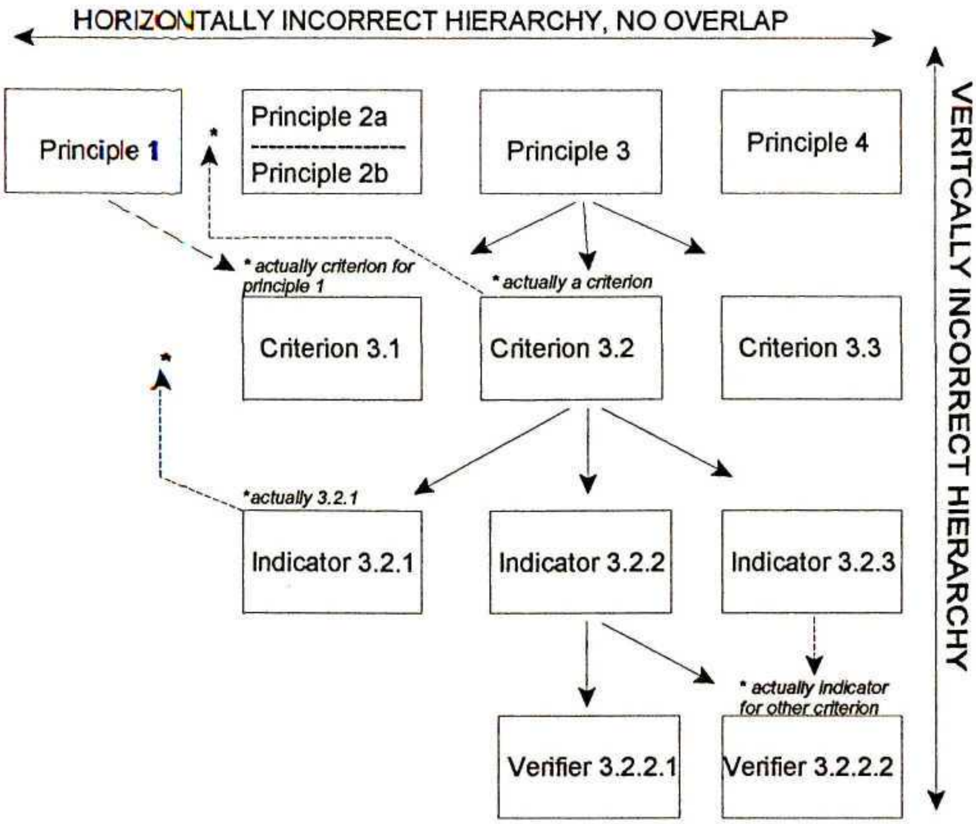


FIGURE 1: MODEL OF A HIERARCHICALLY CORRECT STANDARD FORTHE ELABORATION OF THE CONCEPT OF 'SUSTAINABLE FOREST MANAGEMENT', OR 'WELL-MANAGED FORESTS' (Lammerts von Bueren and Blom, 1997)



[*italic*] = how it should be

[roman] = as in hypothetical standard

FIGURE 2: HYPOTHETICAL EXAMPLE OF A HIERARCHICALLY INCORRECT STANDARD (Lammerts van Bueren and Blom, 1997)

CERTIFICATION

There are a number of process-orientated assessment strategies related to sustainable forestry, notably the appraisal of environmental management systems. Many companies have responded to growing public awareness of forest problems by introducing their own environmental policies, which strive to maximize the economic development of the company but also maintain the services and quality of natural resources over time. They have realised that natural resources are an economic asset, which have the potential to contribute to the economic productivity and welfare of their business. Unfortunately, often to their detriment, maintaining these resources is not always a costless affair. Many of the bigger forestry companies are hoping to incorporate their environmental policies within their certification processes. In South Africa, the greatest challenges to this approach are that certification is not yet legally binding, and that monitoring systems have yet to be implemented. However, the New Forestry Act 84, empowers the Minister to create or promote certification programmes and other incentives to encourage SFM. Lawes *et al.,* (in press) suggest that C&Is be used as a monitoring tool which could be incorporated into the ISO 14 001 auditing process.

Sustainable forest management requires both performance targets and a management process to achieve those targets. There are many initiatives which aim at defining the performance elements of SFM some of which include:

- governmental initiatives, some of which include the Helsinki and Montreal Processes, ITTO's guidelines and Criteria for SFM and the Tarapoto Proposal;
- national standards/industry bodies' initiatives, such as the Canadian Standards Association SFM System, and the American Forestry and Paper Association's Sustainable Forestry Principles and Implementation Guidelines (Bass, 1997); and
- NGO's initiatives (e.g. CIFOR, FAO), many of which are associated with independent certification, such as the FSC's Principles and Criteria.

The management process element of SFM is needed to achieve agreed performance targets. This process of continuous improvement should help plan the integration of the above performance objectives where possible, make informed trade-offs between them where integration is not possible, and then assist in achieving them on the ground.

Certification is designed with the goal of improving the general standing of forest management and to generate market incentives. Certification is a politically contentious issue since it appears to contest the authority of governments and contests the status quo amongst producers and producer countries (Bass, 1997). The standards and institutions which operate the certification programme are also highly political issues. Forest management certification is defined as *the independent evaluation of the quality of forest management according to a set of predetermined standards covering both performance standards and the* *management system* (Granholm *et al.*, 1996). Auditing must be carried out by an independent third-party in a specific area of forest under a single management regime and/or ownership. The procedure, which results in the issuing of a certificate for a defined period and a schedule of required improvements, is fundamental to forest product certification. It involves the assessment of the documented management system, forest-level performance and its impacts.

Forest product certification links the forest management certification with chain-of-custody auditing. Chain-of-custody auditing is a monitoring process involving independent verification of the progression of forest products, with their associated records, from cradle to grave. Labelling of products certified in this way involves the provision and control of a physical label, providing information to the consumer at the end of an unbroken chain of custody. There are two forms of product labelling, i.e. single-issue labelling which address only forest management quality and may be typically applied to solid wood products, and eco-labelling which is usually a multiple-issue label where information on forest management quality may be supplemented by information on critical stages such as processing, transportation, use and disposal, and their impacts (Lathrop and Centner, 1998). The latter form of labelling is typically applied to pulp and paper products where the environmental implications of both forestry and processing are significant.

Certification standards

Certification standards are documented agreements containing technical specifications or other precise criteria which should be used consistently as rules, guidelines or definitions of characteristics, to ensure that processes, products and services are fit for their purpose. There are two types of standards by which forest enterprise is judged:

- performance standards (e.g. FSC) such as those used for the environmental management systems which focus on forest-level operations and their impacts. Before these standards are accepted, stakeholders need to agree that those chosen are; significant, clearly defined, measurable and related to agreed principle and criteria of good forest management. Performance standards should balance economic, social and environmental objectives, focus on global, national and local interests and incorporate both present and future requirements (Bass, 1997); and

- management system standards (e.g. ISO 14 000), which focus on enterprise policies and processes for achieving good forest management. However, they must not themselves prescribe performance levels, since these need to be auditable and related to agreed management system principles and criteria. Management systems achieve certification performance through a process of continuous improvement by making trade-offs if integration is not possible, allowing for uncertainties, building in participation of stakeholders, including experimentation and monitoring, and learning from results (Bass, 1997).

Both types of standards are set by bodies external to the forest enterprise. They may be internationally- or nationally- set, based on global principles and criteria, or set entirely at national level. Enterprises may develop internal policies, processes and targets to meet; external standards, current legislation and their internal objectives. During certification, enterprises have to show that their policies, processes and targets are an adequate interpretation of the external standards.

ENVIRONMENTAL MANAGEMENT SYSTEMS

ISO principles

At the end of 1996, an international committee finalized the ISO 14 001 standards for environmental management systems. These standards require implementation of an Environmental Management System (EMS) in accordance with defined internationally recognised standards (Bass, 1997). ISO 14 001 defines requirements for:

- establishing an environmental policy with a commitment to compliance, prevention of pollution and continual improvement;
- determining environmental aspects and impacts;

- conducting planning which identifies environmental aspects and legal requirements;
- setting objectives and measurable targets which are consistent with policy;
- establishing an environmental planning programme;
- implementation and operation of programs to include defined structures and responsibilities, training and communication, documentation, operational control, and emergency preparedness and response;
- checking and corrective action to include monitoring, corrective and preventative action and auditing; and
- and management review.

ISO 14 001 registration is achieved through a five part process that includes; application of registration, review of the EMS documentation, an on-site readiness review, a registration audit and the actual registration determination. The key to the successful function of ISO 14 001 is the development of EMS which have documented procedures that are implemented and maintained to achieve environmental goals. In addition, EMS must include an appropriate monitoring and review processes and identify and implement corrective measures.

Companies may gain a number of benefits from the implementation of an Environmental Management System in accordance with ISO 14 001 standards. These benefits include; detection of areas where reduction in energy and other resource consumption may occur, reduction in environmental liability and risk, maintenance of consistent compliance with legislative and regulatory requirements, prevention of pollution and reduction of waste, and improved community goodwill. SAPPI, one of the large paper producers and exotic timber growers in South Africa has chosen to follow the ISO 14001 certification route.

Forest Stewardship Council

The Forest Stewardship Council (FSC) is an international NGO that evaluates, accredits and monitors certification organisations in order to guarantee the authenticity of their claims (Bass, 1997). The Council itself does not certify forest management or products but its mandate is to accredit the certifiers (Lammerts van Bueren and Blom, 1997). The process of certification is initiated on a voluntary basis by forest owners, and the services of the certification organisation is requested by the managers. The FSC's Principles and Criteria (P&C) apply to all tropical, temperate and boreal forests, and in many cases may also apply to plantations and partially replanted forests. P&Cs are mainly designed for forests managed for production of wood products, but may also be relevant to forests managed for non-timber products and other services.

The Principles and Criteria of the FSC are incorporated into the evaluation systems and standards of all certification organizations which are seeking accreditation by the council (Lammerts van Bueren and Blom, 1997). Candidates are disqualified from certification if there are major failures in any individual principle, however, the FSC and FSC-accredited certification organizations do not insist on perfection in satisfying the P&Cs. Some flexibility is allowed to cope with local circumstances. In all certification assessments, the scale and intensity of forest management operations, the uniqueness of the affected resource, and the relative ecological fragility of the forest is considered. The P&Cs of the FSC should be used in conjunction with national and international laws and regulations since they are intended to complement, not supplant, other initiatives that support responsible forest management worldwide.

A FSC Principle that has particular importance to plantation forests and ecological resources is Principle 6 which is concerned with environmental impacts (Lammerts van Bueren and Blom, 1997). This principle states that, *forest management shall conserve biological diversity and its associated values, water resources, soils, and unique and fragile ecosystems and landscapes, and, by so doing, maintain the ecological function and the integrity of the forest* (Lammerts van Bueren and Blom, 1997). This principle requires the assessment of environmental impacts, safeguards to protect rare, threatened and endangered species and their habitats in the form of conservation zones and protection areas, and the maintenance, enhancement or restoration of ecological functions and values. It also demands the protection of representative samples of existing ecosystems in their natural state, the formation and implementation of guidelines to control erosion, minimise forest damage during harvesting and road construction, and the protection of water resources.

Principle 10 of the FSC also applies directly to plantations and states that; *plantations shall be planned and managed in accordance with P&C 1 - 9, and Principle 10 and its criteria* (Lammerts van Bueren and Blom, 1997). While plantations can provide an array of social and economic benefits, and can contribute to satisfying the world's needs for forest products, they should complement the management of, reduce pressures on, and promote the restoration and conservation of natural forests. The important criteria which accompany this principle include the design and layout of plantations to promote the protection, restoration and conservation of natural forests, diversity in the composition of plantations, selection of species based on suitability of the site, restoration of the site to a natural forest cover, and prevention and minimisation of outbreaks of pests, diseases, fire and invasive plants.

The FSC is broadly recognised as being the most advanced yet in developing and applying an accreditation scheme. Mondi, another of the large exotic timber growers in South Africa has chosen to follow the FSC Principles and Criteria in reaching certification.

LINKAGES BETWEEN CRITERIA AND INDICATORS AND CERTIFICATION

Both C&Is and certification address sustainable forest management, its characteristics and indicative measurements. It is hoped that C&Is might assist in clarifying issues related to certification. There are many similarities and differences between these two approaches to SFM assessment particularly in their objectives, scale of operation, relation to standards and levels of performance and the need for transparency (Granholm *et al.*, 1996). The major difference between these two approaches relates to objectives. Criteria and indicators are performance standards which provide a means to measure,

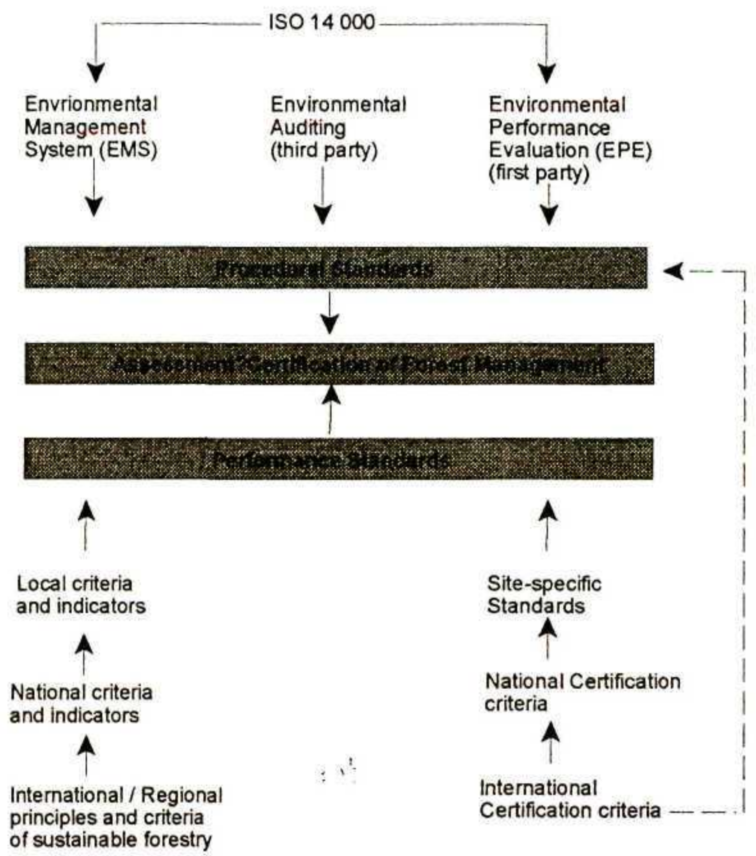


FIGURE 3: PROCEDURAL AND PERFORMANCE STANDARDS IN CERTIFICATION OF FOREST MANAGEMENT (Baharuddin, H.G., and Simula, M., 1996)

assess and demonstrate progress towards SFM, while the purpose of certification is to certify the achievement of certain quality expectations related to SFM (Granholm *et al.*, 1996). Although both approaches make use of the same data, the final result of each is different (Figure 3).

Most certification is concerned with the FMU. Certification at this level is designed to assess forest management practices and/or forest management systems against standards and levels of performance. Criteria and indicators, on the other hand, are instruments for describing, measuring or assessing progress towards SFM, they do not determine performance standards and/or acceptable levels for SFM (Granholm *et al.*, 1996). Criteria and indicators have been developed at the international and national scale, but both the ITTO and the Tarapoto initiative are also concerned with C&Is at the sub-national level and/or the FMU level (Granholm *et al.*, 1996). One of the intentions of developing C&Is at this level should be to link criteria and indicators to certification. However, accomplishing the threshold, limits and norms associated with C&Is will not necessarily lead to certification, but may be used as tools in the process, e.g. during the auditing process. Since there is no internationally

Table 4: Summary comparison of FSC, ISO and C&I (adapted from Bass, 1997; Lammerts van Bueren and Blom, 1997, Lawes and Eeley, 1998).

Issue	FSC	ISO 14 001	C&I
Main Protagonist	Environmental and some social NGOs; Buyers' groups	Industry, especially large producers; Governments; WTO	Originally were environmental NGOs; Governments; Some Industry
Inherent	'Value-laden'; Sustainable development - both environmental and social;; Equity of application	'Value-neutral'; Modernist; EMS tool is enterprise-focussed; Continuous improvement;	'Value-laden' principles and criteria; sustainable development paradigm; can operate within EMS
Purpose	Define good forest stewardship and accredit certifiers; third party certification; Labels and chain of custody can be provided to market	Specify elements of management systems to improve performance; third party certification optional; Certification permits general publicity, but no labels	Measures progress towards SFM at FMU level and state of industry. Adaptive management tool; Reduce interpretation of existing standards; National guidelines -accountability through hierarchical framework; No labels or publicity
Standards	Performance standards based on global principles and criteria; encouraging compatible national standards; Normative	Management system standards; No performance standards specified - but information documented suggests options	No explicit standards; based on FMU-EMS relevant standards; but within national hierarchical framework; Flexible - adaptive management
Governance	NGO; NGO/private members; Equal economic, social and body environmental chambers North/South balance	NGO; Members are national standards bodies	NGO/Govt? private; International process adapted National body- DWAF prescribed;. Industry members subscribe to process, but mainly NGO motivated
Accreditation	An international accreditation body itself	National accreditation bodies	No accreditation
SFM compatibility	Stresses high environmental and social performance -challenged by managers	Stresses management capacity and continuous improvement; enterprise chooses performance standards; Socially difficult to integrate	Stresses adaptive management; Flexibility promotes continual improvement; Challenges managers; Environmental, production, and social criteria addressed
Credibility with stakeholders	High with NGOs/buyers; Lower with some governments; Mandate problems; Risk of 'monopoly'	High with intergovernmental bodies and industry; Low with NGOs/others; Narrow participation; No chain-of-custody reduces market potential	High with NGOs and government bodies; Low with industry - seen as part of current EMS; Limited market potential
Trade distortions	Standards may be considered too high; Social standards may be considered unwarranted	TBT recognises ISO; ISO standards not considered unnecessary trade restrictions	No adverse affects - but can be used to verify achievement of standards and promote products

agreed framework for harmonizing certification systems with criteria and indicators (Lowe, 1995), the processes will largely depend on how well they both serve the progress of forest management towards sustainability. A comparison of the different certification processes and C&Is shown in Table 4.

ADAPTIVE MANAGEMENT

Adaptive management is an administration strategy used to guide ecological intervention in the face of uncertainty about the system. Management actions are taken not only to manage but also to learn about the processes governing the system. New information gleaned from this process is used to improve the understanding of the system and to inform future management decisions (Shea, 1998).

Adaptive management is a process which couples scientific and social values to promote sustainable management of natural systems (Holling, 1978; Thomas, 1996). For the best results in sustainable use of natural resources, scientific information should be coupled to holistic management at the appropriate scales (Haney and Power, 1996). Even though it is often difficult to apply scientific methods at the appropriate scales of time and space, it is the only way to learn how complex ecosystems work (Carpenter, 1990). Adaptive management is therefore, a process of "learning by doing", which begins with the compiling of information relating to ecological, socioeconomic, institutional and cultural issues of each specific management unit.

This process is followed by the laying out of goals and aims of management for each ecosystem, the composition of a working hypothesis, implementation of the management regime selected and monitoring to document and analyse social and ecological response to the chosen management practices. Reassessment of the model predications and revision of the model and data base completes the cycle of adaptive management (Haney and Power, 1996) shown in Figure 4.

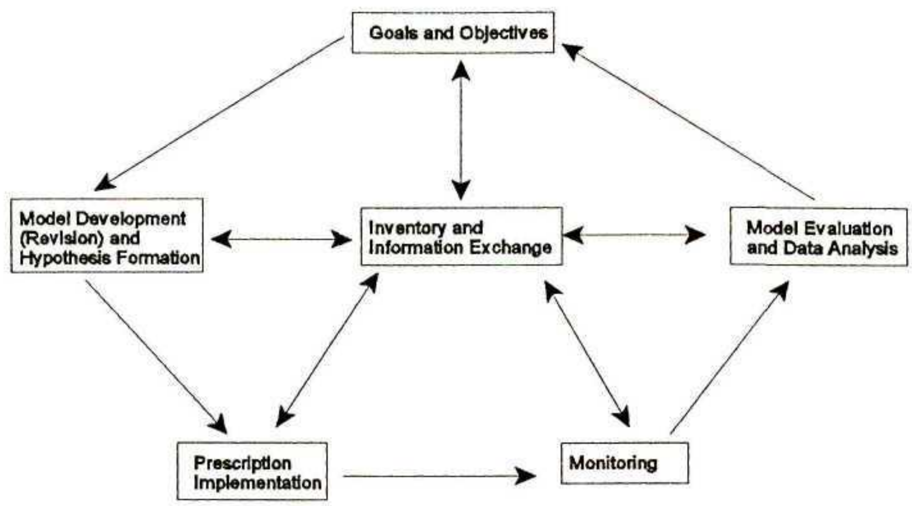


Figure 4: The cyclic nature of adaptive managment (Haney and Power, 1996)

For adaptive management to be a useful administrative tool, it is essential to include all six of these steps which encourage thoughtful, disciplined management but at the same time does not constrain creativity which is fundamental in dealing with uncertainty and change. An expansion on the six steps include;

- *Problem assessment*: This step defines the scope of the management problem. Adaptive management begins with collection and compilation of existing information for areas to be managed, exchange of ideas and information with stakeholders, analysis of preliminary information, and the setting of clear goals and objectives. For adaptive management to be useful in the real world it needs clear statements of objectives, constraints and tradeoffs.
- *Design*: This stage includes the designing of management plans and monitoring programs which will provide credible feedback about the effectiveness of a chosen actions. Ideally this information should fill key gaps in understanding.
- *Implementation:* This step is where the plans are put into practice. In executing the management practices selected, managers should be sensitive to landscape issues. Large management units, in which

ecological gradients are retained, are better than smaller units (Haney and Power, 1996).

- *Monitoring:* Since everything cannot be monitored in this step of adaptive management, it is critical that indicators are selected to monitor and assess how effective actions are in meeting management objectives. Monitoring should allow managers to demonstrate progress towards meeting goals and objectives (Odum, 1985).
- *Evaluation:* This stage compares the outcomes of the actions to the forecasts and interprets the differences which have occurred.
- *Adjustment:* Practices, policies, objective and models are adjusted to reflect new understanding (Haney and Power, 1996). The assessment of each of the six steps may lead to new problems, questions and options, which may result in the process beginning at step one again. The adaptive management process may thus result in a continual cycle of improvements.

Adaptive management allows the forest manager to keep pace with changes in demands from clients but at the same time offers the potential to learn from the results of operational policies and practices. It may act as an important supplement for forest research programs. Adaptive management attempts to:

- find better ways of attaining goals;
- ascertain key gaps in understanding;
- enhance understanding of ecosystem responses, thresholds and dynamics;
- gain reliable feedback about effectiveness of alternatives;
- encourage innovation and learning; and
- pass on information and knowledge.

However, for the process to be successfully a number of issues have to be clarified, one of which is the barriers which are likely to occur in the implementation of the management process. The first is to acknowledge uncertainty about which policy or practice is "best" for the particular management issue. In large part, controversy has centred around the underlying assumption that planning is an objective process and that scientists and bureaucrats involved in the process are neutral policy actors. Scientists frequently disagree with the "facts" and policy makers are divided as to which community preferences should be incorporated into the decision structure of the model (McLain and Lee, 1996). It is therefore, important to allow for results that critics may subsequently call "mistakes" by acknowledging publicly that there is uncertainty about the results of at least some of the actions.

The adaptive management approach often relies upon the use of interdisciplinary teams of scientist working closely with resource managers and policy makers. However, this approach may be problematic since the selection of who constitutes decision makers and implementers is left to the modellers of the adaptive management processes. This may result in the hiding of information unfavourable to the data keeper's and in many cases one decision-making group may attempt to dominate and influence the outcome of the adaptive management process (McLain and Lee 1996). Other problems include; designing powerful experiments, difficulties in replication, reluctance to "experiment" with high value, threatened ecosystems and maintaining funding and staff over the long time period.

LINKAGES BETWEEN ADAPTIVE MANAGEMENT AND C&Is

There are a number of similarities between these two procedures, suggesting the C&Is may be used as a tool in the adaptive management processes.

- Both processes are flexible allowing for change and adjustment to reflect new understanding and information;
- Both processes are based on formative steps on sound social and ecological information. The concept of SFM associated with C&Is includes the social functions of the forest and the social system that interacts with the forests. The selection of a definition of SFM and choice of principles are both results of a political process where interests of policy makers and stakeholders are important driving factors (Lammerts van Bueren and Blom, 1997). In the adaptive management processes, the managers is expected to identify stakeholders and involve them from

the beginning into development of management goals and prescriptions (Haney and Power,1996); and

- Both processes attempt to combine the best of science and sound social values to promote the sustainable management of natural resource systems.

As of a result of the similarities in these two processes, many interested parties hope to link the two and apply C&Is as an adaptive management tool. Figure 5 below gives an example of how the two processes may possible be linked.

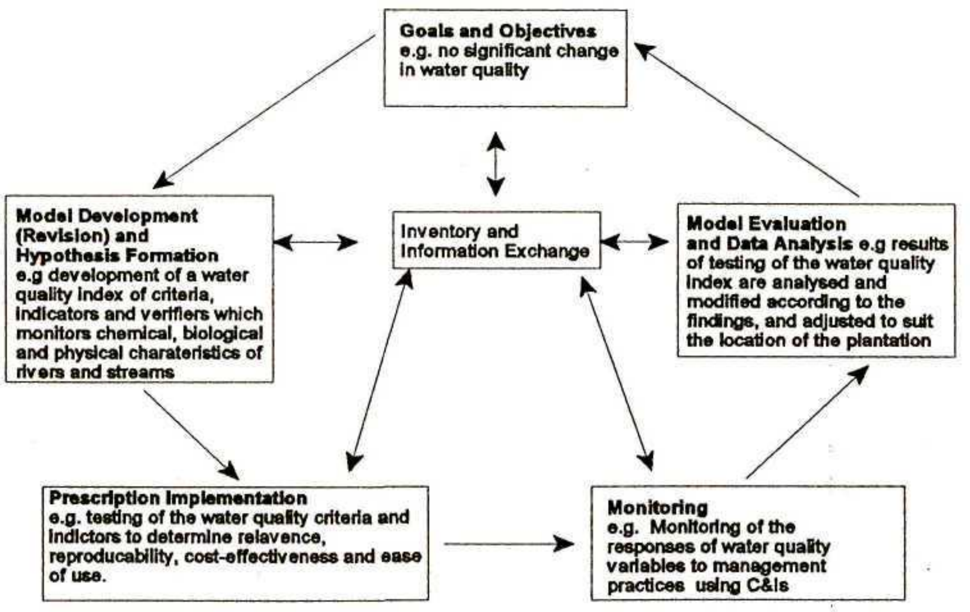


Figure 5: Model linking C&Is to adaptive managment (adapted from Haney and Power, 1996)

SYNTHESIS

In plantation management, any assessment system requires the formulation of clear outcome targets and clear concepts as to management procedures and tools. Since exotic timber growers in South Africa cannot agree on a common set of management procedures and standards it is perhaps best that the initial development of C&Is occur independently of FSC and ISO 14 001. Once a 'tool box' set of C&Is has been developed, compatibility with FSC and/or ISO can be considered for the issues for which it is relevant, notably for international trade.

Since adaptive management is an essential tool for evaluating and integrating the complex issues surrounding natural resource management it would be best to concentrate on incorporating these procedures in the formulation of C&Is. When properly integrated, the C&I process will be continuous and cyclic as it evolves from information gained and with changes in social and ecological systems. As a result the C&I processes will be flexible and innovative, outcomes will be more sustainable and have greater acceptance with stakeholders. The C&I concept will be a holistic management system, based on good science and include critical evaluation of each step of the process.

CHAPTER FOUR

SELECTION OF SOIL AND WATER CRITERIA AND INDICATORS FOR SUSTAINABLE PLANTATION MANAGEMENT USING INTERNATIONAL C&I INITIATIVES

There are various intergovernmental initiatives to develop criteria and indicators for sustainable forestry management at the national level. While these initiatives suggest criteria for policy and sustainability at a national level, they do not recommend criteria for assessing sustainability at a forestry management unit level. Players in the development of international C&I believe that criteria and indicators for the FMU level should be applied and evaluated according to individual countries needs and conditions (Lowe, 1995). However, to date, most C&I development has been concentrated at the international and regional levels, with very little formulation occurring at the FMU level. Although some of the international initiatives have suggested criteria at the FMU level, it is only CIFOR which has managed to produce any criteria for testing at the FMU levels (Prabhu *et al.*, 1996). Prabhu *et al.* (1996), used independent, international, multi-disciplinary teams, for comparative field testing of over 1100 C&Is, selected from several different proposed systems of C&I, and covering all aspects of forest management. The general conclusion from these field tests was that all of the currently proposed local level C&Is were deficient in some way or another (Stork *et al.*, 1997; Boyle *et al.*, in press).

INTERNATIONAL POLICY

The first initiative to formalized sustainable development occurred at the United Nations Conference for Environment and Development (UNCED) set in Rio de Janeiro in 1992 which culminated in 179 Heads of States and Governments becoming signatories to the convention. Major outcomes of this initiative which relates to forestry are found in Chapter 11 of Agenda 21 on Combatting Deforestation, and the 'Forest Principle'. In Chapter 11 of Agenda 21, the signatories agreed to pursue - *the formulation of scientifically sound criteria and* *guidelines for the management, conservation and sustainable development of all types of forests* (Lowe, 1995).

The Forest Principles are a *non-legally binding authoritative statement of principles for and global consensus on the management, conservation and sustainable development of all types of forests* (Lowe, 1995). The principles, which apply to all forests, endeavour to reconcile the economic role of forests with their conservation, environmental and social roles. Forest components are also found in the Convention on Biological Diversity, the Framework Convention on Climate Change and a number of other Chapters of Agenda 21. Article 7 of the Convention of Biological Diversity calls for *identifying components of biological diversity which are important for its conservation and sustainable use*, and further, *monitoring through sampling and other techniques, the component of biological diversity identified.* UNCED has led to the development of five ongoing regional and international initiatives; i.e. the Helsinki, Montreal and Tarapoto, Dry-zone Africa and International Tropical Timber Organisations (ITTO) processes (Lowe, 1995; Granholm *et al.*, 1996; Lammerts van Bueren and Blom, 1997).

The ongoing international and regional initiatives report on development of national level criteria and indicators for sustainable forest management for their specific regional economic, ecological, social and cultural conditions.

The Helsinki Process

The Helsinki Process, which began in 1990, developed a set of guidelines for the sustainable management of forests in Europe. Emerging from the two ministerial conferences held in France in 1990 and Helsinki in 1993, was a General Declaration and four resolutions. The resolutions, named H1 to H4, dealt with general guidelines for sustainable management of forests (H1), the conservation of biodiversity of European forests (H2), forestry cooperation with countries with economies in transition (H3), and strategies for a process of long term adaptation of forest in Europe to climate change (H4) (Granholm *et al.*, 1996). These conferences were followed by two expert level follow-up meetings at which a core set of six criteria and twenty-seven indicators were adopted for sustainable forest management in Europe.

At the second expert level follow-up meeting of the Helsinki Process held in Anatalya, Turkey in 1995, the Anatalya Statement was produced. At this meeting the six criteria were sub-divided into 21 concept areas (Lowe, 1995). The participants also agreed that where previously the emphasis was on the adoption of *quantitative indicators*, they should now begin to consider more *qualitative and descriptive indicators* (Helsinki Processes, 1995). The reporting in the Helsinki process is focussed on the national experiences and progress in implementation of individual countries. The European countries have emphasised the need to further develop both the questionnaire to gather information as well as, terms, definitions and classification in order to have comparable results (Granholm *et al.*, 1996). Further development of criteria and indicators at a sub-national and FMU levels have also been considered.

The Montreal Process

The Montreal Process began as an initiative of the Canadian Government with the convening of the International Seminar of Experts on Sustainable Development of Boreal and Temporal Forests in Montreal in September 1993. The goal of the meeting was to establish a scientifically rigorous set of C&I for sustainable forest management. At the sixth meeting of the Montreal Process in Santiago in 1995, the ten participating countries endorsed a statement of political commitment known as the Santiago Declaration. The declaration included a set of non-legally binding criteria (7) and indicators (67) (Lowe, 1995; Montreal Process, 1995; Granholm *et al.*, 1996).

The Montreal Process criteria and indicators reflect the approach of managing forests as ecosystems (Granholm *et al.*, 1996). Currently this process is concerned with the further elaboration of the C&Is through legislation, policies and regulations that govern forest management. Future cooperation among countries in the implementation of criteria and indicators at the national level is central to this initiative. Early in the Montreal Process, at a meeting in December of 1993, both the Canadian and United States delegates expressed an interest in bringing the European(Helsinki) and post-Montreal criteria and indicator processes together. However, representatives from the Governments of France, Germany and the United Kingdom expressed a preference to remain within the Helsinki Process. From this point on the two processes developed separately but in parallel, with both ensuring that observers from each group attend the other's meetings.

Tarapoto Proposal

During 1994, efforts were initiated under the auspices of the Amazon Cooperation Treaty to formulate sustainability criteria and indicators for the Amazon forest (Lowe, 1995). The Amazonian countries created a framework for development to occur in a manner which is equitable, preserves the environment, and achieves the rational use of the natural resources in their respective territories (Granholm *et al.*, 1996). The first workshop to Define Criteria and Indicators of Sustainability of the Amazon Forest was held in Tarapoto, in February of 1995. The outcome of the workshop was the identifying and defining of C&Is for Amazonian forests which emphasise the special nature and conditions of the region's ecosystem, social and cultural factors (Granholm *et al.*, 1996). The goal of this proposal was to constitute a useful guide both for policy formulation and for the establishment of common positions in meetings, conferences and international organisations. Another outcome of this meeting was the recommendation of 8 criteria and 54 indicators applicable to SFM at the national, management unit and global levels (Lowe 1995; TCA, 1995; Granholm *et al.*, 1996).

All but one of the eight countries associated with the Tarapoto Proposal are also members of the ITTO and have in that context endorsed the ITTO criteria. However, the Tarapoto criteria and indicators are conceptually closer to the Helsinki and Montreal Processes in that they capture the wide array of forest benefits to society.

Dry-zone Africa

At an Expert Meeting on Harmonization of Criteria and Indicators for SFM held by the FAO/ITTO in Rome in February 1995, it was noted that arid and semi-arid areas of Africa and the Near East had not received attention under the international initiatives which were involved in the development of C&Is. It was also noted that due to environmental and socio-economic conditions of these areas, controlled and cautious management of forests is required since forestry plays an essential role in the survival and sustenance of the local human populations. At the recommendation of this Expert Meeting, the FAO and UNEP hosted a meeting of experts in Nairobi in November 1995, involving 27 sub-Saharan countries, to develop criteria and indicators appropriate for forests in Dry-zone Africa (UNEP/FAO Expert Meeting, 1995; Granholm *et al.*, 1996). The seven national-level criteria and 47 indicators which were the outcome of this meeting were reported at the 10th session of the African Forestry and Wildlife Commission in South Africa in December 1995.

The commission recognised the need to further develop, improve and adapt the set of C&Is identified by the UNEP/FAO Expert Meeting. The Expert Meeting also recommended that the proposed C&Is should be adapted at sub-regional and national scales in a way that criteria remain the same but that indicators may be added under a criterion to reflect conditions specific to the sub-region or country concerned (Granholm *et al.*, 1996).

ITTO

Prior to the Earth Summit, the International Tropical Timber Organisation (ITTO) developed guidelines for Sustainable Management of Natural Tropical Forests. In 1989 an International Panel of Experts was convened to develop the ITTO Guidelines for the Management of Tropical Forests. This document endorsed 41 principles (guidelines) in the area of (Granholm *et al.*, 1996):

- policy and legislation;
- forest management, and
- socio-economic and Financial aspects.

In 1991 and 1993 respectively, the ITTO Guidelines for the Establishment and Sustainable Management of Planted Tropical Forests and the Guidelines on the Conservation of Biological Diversity in Tropical Production Forests were adopted (Lowe, 1995; ITTO 1993a;1993b). In the years following, the ITTO International Panel of Experts have formulated an operational definition of sustainable forest management, and accepted the definition *criteria and indicators for sustainable tropical forest management* as a basis for testing and demonstrating SFM. The end result of these initiatives were five national and six FMU criteria.

These C&Is which cover the forest of ITTO producer countries in all tropical regions are not legally binding (Granholm *et al.*, 1996). The ITTO Criteria and Indicators are designed to assess progress towards achieving sustainable tropical forest management within the framework of ITTO's Year 2000 Objective. The issue of timber certification has been the focus of increasing debate withing the ITTO, with the primary issue seemingly what role, if any, the ITTO should play in the certification arena.

Other Initiatives

There are a number of international non-governmental organisations (NGOs) that are also in the process of developing criteria and indicators, these include:

- the mandate of the Inter-governmental Panel on Forests (IPF);
- the World Wildlife Fund for Nature (WWF). WWF has been concentrating on developing the concept of forest quality. They have established four criteria and twenty-five specific elements for the assessment of forest quality. The Fund's target for forest management is to achieve high quality and sustainable management of all forest types by the year 2000 (Granholm *et al.*, 1996); and
- CIFOR - CIFOR was established in response to global concern about social, environmental and economic consequences of loss and degradation of forests. Their objectives are to improve the scientific basis for ensuring the balanced management of forests and forest land, and to strengthen national capacities for research to support the development of policies and technologies. CIFOR has already selected and tested C&Is

for natural forests and are in the process of developing C&Is for plantations.

Table 5 below shows those criteria which are common to all the international/regional initiatives.

Table 5: Summary of national criteria which have been put forward by each international C&I initiative (adapted from Lowe, 1995 and Granholm *et al.*, 1996)

CRITERIA FOR SUSTAINABLE FOREST MANAGEMENT	Helsinki Process	Montreal process	Tarapoto Process	Dry-zone Africa	ITTO
Forest Resources					
• Extent of forest resources	✓	✓	✓	✓	✓
• Global carbon cycles	✓	✓	✓	✓	✗
• Forest ecosystem health and vitality	✓	✓	✗	✓	✗
• Biological diversity in forest ecosystem	✓	✓	✓	✓	✓
Forest Functions:					
• Productive functions of forests	✓	✓	✓	✓	✓
• Protective functions of forests	✓	✓	✓	✓	✓
Development and social needs:					
• Various socio-economic functions and conditions	✓	✓	✓	✓	✓
Institutional Framework:					
• Policy and legal framework, and capacity to implement sustainable forest management	✗	✓	✓	✓	✓

✓ the criterion is endorsed by the international/regional initiative

✗ *the criterion is absent from those endorsed by the international/regional initiative*

COMPARISON OF INTERNATIONAL INITIATIVES

The overriding aims of all the regional and international initiatives involved in the development of C&Is, are to define and monitor progress towards SFM. The measurement of progress towards sustainable forest management is carried out through the assessment of the changes in indicators over a given period of time (Granholm *et al.*, 1996). In all the initiatives, indicators have been developed;

- to measure state of forest and forest management; and
- to assess policy instruments.

The ongoing initiatives have used different types of approaches to develop and accept C&Is for SFM (Granholm *et al.*, 1996). An ecological approach (e.g. Dry-zone Africa) or political approach, each resulting in different direct benefits e.g. either technical and scientific level dialogue and formulation of proposed strategies of action, or commitment by government. However, this is not to say that by using one approach the benefits are limited to one specific area. Many of the initiatives use the step-by-step approach, which allows for early dialogue and regular review and refinement of C&Is at the technical and scientific level.

In comparing the criteria of the five regional and international processes (Table 5), the sets of criteria in the Helsinki, Montreal and Dry-zone Africa processes are, for the most part, identical except in policy questions in the form of legal, institutional and economic elements. The ITTO and Tarapoto Proposal differ structurally in comparison to the other three initiatives. They have developed C&Is at both the national and the forest management unit levels. However, many of these issues covered at the forest management level are covered by the national level criteria of the other initiatives. According to the FAO's review of the ongoing initiatives, the criteria in all the processes include the six elements:

- extent of forest resources;
- biological diversity;
- health and vitality;
- protective function;
- protective and environmental function;
- development and social needs;

Table 6 gives a more comprehensive table of the similarities and contrasts of the criteria endorsed by the five ongoing initiatives.

CRITERIA AND INDICATORS IN SOUTH AFRICA

Individual countries are at different stages of adapting criteria and indicators for sustainable forest management to their national conditions. Most nation's criteria and indicators are based, to a large extent, upon the international and regional initiatives. Some countries implement these C&Is directly, while others adjust them according to their specific conditions. South Africa lags behind in the development and implementation of C&Is for SFM. This is due to a number of obstacles, one of which is that the concept of C&Is for the industrial forestry sector remains confused. Confusion also exists over who should be developing C&Is and how they should be implemented. Currently, a national framework of

Table 6: Comparison of Criteria of International and regional initiatives (Lammerts van Bueren, and Blom, 1997).

IPF	ITTO	Helsinki	Montreal	Tarapoto	Dry-zone Africa
Extent of forest resources	**Criterion 1:** The forest resource base	**Criterion 1:** Maintenance and appropriate enhancement of forest resources and their contribution to global carbon cycles.	**Criterion 1:** Conservation of biological diversity **Criterion 2:** Maintenance of productive capacity of forest ecosystems **Criterion 5:** Maintenance of forest contribution to global carbon cycles	**Criterion 3:** Sustainable forest production **Criterion 4:** Conservation of forest cover and biological diversity	**Criterion 1:** Maintenance and improvement of forest resources including their contribution to global carbon
Health and vitality	**Under the forest management unit criterion:** The conservation of flora and fauna	**Criterion 2:** Maintenance of forest ecosystem health and vitality	**Criterion 3:** Maintenance of forest ecosystem health and vitality	**Criterion 4:** Conservation of forest cover and biological diversity	**Criterion 3:** Maintenance of forest ecosystem health, vitality and integrity
Productive functions	**Criterion 2:** The continuity of flow	**Criterion 3:** Maintenance and encouragement of productive functions of forests (wood and non-wood)	**Criterion 2:** Maintenance of productive capacity of forest ecosystems	**Criterion 1:** Socio-economy benefits **Criterion 3:** Sustainable forest production	**Criterion 4:** Maintenance and enhancement of production function of forests and other wooded lands
Biological diversity	**Under the forest management unit criterion:** The conservation of flora and fauna	**Criterion 4:** Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems	**Criterion 1:** Conservation of biological diversity	**Criterion 4:** Conservation of forest cover and biological diversity	**Criterion 2** Conservation and enhancement of biological diversity in forest ecosystems
Protective and environmental functions	**Criterion 3:** The level of environmental control	**Criterion 5:** Maintenance and appropriate enhancement of protective functions in forest management (notable soil and water)	**Criterion 4:** Conservation and maintenance of soil and water resources	**Criterion 5:** Conservation and integrated management of water and soil resources	**Criterion 5:** Maintenance and improvement of protective functions in forest management
Developmental & social needs	**Criterion 4:** Socio-economic effects	**Criterion 6:** Maintenance of other socio-economic functions and conditions	**Criterion 6:** Maintenance and enhancement of long-term multiple socio-economic benefits to meet the need of societies.	**Criterion 1:** Socio-economic benefits **Criterion 3:** Sustainable forest production	**Criterion 6:** Maintenance and enhancement of socio-economic benefits
Legal, policy & institutional framework	**Criterion 5:** Institutional frameworks	The descriptive indicators of the Helsinki Process: -legal / regulatory framework -institutional framework -financial instrument / economic incentives -information means	**Criterion 7:** Legal, institutional and economic framework for forest conservation and sustainable management	**Criterion 1:** Socio-economic benefits **Criterion 2:** Policies and legal-institutional framework for sustainable management of the forests **Criterion 7:** Institutional capacity to promote sustainable development in Amazonia **Criterion 6:** Science and technology for the sustainable development of forests	**Criterion 6:** Maintenance and enhancement of socio-economic benefits **Criterion 7:** Adequacy of legal, institutional and policies framework for sustainable forest management

C&Is does not exist in South Africa but the Department of Water Affairs and Forestry (DWAF) is presently responsible for co-ordinating the development of these criteria and indicators (NFAP, 1997).

The South African government's goal is *to promote a thriving forest sector, utilised to the lasting and sustainable benefit of the total community and developed and managed to protect and to improve the environment* (Forestry White Paper, 1996). The new Forest Policy (Forestry White Paper, 1996) makes provision for C&Is and requires that *the forest industry must not only be internally efficient and profitable, but also rational in its use of resources, equitable in its development, and environmentally sustainable* (NFAP, 1997). The policy also defines the role of government in dealing with the forest sector. Following on from the White Paper is the National Forestry Action Programme (NFAP) which according to the Minister is an attempt to *translate the vision of the White Paper of Sustainable Forest Development into concrete and discrete actions*. The NFAP takes the stance that South Africa must immediately begin developing and implementing C&Is if the new forest policy is to achieve the desired goal of sustainable forest development.

Arising from a workshop convened by DWAF in March 1997, a set of six principles, each with some criteria, were identified to form a basis for the industrial forestry strategy (NFAP, 1997). From these six principles, three relate directly to conserving the environment and biodiversity, i.e. maintain the resource base; maintain biodiversity; and wise use of water (DWAF, 1997b). Whether these are principles according to the definition of Prabhu *et al.* (1996) and Stork *et al.* (1997) is debatable. For the purpose of sustainable plantation management Lawes and Eeley (1998), felt that it would be better to place these as criteria under the principle *the maintenance of ecosystem integrity and environmental capability*. However, the selection of this principle, leads to the dilemma of defining ecosystem integrity and environmental capability. Nambiar and Brown (1997) define environmental capability of a site as bounded by (i) the inherent soil and bio-physical constraints, (ii) the responsiveness of the soil to management inputs, and (iii) the genetic potential of the plantation species and their interaction with the environment of the site.

There are a number of other policies and statutes which impact directly or indirectly on the development of C&Is for the forest sector at a national scale in South Africa:

Policies

- White paper on Environmental Management Policy of South Africa - which recognises the participation of interested and affected parties as important in environmental decision-making and that public interaction should be incorporated into determining the future of the forestry sector.
- White Paper on Conservation and Sustainable Use of Biological Diversity - recognises the need for sustainable use and conservation of the biological diversity of the country. This could be achieved by restoring degraded ecosystems, controlling the spread of alien organisms and integrating biodiversity considerations into land-use planning and environmental assessments.
- White Paper on National Water Policy for South Africa - recognises water as vital in achieving the national goals. Stresses the creation of better management and planning of water allocation and the placing of a value on water resources.

Statues

- Conservation of Agricultural Resources Act
- Mountain Catchment Areas Act
- Environmental Conservation Act

SELECTION OF CRITERIA AND INDICATOR FOR PLANTATION FORESTRY

Once the selection of the principle; *the maintenance of ecosystem integrity and environmental capability* is complete, the next step is to determine those criteria which could be applied to plantation forestry. The selection of C&Is to be used at the FMU level in industrial plantations commenced with the comparison of the differences and similarities of the international and regional C&I initiatives (Lammerts van Bueren and Blom, 1997). An examination of the C&Is of the five international and regional initiatives was carried out in order to determine whether it was possible to applied them at the FMU level in industrial forests. Table 6 shows a summary of similarities and differences of criteria of the various initiative. On comparing these initiatives, it appeared that only one of the criteria was immediately applicable to soil and water resources, i.e. *protective and environmental functions* (IPF) or *conservation and integrated management of water and soil resource* (Montreal process) (shown in Table 6 as the shaded column).

After careful examination of the indicators associated with this criterion (Table 7), it appeared that the Montreal Process included the most comprehensive set of indicators which could be adapted and applied at the FMU level. Although the Dry-zone Africa criteria and indicators should be the most applicable to South Africa, it was concluded that since this process was still in its infancy and was largely based on the other initiatives, the criteria and indicators they selected would be covered by the Montreal Process. Therefore, the criteria and indicators applicable to soil and water resources were selected based on the Montreal Process. Since this initiative has developed C&Is at the national level, to be applicable at the FMU level, those selected had to be slightly modified. Under this criterion *the conservation and maintenance of soil and water resources*, a number of indicators could be applied at the FMU level. These indicators included (Lammerts van Bueren and Blom, 1997):

- area and percent of land with significant soil erosion;
- area and percent of land managed primarily for protective functions eg. riparian zones and wetlands;
- no significant variation in levels of soil organic and soil chemical properties;
- no significant variation of soil physical properties;
- stream flow and timing has not significantly deviated;
- no significant variation of physical and chemical characteristics of the water body;
- no significant variation of biological diversity of the water body; and
- no variation in the accumulation of persistent toxic substances in the water body.

Table 7: Comparison of indicators which are applicable to the criterion "protective and environmental functions" (Lammerts van Bueren, and Blom, 1997).

ITTO	Helsinki	Montreal	Tarapoto	Dry-zone Africa
Criterion 3: The level of environmental control	**Criterion 5:** Maintenance and appropriate enhancement of protective functions in forest management (notable soil and water)	**Criterion 4:** Conservation and maintenance of soil and water resources	**Criterion 5:** Conservation and integrated management of water and soil resources	**Criterion 5:** Maintenance and improvement of protective functions in forest management
Under the forest management unit level criteria	5.1. Proportion of forest area managed primarily for soil protection	4.a. Area and percent of forest land with significant soil erosion 4.d. Area and percent of forest land with significantly diminished soil organic matter and/or changes in other chemical properties. 4.e. Area and percent of fores land with significant compaction or change in soil physical properties resulting from human activities 4.h. Area and percent of forest land experiencing an accumulation of persistent toxic substances.	5.a. Measures for soil conservation 5.b. Area and percentage of forest lands managed for environmental protection	5.1. Areas and percentages of forest and other wooded land managed mainly for the protection and/or rehabilitation of degraded lands and relevant important infrastructure work
The availability of engineering, watershed protection and other environmental management prescriptions for production forests	5.2. Proportion of forest area managed primarily for water protection	4.b. Area and percent of forest land managed primarily for protective functions eg. Watersheds, flood protection, avalanche protection, riparian zones 4.c. Percent of stream kilometres in forested catchments in which stream flow and timing has significantly deviated from the historic range of variation 4.f. Percent of water bodies in forest areas (e.g. stream kilometres, lake hectares) with significant variation of biological diversity from the historic range of variability 4.g. Percent of water bodies in forest areas (e.g. stream kilometres, lake hectares) with significant variation from the historic range of variability in pH, dissolved oxygen, levels of chemical (electrical conductivity), sedimentation or temperature change	5.c. Percentage of forest flooded in relation to the historic range of variation and maintenance of the relationship between the forest and hydrobioligcal resources. 5.d. Effects of forest conservation on the integrated management of water resources	5.2. Areas and percentage of forests and other wooded land areas managed mainly for the production of water, protection of watersheds riverine zones and for flood control.

ACCEPTABLE CHANGE

All the indicators selected from the Montreal process mention 'no significant variation' in one or more of the soil and water characteristics. Before the C&I process is implemented it will be important to decide what 'significant variation' implies. The levels of acceptable change will have to be negotiated by all the major stakeholders in the C&I process. One of the major stumbling blocks to the C&I process, is the conflict between scientists, decision-makers and forest managers on their perceptions of acceptable levels of change. 'Scientifically defensible' analysis sets high standards for statistically defensible conclusions. It is important that proposed verifiers are not based on the faith of 'experts' alone and lack either the theoretical or empirical underpinning. A compromise will have to be reached, where thresholds are set at realistically attainable levels for forest managers but which will also be acceptable to scientists and policy-makers. This could perhaps be achieved by making use of Bayesian Inference.

Unlike traditional statistics where conclusions are based on falsificationist means of analysis, Bayesian statistics directly analyzes the *probability* of a hypothesis, allowing scientists and manager to formally update their beliefs in a variety of experimental and non-experimental situations (Ellison, 1996). Bayesian analysis, focuses on estimating the probability that a hypothesis is true based on the observer's confidence or degree of belief in it, and allows for the updating of that probability as data accumulates (Anderson, 1998). The inputs to Bayesian analysis include: estimates of 'prior' probabilities (the degree of confidence in each hypothesis before the data is seen), and the probabilities of the data (the probability that the data would be observed if each hypothesis were true). These are then combined using the Bayes' theorem to produce "posterior" probability estimates that represent the updated degree of belief in each hypothesis under consideration (Anderson, 1998). The ideas is that, if the manager/scientist believes strongly in a specific hypothesis based on past experiences, and they now observe data that would be likely to occur given that hypothesis, their posterior (after the data) confidence in the hypothesis should be strengthened. Bayesian decision theory demonstrates that the optimal decision is the one for which the maximum possible loss or risk is minimized.

Bayesian inference can therefore, provide an alternative statistical framework in which to synthesize existing information, generate useful ecological theory and contribute to sound environmental policy (Ellison, 1996). Since environmental decisions are made in light of incomplete and uncertain data, decisions should be made in ways that reflect this uncertainty and that can be modified when new data becomes available. With this in mind, it is easy to see the similarities between this statistical method and adaptive management. Since adaptive management incorporates initial uncertainty and treats decisions as hypotheses to be tested, it is easy to see where these two processes can be linked. Using Bayesian Inference, the consequences of any adaptive management decision (hypothesis) can be determined, which may lead to modification of these management practices. Bayesian inference and decision theory can therefore, provide a framework and intelligible language in which to analyze and express adaptive management procedures with input from both scientist and forestry managers (Ellison, 1996).

Before evaluating indicators and verifiers it is important to establish appropriate targets, thresholds and/or benchmarks. Indicators employed by policy makers should provide context to data so they can be understood by a non-technical audiences. Indicators do this by referencing targets, thresholds and/or benchmarks, i.e. change since a baseline year; benchmarks that describe a sub-component relative to the whole; criterion benchmarks ; and distance to a policy target, or goal (e.g., the ambient water pollution relative to the ambient level desired by year X). Assessment of soil and water quality based on thresholds, will need to acknowledge that there are many destructive events and different dynamics associated with each verifier. Deciding threshold levels becomes more complex with verifiers which show hysteretic behaviour (relationships may change after thresholds have been passed), e.g. after water quality has deteriorated to eliminate certain species, a drastic improvement in quality may not be sufficient for rapid re-colonisation. It may be possible to determine objective thresholds for some indicators, but may be difficult for others due to insufficient theoretical backing. Another problem facing the operators of

C&Is is that verifier 'values' vary greatly over time and space. This may create further analytical uncertainties and problems.

Once the levels of acceptable change have been decided, it is important to determine whether historical data exists, against which this change can be measured. If this data is not available, information collected at the affected sites could be compared with that of a control site or over time with the same site.

SYNTHESIS

Sustainable forest management, was identified at the UNCED conference, as one of the key factors in sustainable development. A number of international and regional initiatives have attempted to develop sets of criteria and indicators for SFM at the national level. This has led to the division of C&I development into five large regions/zones each with their own set of criteria and indicators. Most C&I development has been concentrated at the international and regional levels, with very little formulation occurring at the FMU level

South Africa lags behind in the development and implementation of C&Is for SFM. This is due to a number of obstacles, one of which is that the concept of C&Is for the industrial forestry sector remains confused. Confusion also exists over who should be developing C&Is and how they should be implemented. In an attempt to develop C&Is at the FMU level for sustainable plantation management in South Africa, it was established that the C&Is of the Montreal Processes could best be adapted and modified to suit this level of assessment. From this process one criterion and 10 soil and water indicators were selected to be used at the FMU level in the assessment of the progress of a plantation towards sustainable management.

Before the C&I process is implemented it will be important to decided what the thresholds associated with these indicators, implies. The levels of acceptable change will have to be negotiated by all the major stakeholders in the C&I process. One of the major stumbling blocks to the C&I process, is the conflict between scientists, decision-makers and forest managers on their perceptions of acceptable levels of change. A compromise will have to be reached, where thresholds are set at realistic attainable levels for forest managers but which will also be statistically acceptable to scientists. This could perhaps be achieve by making use of Bayesian Inference. Unlike traditional statistics where conclusions are based on falsificationist means of analysis, Bayesian statistics directly analyzes the *probability* of a hypothesis, allowing scientists and manager to formally update their beliefs in a variety of experimental and non-experimental situations. Bayesian analysis, focuses on estimating the probability that a hypothesis is true based on the observer's confidence or degree of belief in it, and allows for the updating of that probability as data accumulates.

Before evaluating indicators and verifiers it is important to establish appropriate targets, thresholds and/or benchmarks. Indicators employed by policy makers should provide context to data so they can be understood by a non-technical audience. Indicators do this by referencing targets, thresholds and/or benchmarks, i.e. change since a baseline year; benchmarks that describe a sub-component relative to the whole; criterion benchmarks ; and distance to a policy target, or goal (e.g., the ambient water pollution relative to the ambient level desired by year X).

CHAPTER FIVE

SELECTION OF VERIFIERS OF CHANGE IN SOIL QUALITY

Defining soil quality, and identifying appropriate parameters for measuring and evaluating it with respect to various soil functions is an ongoing process. Larson and Pierce (1994) define soil quality as *the capacity of a soil to function, both within its ecosystem boundaries (e.g., soil map unit boundaries) and with the environment external to that ecosystem (particularly relative to air and water quality).* This framework may be further broadened to include a range of human and soil interactions. Several other definitions for soil quality have been proposed, some of which are:

- the ability of soil to support crop growth which includes factors such as degree of tilth, aggregation, organic matter content, soil depth, water holding capacity, infiltration rate, pH changes, nutrient capacity, and so forth (Power and Mayers, 1989);
- the capacity of a soil to function in a productive and sustained manner while maintaining or improving the resource base, environment and plant, animal and human health (NCR-59, September, 1991); and
- the capability of a soil to produce safe and nutritious crops in a sustained manner over the long-term and to enhance human and animal health, without impairing the natural resource base or harming the environment (Parr *et al.*, 1992).

Difficulty arises in quantifying soil quality due to natural differences among soil orders, variations between the same soil series found in different places, and the diversity of potential land uses. As a result, Karlen *et al.* (1997) suggested that the evaluation of soil quality be viewed as relational rather than absolute, which allows the quality of soils to be different without necessarily being limiting. Karlen *et al.* (1997) further recommended that soil quality be evaluated based on soil function. By focussing on how well a specific soil functions within an ecosystem, it is possible to use the concept of soil quality as a bridge between the different land uses and as a direct and indirect measure of environmental impacts of human management practices.

MEASURING SOIL QUALITY

The maintenance of soil quality is critical for the conservation of forest ecological values which underpin sustainable forest management. The ability to assess and define soil quality is essential in development, performance and evaluation of sustainable land and soil management systems.

Soil quality can be considered from two distinctive points of view, i.e. as an inherent characteristic of the soil, and as the condition or "health" of the soil (Karlen *et al.*, 1997). When viewed as an inherent attribute of the soil, the evaluation of soil quality includes; the assessment of a range of parameter values that measure soil-forming processes which reflect the full potential of a soil to perform a specific function. However, when soil quality is viewed as the condition or "health" of a soil, assessment will include the determination of whether the soil is functioning to its potential. Soils functioning to their full potential will be of an excellent quality, while those functioning below their potential will be concluded to have poor or impaired quality (Karlen *et al.*, 1997). Soil quality assessment would require measuring the current state of an indicator and comparing the results to known or desired values. To this end, C&Is view soil quality as the condition of a soil. The "health" of the soil is assessed using verifiers, and the results are compared with previous results, against a desired value, or against threshold values.

Anthropogenic impacts on soil quality characteristics lead to a number of areas of particular concern i.e. the soil's ability to hold, accept, and release water, nutrients and other chemicals, its capacity to promote and sustain root growth, its potential to maintain a suitable soil biotic habitat, and the soil's response to management practices and resistance to degradation (Doran and Parkin, 1994; Acton and Gregorich, 1995). To determine whether these characteristics are maintained, a soil quality index is needed. This index should include practical and measurable criteria, indicators and verifiers which can identify those production areas which may cause problems, monitor change in sustainability and environmental quality, and assist in the formulating and evaluating of sustainable agriculture at a national level.

Table 8: Proposed soil physical, chemical and biological characteristics to be included as basic verifiers of soil quality (Doran *et al.*, 1994)

Soil Characteristic	Methodology	Reference of methodology or interpretation, comments
Physical		
Soil texture	Hydrometer methods	Gee & Bauder, 1986
Depth of soil and rooting	Soil coring or excavation	Taylor & Terrell, 1982
Soil bulk density and infiltration	Field determined using infiltration rings	Blake & Hartge, 1986
Water holding capacity*	Field determined after irrigation of rings	Cassel & Nielsen, 1986
Water retention characteristics	Water content at 33 and 1500 kPa tensions	Klute, 1986
Water content*	Gravimetric analysis, wt. loss, 24 h at 105°C	Sampled in field before and after irrigation
Soil temperature*	Dial thermometer or hand temperature probe	Measured at 4 cm soil depth
Chemical		
Total organic carbon and nitrogen	Wet or dry combustion, *volumetric basis***	Nelson & Sommers, 1982; Schultz, 1988
pH	Field or lab determined, pocket pH meter	Eckert, 1988; 1:1 soil/water mixture
Electrical conductivity	Field or lab, pocket conductivity meter	Dahnke & Whitney, 1988; 1:1 soil/water
Mineral N (NH_4 and NO_3), P and K	Field or lab analysis, *volumetric basis***	Gelderman & Fixen, 1988; 2*M* KCL extract for NH_4 and NO_3
Biological		
Microbial biomass C and N	Chloroform fumigation/incubation, *volumetric basis***	Parkinson & Paul, 1982
Potentially mineralizable N	Anaerobic incubation, *volumetric basis***	Keeney, 1982
Soil respiration*	Field measured using covered infiltration rings, lab measured in biomass assay	Anderson, 1982; CO_2 specific gas analysis tubes (Draeger)
Biomass C/Total org C-ration	Calculated from other measures	Estimate of ecosystem stability; Visser & Parkinson, 1992
Respiration/biomass ration	Calculated from other measures	Visser & Parkinson, 1992

*Measurements taken simultaneously in field for varying management conditions, landscape locations and time of year.
**Gravimetric results must be adjusted to volumetric basis using field measured soil bulk density for meaningful interpretations

Practical assessment of soil quality requires the development of a basic soil quality index of verifiers which include physical, chemical and biological factors. They should also be accessible, applicable and sensitive to varying management and climatic conditions (Doran and Parkin, 1994). Doran *et al.* (1994), proposed a basic set of verifiers of soil quality which are shown in Table 8. This is a list of measurable soil properties that define the major processes functioning in a soil.

Since the Montreal Process has been developed to be applicable at the national level, no verifiers have as yet been developed at the level of FMU. Therefore, the selection of verifiers which could be applied at this level in industrial plantations, had to be based on the impacts of this agricultural process on the natural resources of an area. An index of soil verifiers was proposed which could be adapted to meet the needs of a specific area. This process attempts to develop a soil index of verifiers which monitor and measure as many eventualities of plantation management as it progresses towards sustainable management.

Stork *et al.* (1997), selected a single soil indicator i.e. *the status of decomposition and nutrient cycling shows no significant change,* while investigating C&Is for use in evaluating the sustainability of logging at the FMU level of natural forests. Eight verifiers were selected to measure this indicator, the verifiers included; standing and fallen dead wood; state of decay of dead wood; abundance of small woody debris; depth of leaf litter and gradient of decomposition; abundance of decomposer organisms; leaf bags; soil conductivity and pH; soil nutrient levels. Boyle *et al.* (in press), then assessed these verifiers in relation to the following aspects; ease of data collection and interpretation, relevance to biodiversity, responsive to change, cross-linkage to other indicators, and accountability.

Making use of Stork *et al.* (1997), Boyle *et al.* (in press), and Doran *et al.* (1994), a soil quality index which included a number of verifiers was selected and investigated as a tool to evaluating progress towards sustainable plantation management. Since the ecological functioning of a soil is the only function which is not man-bound (e.g. it is not a user-function to man or reflects his appreciation for his surroundings, like the aesthetical function), it is this function which determines the selection of soil quality verifiers (Vonk, 1982). The ecological functioning of a soil is the most important basic function from both man's and natures' concern, and it was therefore important that this was taken into consideration when selecting parameters which measure and define soil quality.

Table 9: *Soil indicator and verifiers which could be used to assess progress towards SFM of plantations.*

INDICATORS	VERIFIERS
1.1. No significant variation in physical redistribution of soil from the historic range of variation where records are available, alternatively time series could be employed	**1.1.1.** Area and Percent of land with significant soil erosion
1.2. No significant variation in the levels of soil organic matter and/or changes in other chemical properties from the historic range of variation where records are available, alternatively time series could be employed	**Chemical**
	1.2.1. *Total organic carbon and nitrogen*
	1.2.2. Soil pH
	1.2.3. Electrical conductivity
	1.2.4. Exchangeable base cations Ca, Mg, Al and K
	Biological
	1.2.5. Microbial biomass C and N
	1.2.6. Soil respiration
	Decomposition
	1.2.7. Depth of litter/gradient of decomposition
	1.2.8. Abundance of important decomposers
1.3. No significant variation of soil physical properties from the historic range of variability where records are available, alternatively time series could be employed	**1.3.1.** Soil bulk density / porosity
	1.3.2. Soil strength
	1.3.3. Soil moisture content
	1.3.4. Aeration
1.4. No significant variation in the accumulation of persistent toxic substance from the historic range of variability where records are available, alternatively time series could be employed	**1.4.1.** Organic pollutants
	1.4.2. Heavy metals

Therefore only those verifiers which were thought to be relevant to industrial plantations and which showed impacts of this agricultural process on the ecological functioning of the soil, were examined (Table 9). It will be clear that a certain activity does not have an influence on all soil parameters, and it might therefore, be possible to indicate for each category which soil parameters are important for judging the effects of the activity in question (Vonk, 1982). The remainder of this chapter discusses each of the verifiers and their relevance to SFM. Those verifiers which were accepted from this vetting process, were presented to and evaluated by environmentalists and forestry managers at a C&I workshop.

ASSESSMENT OF SOIL QUALITY VERIFIERS

Indicator 1.1. No significant variation in the physical redistribution of soil from the historic range of variation where records are available, alternatively time series could be employed.

This indicator provides a measure of soil loss, which may impact on soil fertility and/or sediment delivery to streams. Although soil erosion can lead to improved productivity in some soils, it is generally the major agent of soil degradation (Pierce, 1991). Through removal and sedimentation deposition, the soil's physical and chemical properties may be altered (Australian Framework, 1998).

Verifier 1.1.1. Area and Percent of land with significant soil erosion.

A rating or description of the extent, severity and type of surface erosion is an easily attainable parameter that needs increased emphasis in forestry soil surveys (Musto, 1992). The extent of erosion may be measured using a number of techniques, i.e. point measurements, volumetric assessment and empirically based techniques. However, this verifier implies the assessment of spatial variation in erosion and not point measurements. This can be achieved using aerial photography or geographic information systems (GIS).

The monitoring of this verifier is considered vital to sustainable management of industrial plantations, since a change in this parameter will impact on both soil and water quality. It is therefore, imperative that this verifier be included in any soil quality index which measures sustainable soil exploitation and management.

Indicator 1.2. No significant variation in the levels of soil organic matter and/or changes in other chemical properties from the historic range of variation where records are available, alternatively time series could be employed.

This indicator attempts to measure those chemical properties which impact on soil fertility. Since soil organic matter (SOM) impacts on the physical, chemical and biological properties affecting ecosystem processes, it may be used as an alternate measure of soil fertility (Australian Framework, 1998).

Verifier 1.2.1. Total Organic Carbon and Nitrogen

Change in organic matter is a good verifier of modification of soil quality, since it is a characteristic which affects physical, chemical and biological properties. It impacts on a number of soil quality parameters, i.e. it increases the water infiltration and holding capacity of the soil and through increased granulation, promotes the development of soil stability (Tan, 1996); it acts as a source of plant nutrients, especially nitrogen and sulphur; it influences the soil's ability to absorb and deactivate agricultural chemicals (Nelson and Sommers, 1982); and influences colour, temperature and cation exchange capacity of a soil. Since change in any of these parameters will impact on the ecological functioning of a soil, it is important that this verifier be included as a measure of progress of industrial plantation to sustainable management.

Total Nitrogen

Nitrogen is a major plant nutrient that is commonly a limiting factor in plant growth. Although present in small concentrations, nitrogen is taken up in large quantities by plants and is consequently, classed as an essential nutrient for growth (Tan, 1996). Nitrogen forms a major component of fertilizers, an over-application of which influences the ecological functioning of a soil through modification of soil chemistry, and changes soil fauna and flora. Like most agricultural process, the planting of exotic timber often requires the application of fertilizers. It is therefore important that the levels of nitrogen in the soil be carefully monitored and measured.

Verifier 1.2.2. Soil pH

Many soil quality properties and process are affected by soil pH. Processes that would tend to acidify a soil include: organic matter accumulation; clay formation; or leaching of bases in association with an acid anion. Processes that would tend to make a soil more basic include: the weathering of soil minerals; or destruction of organic matter by fire (Reuss and Johnson, 1986).

Although Boyle *et al.* (in press), rejected this verifier, it was felt that since this verifier influenced the ecological functioning of a soil through impacts on crop production, soil chemistry, availability of nutrients and toxic substances, the nature and activities of microbial species and the activities of pesticides, it should be included in any index which measures the quality of a soil under exotic timber species.

Verifier 1.2.3. Electrical Conductivity

Soil salinity is one of the oldest soil pollution problems. It is a problem primarily associated with arid and semi-arid regions where there is insufficient rain for the leaching of soluble salts. Increased salinity may affect plant growth in a number of ways, i.e. direct toxicities (sodium, chlorine), creating an ionic balance, or decreasing the available water by lowering the osmotic potential (Rowel, 1994).

Assessment of dissolved salts in soil solution is normally determined by preparation of a saturated extract (Rowel, 1994). However, this verifier was rejected as a verifier of sustainability on the basis that it was difficult to assess. Boyle *et al.* (in press), also rejected this verifier on the grounds that they were unsure whether it showed consistent response to change for all human interventions in natural forests.

Verifier 1.2.4. Exchangeable base cations calcium, magnesium and potassium

Soil test extractants for calcium, magnesium and potassium are designed to rapidly assess the available nutrient status of a soil. This is a critical verifier of soil quality since one of the most important characteristics of soils is the cation-exchange complex. The ions which have been absorbed onto the colloidal complex form the reserve acidity and therefore play a vital role in determining the acidity of a soil.

In alkaline or neutral soils, the negatively charged exchange complex is dominated by basic cations (Ca^+, Mg^+, K^+ and Na^+), while acid mineral soils are usually dominated by aluminum species (Al^{3+} and $Al(OH)_2^+$)(Reuss and Johnson, 1986). The acidity of a soil is thus determined by the relationship between the amounts of the basic cations and the acid aluminum species on the exchange complex. The most likely effect of acid deposition on a neutral soil is an increase in the reserve acidity and a decrease in exchangeable bases.

Verifier 1.2.5. Microbial biomass C and N

The mass of living micro-organisms in a soil is known as the microbial biomass (Rowel, 1994). Since soil micro-organisms play a role in the retention and release of nutrients and energy (Parkinson and Paul, 1982), microbial biomass and its activities are important indicators of soil fertility. However, direct measurement of the mass of soil micro-organisms is time consuming and a highly specialized task and is therefore, not relevant to C&Is. Fumigation-extraction and fumigation-incubation methods have been developed which are simpler, more reliable procedures, but are still too complex for the C&I process (Rowel, 1994, Parkinson and Paul, 1982).

Verifier 1.2.6. Soil Respiration

The evolution of carbon dioxide from the soil can be attributed to three sources; soil microbes, soil fauna and plant root respiration (O'Connell and Sankaran, 1997). The measurement of soil respiration is recommended as a verifier to monitor an ecosystem's response to disturbance. Field measurements are widely used to assess the influence of climatic, physical, chemical and agricultural processes on the below ground soil biomass. The objective of the measurements being to gain a clearer understanding of mineralization processes and insight into how mineral and organic matter in soils can be more efficiently utilized and conserved. However, this verifier was discounted as a measure of soil quality on the grounds of difficulty and time constraints of measurement.

Verifier 1.2.7. Depth of Leaf Litter and Gradient of Decomposition

The weight of organic matter which accumulates on the surface of a soil varies with vegetation types. By comparing the litter depth of different areas it is possible to determine the variation in decomposition rates of organic matter. An absence of a decomposition gradient (least broken down materials at the top of the litter to the most decomposed at the bottom) indicates a breakdown in the decomposition process (Stork *et al.*, 1997) and consequently a resultant change in the ecological functioning of a soil. It is therefore, important that this verifier be included in any soil quality index which measures progress towards SFM.

Since the litter layer under plantations is either very thin or thick but loose, the extent of the litter layer may be determined by measuring the weight of litter from a standard area (i.e. 20 cm^2). Boyle *et al.* (in press), accepted this soil quality parameter as an important measure of sustainable use of natural forests on the basis that it was relatively easy to measure, responds consistently to interventions and is a relevant measure of sustainability.

Verifier 1.2.8. Abundance of Decomposer organisms

Soil organisms contribute to the maintenance of the ecological functioning and therefore, the quality of a soil, by controlling; the decomposition of plant and animal materials, biogeochemical cycling, the formation of soil structure and the fate of organic materials applied to the soils (Turco *et al.*, 1994). This is an important verifier of soil quality since soil micro- and macro-organism are potentially one of the most sensitive biological markers that provide advance evidence of trouble in the soil, long before these transitions can be accurately determined by measuring changes in organic matter. There are however, a number of factors which limit the use of soil fauna as an indicator of soil quality, one of which is that the distribution of the organisms may be limited by environmental factors other than disturbance of the habitat i.e. inadequate and unsuitable food supplies, inadequate soil moisture contents, unsuitable temperatures, incorrect lighting, unsuitable soil texture, pH and electrolyte concentrations, and the presence of physical barriers to movement.

The use of decomposer organisms (e.g. earthworms) as verifiers of change in soil physical and chemical properties was therefore, discounted on the ground that it is often difficult to link variation in diversity directly to management practices. Boyle *et al.* (in press), rejected this verifier as a measure of sustainable management of natural forests on the basis of difficulty of assessment. But, if the industry were prepared to monitor sites where change is anticipated then this may be a useful verifier to the C&I process.

Indicator 1.3. No significant variation of soil physical properties from the historic range of variability where records are available, alternatively time series could be employed.

This indicator determines the extent of change of the physical properties of soil induced by human activities. Change in these properties may impact on soil fertility and other ecosystem processes (Australian Framework, 1998).

Verifier 1.3.1. Soil bulk density

The bulk density value of a soil depends on the mineral and organic matter content, and the amount of pore spaces present (porosity). It is an important physical property of the soil since denser soils may be less permeable and may therefore, impact on its agricultural potential (Tan, 1996). A change in this verifier will indicate change in soil structure; decreased pore space; and decline in water infiltration capacity. Since management practices (e.g. use of heavy wheeled and tracked vehicles) can be directly linked to change in this soil characteristic, it is an important measure of soil quality in plantations and will therefore, be a good measure of progress towards sustainable management of industrial forests.

Verifier 1.3.2. Soil Strength

Soil strength is the degree of resistance of a soil mass to crushing or breaking when force is applied. Although soil strength is related to bulk density, water, clay and carbon content of the soil, it is a good verifier of change in soil compaction in disturbed soils. This is therefore, a useful verifier of soil quality, and a vital determinant of change in the sustainable use of a soil.

Verifier 1.3.3. Soil moisture content

Water is an integral part in most of the processes which maintain the ecological function of a soil and therefore, has a major influence on several soil quality properties. Plant-available water is that portion of water stored in the soil that can be absorbed fast enough by plant roots to sustain life (Miller and Donahue, 1995). The amount of water retained in the soil is affected by physical characteristics such as pore size distribution, and texture. Since soil profile hydrological properties are modified by plantation forestry, with the profile becoming drier (especially in the topsoil), this verifier would supply little relevant information on progress towards sustainability management of a soil and was therefore, not considered for the C&I process.

Verifier 1.3.4. Soil aeration

In soils, the amount of pore space between the solid particles is limited; the greater the amount of water present, the less space there is available for air. If the air porosity is small, the diffusion of gases slows up, roughly in proportion to the air porosity (Leeper and Uren, 1993). The vital point is how much of the total pore space in the soil is still occupied by air when the soil is wetted to field capacity, i.e. the macro-porosity. Soils which have high macro-porosity (greater than 20 %), are well aerated even in very wet spells. The amount of water retained in a soil is affected by the physical characteristics of the wetted part of the profile (Miller, 1973). Any soil profile discontinuity that affects soil pore size distribution, such as textural change, will result in decreased water movement. It is therefore, important for the maintenance of the ecological functioning of a soil that this verifier be included in any soil quality index which may be developed.

Indicator 1.4. No significant variation in the accumulation of persistent toxic substances from the historic range of variability where records are available, alternatively time series could be employed.

This verifier determines the degree to which industrial pollutants and environmentally damaging chemicals impact on soil properties (Australian Framework, 1998).

Verifier 1.4.1. Organic pollutants

Pesticides fall into three major categories; herbicides which control weeds, fungicides which curbs fungal diseases and insecticides for the control of insects (Rowel, 1994). Organic pesticides may influence the ecological functioning of a soil by modification of microbial activity (Soil Science Society of America, 1966). The presence of pesticides represents a change in the chemical properties of the soil, affects the decomposition process if nitrifying organisms are killed, and has negative impacts on sensitive plants if insufficient time is allowed for decomposition, volatilization or leaching of the substance or repeated application (Soil Science Society of America, 1966). Apart from destroying target organisms, they often affect non-parasitic soil organisms by killing or reducing their numbers.

This soil quality parameter is a good verifier of soil quality since a variation in the levels of organic pesticides may result in changes in microbial activity, variations in soil faunal communities and adjustments to soil chemistry. Although difficult to measure, this verifier is vital for the maintenance of the ecological functioning of a soil and therefore, impacts directly on the long-term sustainability of a soil.

Verifier 1.4.2. Heavy metals

The addition of heavy metals and other potentially toxic substances to soils leaves residues which are enduring unless leached (Rowel, 1994). Heavy metals are usually more damaging to the soil than pesticides. Higher plants (spermatophytes) and some of the so called lower plants (lichens, mosses and fungi) are often used as acculative bioindicators of heavy metals (Market, 1993). Which group or species is selected as the *bioindicator* will depend on the monitoring purpose. Although difficult to measure, this verifier is an important determinant of the long-term sustainability of soil. It is therefore, vital that this soil quality parameter be included in any soil quality index which is developed to determine the progress of plantations to sustainable management.

SYNTHESIS

The maintenance of soil quality is critical for the conservation of forest ecological values which underpin sustainable forest management. The ability to assess and define soil quality is therefore, essential to the development, performance and evaluation of sustainable land and soil management systems. Practical assessment of soil quality under exotic timber requires the development of a basic soil quality index of verifier which include physical, chemical and biological parameters.

Since as yet, no verifiers have been developed at the FMU level, the selection of verifiers which could be applied at this level in industrial plantations was based on the impacts of this agricultural process on the natural resources of an area, and those already selected by Stork *et al.* (1997), Boyle *et al.* (in press), for natural forests and by Doran *et al.* (1994), for soil quality. The relevance of each of these verifiers to the maintenance of soil quality of industrial plantations was examined, culminating in their rejection or acceptance for further investigation in the C&I workshop (Table 10). Those verifiers which were accepted from this vetting process, were presented to, and evaluated by environmentalists and forestry managers at a C&I workshop.

Table 10: Outcome of the investigation into verifiers which could form part of a soil quality index.

Accepted Verifiers	**Characteristics on which the verifier impacts**	**Reason for acceptance**
Erosion	Removal and sedimentation deposition change chemical and physical properties of soil	Considered for further investigation based on the fact that this verifier impacts on both water and soil quality.
Total organic carbon	Affect physical, chemical and biological properties	Considered for further investigation due to the number of soil quality characteristics on which it impacts.
Total nitrogen	Application of fertilizers to plantations may influence soil chemistry and soil fauna and flora.	Considered for further investigation since monitoring of levels of nitrogen due to fertilizer application is vital.
Soil pH	Influences facets of crop production, soil chemistry, availability of nutrients and toxic substance, nature and activity of microbial species and activities of pesticides.	Considered for further investigation since it influences a number of soil quality characteristics.
Exchangeable base cations	Vital role in determining soil acidity.	Considered an important verifier due to the role it plays in determining soil acidity.
Depth of litter	Indicates a breakdown in the decomposition process.	Already accepted by Boyle *et al.,* (in press) as a practical measure of sustainability.
Soil bulk density	Influences soil structure, pore space, and infiltration capacity.	Considered for further investigation as this verifier shows the direct impacts of management practices.
Soil strength	Indicates compaction caused by heavy machinery	Considered for further investigation as this verifier shows the direct impacts of management practices.
Aeration	Influences water retention.	Considered for further investigation.
Organic pollutants	Influences microbial activity, soil faunal community structure and soil chemistry.	Considered for further investigation as application of pesticides should be closely monitored.
Heavy metals	Influences soil chemistry.	Considered for further investigation.
Rejected Verifiers	**Characteristics on which the verifier impacts**	**Reason for rejection of the verifier**
Electrical conductivity	Influences plant growth.	Rejected by Boyle *et al.*, (in press) based on the consistence of response of this verifier to human intervention. Also rejected based on the relevance of this verifier as a measure of sustainable plantation management.
Microbial biomass C and N	Influence retention and release of nutrients and energy.	Rejected on the grounds of difficulty of measurement.
Soil respiration	Monitors an ecosystem's response to disturbance.	Rejected on the bases of difficulty of measurement.
Insect herbivory	Influence decomposition and nutrient cycling.	Rejected by Boyle *et al.*, (in press) on the basis of difficulty and time required for measurement.
Abundance of important decomposers	Influences soil physical and chemical properties.	Rejected by Boyle *et al.*, (in press) on the basis of difficulty of measurement, uncertainty of response to change and confusion concerning accountability
Soil moisture content	Influences available water for plant growth.	Rejected on the grounds that plantations always exhibit a drier profile and therefore, measurement of this verifier will not supply relevant information on sustainability.

CHAPTER SIX

SELECTION OF VERIFIERS OF WATER QUALITY AND QUANTITY

WATER QUALITY

The term 'water quality' refers to *those physical and chemical attributes of a sample of water that determine its value for a specific purpose* (Dallas *et al.*, 1994). The term was first introduced as an expression to describe the quality of water required for human consumption, (e.g. for drinking, watering stock, and other agricultural and industrial purposes) however, this description is entirely from a human perspective. Although most aquatic biotas may survive in water which has been classified as adequate for human use, these levels may not be acceptable for all organisms. Therefore, it is important when monitoring the sustainability of water use and changes in water quality, to select parameters which could be evaluated and monitored from the perspective of down-stream users, and the aquatic biotas in the river system.

The physical attributes and chemical constituents of natural fresh waters differ from region to region due to differences in climate, geomorphology, geology and soils, and aquatic and terrestrial biotas. Chemical constituents of river water vary naturally in concentration from region to region, from river to river and even from the headwaters of a river to its lower reaches (Dallas *et al.*, 1994). It is therefore, often difficult to decided which water quality parameters should be evaluated and monitored when determining those verifiers that could be applied as a measure of progress towards sustainable plantation management.

Further problems with measuring water quality are that: (1) pulse release of contaminants that result in an alteration of water quality may not be recorded unless sample collection is continuous; (2) the number and type of potentially toxic compounds which could affect water quality are vast; (3) the cost of chemical analysis may be high; and (4) the overall effect of changing more than one variable may be greater or less than the effect of each in isolation. It is therefore important when measuring water quality to include physical, chemical and biological parameters (verifiers) as measures of sustainable forest management. Those water quality verifiers which are selected and tested in the C&I process may form a water quality index which can be used to determine sustainable water use and sustainable plantation management practices.

WATER QUANTITY

The type of vegetation which covers an area will have considerable influence on a catchment's response to precipitation. Therefore, forest management activities (e.g. deforestation, thinning, clear cutting, reforestation, introduction of exotic species, etc.) may have considerable impacts on local hydrological properties (Falkenmark and Chapman,1989).

Land-use and the modification of natural vegetation play an important role in determining the proportion of rainfall that reaches each part of the system, and particularly the ratio of runoff to rainfall (O' Keefe *et al.*, 1992). Forests have greater water interception than do grassland or cultivated crops (Falkenmark and Chapman,1989). The surface litter protects the soil against the splashing effect of raindrops, and the effects of the surface mulch on decomposing vegetation is to increase infiltration relative to surface runoff. Evapotranspiration is also increased due to the direct re-evaporation of intercepted water, the higher consumptive use of water by trees, and the greater amounts of water available in the root zone (Falkenmark and Chapman, 1989). Deforested areas result in increased intensities of runoff due to the loss of protection of the soil and as a result, extreme increases in erosion. The result is larger floods of shorter duration, followed by lower base flows (O' Keefe *et al.*, 1992).

In South Africa, the trend for constantly flowing rivers to become seasonal, with no flow during the drier months, is a consequence of land-use and vegetation changes in the catchment (O' Keefe *et al.*, 1992). The result is that water is a very scarce resource in most of southern Africa, which is otherwise blessed with an abundance of natural resources. The afforestation of the upper catchments by alien species such as *Pinus radiata* may reduce runoff by half (Witch, 1971) and clear-felling causes periodic catastrophic changes in runoff and sediment loads (O' Keefe *et al.*, 1992).

It is important to monitor water quantity in afforested areas because South African rivers in their natural state tend to have variable flow regimes, which are governed by stochastic events such as floods and droughts. The consequences for the natural biota, which have co-evolved with variable and unpredictable events, can be severe. It has also become obvious that South Africa needs to manage catchments and river basins in an integrated way, where the ecological importance of the catchment is fully realized (O' Keefe *et al.*, 1992).

Water is a naturally renewable resource if exploitation is within sustainable limits. However, South Africa has yet to determine what these sustainable limits are, since there are large variations in local conditions and requirements.

MEASURING WATER QUALITY AND QUANTITY

To gain a true picture of the nature of a particular water sample it is often necessary to measure several different properties by carrying out analyses under broad headings of physical, chemical and biological characteristics (Tebbutt, 1983).

As yet, no water quantity and quality verifiers have been developed, or applied as measures of progress toward sustainable management of industrial plantations. Stork *et al.* (1997), selected a single water indicator, i.e. *there is no significant change in the quality and quantity of water from the catchment,* while investigating C&Is for use in evaluating the sustainability of logging natural forests. Four verifiers were selected to measure this indicator, the verifiers included; abundance and diversity of aquatic stream organisms, chemical composition of stream water, leaf bags and stream flow. Boyle *et al.* (in press), assessed these verifiers in relation to the following aspects; ease of data collection and interpretation, relevance to biodiversity, responsive to change, cross-linkage to other indicators, and accountability.

Making use of the work carried out by Stork *et al.* (1997), and Boyle *et al.* (in press), and keeping in mind the impacts of industrial plantations on water resource, a water quality index was drawn up which included a number of verifiers. Since the ecological functioning of a water body is the only function which is not man-bound (e.g. it is not a user-function to man or reflects his appreciation for his surroundings, like the aesthetical function), it is this function which determined the selection of water quality verifiers (Vonk, 1982).

Table 11: Water indicators and verifies which can be used in the assessment of progress towards SFM of plantations.

Indicators	**Verifiers**
2.1. Area and Percent of land managed primarily for protective functions eg. riparian zones	**2.1.1.** Width of riparian buffer zones
2.2. Stream flow and timing has not significantly deviated from the historic range of variation where records are available, alternatively time series could be employed	**2.2.1.** Stream flow rate
2.3. No significant variation in biological diversity from the historic range of variability where records are available, alternatively time series could be employed	**2.3.1.** Biomonitoring
2.4 .No significant variation in physical and chemical characteristics from the historic range of variability where records are available, alternatively time series could be employed	**Physical characteristics**
	2.4.1. Turbidity
	2.4.2. Temperature
	2.4.3. Colour
	Inorganic chemical characteristics
	2.4.4. Suspended sediments
	2.4.5. Deposited sediments
	2.4.6. pH
	2.4.7. Electrical conductivity
	2.4.8. Total Alkalinity
	2.4.9. Dissolved oxygen
	2.4.10. Total Nitrogen, nitrate, nitrite and ammonia
	2.4.11. Chloride
	2.4.12. Phosphate
	Organic chemical characteristics
	2.4.13. Organic material
	2.4.14. Organic pollutants

The ecological functioning of a water body is an important basic function from both man's and natures concern, and it was therefore important to consider this function when selecting parameters which measure and define quality. Therefore, only those verifiers which were thought to be relevant to industrial plantations and reflected the ecological functioning of a water system, were examined (Table 11). It will be clear that a certain activity does not have an influence on all water parameters, and it might therefore, be possible to indicate for each category which parameters are important for judging the effects of the activity in question (Vonk, 1982). The remainder of this chapter discusses each of the verifiers and their relevance to SFM. Those verifiers which were accepted from this vetting process, were presented to and evaluated by environmentalists and forestry managers at a C&I workshop.

ASSESSMENT OF WATER QUALITY VERIFIERS

Indicator 2.1. Area and percent of land managed primarily for protective functions, e.g. riparian zones.

This indicator determines the extent of land on the plantation estate which is managed in a natural state primarily for any protective functions that it may perform, e.g. riparian zones (Australian Framework, 1998). Explicit legal protection has been applied to riparian zones in South Africa, however, there has been little enforcement of this legislation (Bosch *et al.*, 1994).

Verifier 2.1.1. Width of riparian buffer zones

This verifier can be directly related to management practices and their impacts on water quality. It is therefore, important that it is included as one of the C&I parameters that evaluate the progress of management practices towards sustainability. Management of riparian zone vegetation has both hydrological and ecological benefits. Hydrological benefits of maintaining riparian zone vegetation include improvements in water yield, flow regulation and water quality. They are highly effective as buffer strips in filtering sediments, nutrients, pesticides, particulate organic matter and bacteria from runoff (Bosch *et al.*, 1994).

Through shading effects, riparian vegetation may ameliorate and control stream temperature (Bosch *et al.*, 1994). This is important to aquatic organisms which have high or low optimum temperature tolerances. If riparian vegetation is removed, the resulting increase in temperature may shift the aquatic community structure. These vegetation zones also provide organic matter for streams and rivers. Removal will disrupt the food chain, reduce the input of terrestrial organisms, and lead to excessive algal growth, resulting in a change in aquatic faunal diversity.

Indicator 2.2. Area of stream kilometres in catchments in which stream flow and timing has significantly deviated from the historic range of variation.

This indicator attempts to show the impacts of management practices and other factors on water flow and deviation in flow. Monitoring of stream flow and changes thereof, are important for water quality and health (Australian Framework, 1998).

Verifier 2.2.1. Stream Flow Rate

This is an important verifier of sustainable plantation management. If the relationship between nutrient concentration, rainfall and run-off rates can be established, estimates of the quantities of nutrients lost to the system can be made from the volume of water leaving the catchment, provided there are not additional nutrient inputs (Stork *et al.*, 1997).

This verifier was rejected by Boyle *et al.* (in press), on the grounds that measurement required too great an effort to make it practical. However, it was considered a vital parameter in the measurement of sustainable plantation management due to the extensive impacts of exotic timber plantations on water hydrology and was therefore, included in the water quality index.

Indicator 2.3. No significant variation in biological diversity from the historic range of variability where records are available, alternatively time series could be employed.

The quality of stream habitats is reflected by the composition of fauna found there. Changes in this in-stream faunal structure will reflect the impacts of management activities on the stream, therefore, aquatic biodiversity is a good instrument to assess the effects of management practices on water quality (Australian Framework, 1998). There are three fundamental methods of monitoring the effects of water quality on riverine biota, i.e. physical, chemical and biological assessment. A monitoring system that integrates all three assessment processes will increase the accuracy of environmental evaluation (Roux and Everett, 1994). Aquatic organisms provide a more sensitive and reliable measure of water quality conditions than do physical and chemical assessments, since biological communities integrate the impacts of numerous stresses and illustrate cumulative effects (Dallas and Day, 1993).

Verifier 2.3.1. Biomonitoring

Biomonitoring makes use of the biological responses of aquatic organisms to assess change in the water environment. These environmental changes usually stem from anthropogenic causes.

The use of biological communities for monitoring water quality is advantageous, as it determines the effects of changes on the whole ecosystem. Aquatic community structure may provide some memory of water quality impacts that were short-lived (Roux and Everett, 1994). Changes in the quality of the water environment may exceed the tolerance levels of key organisms in the community, which may cause further consequential changes for those organisms which remain (Hellawell, 1989). Organisms which have been used in biological monitoring of water quality have included a variety of species of algae, invertebrates and fish (Dallas and Day, 1993). In South African rivers and streams the biotic index developed by Chutter has been widely used in monitoring water quality. This index has been modified, with certain aspects of the BMWP system having been incorporated in the updated index (SASS: South African Scoring System, see Appendix A for the SASS 4 Score Sheet used by Umgeni Water) (Chutter, 1994).

Monitoring of aquatic biotas is a sensitive manner of determining the impacts of pollutants. Although these methods of monitoring are labour intensive and less precise than chemical and physical analysis, biomonitoring is a sensitive tool in determining changes in water quality and should therefore form one of the basic parameters which measure sustainability in the C&I process. Boyle *et al.* (in press) felt that this was a feasible verifier of water quality since members of the team testing the C&Is for natural forest had no training in taxonomy of stream organisms but were still easily able to use a simple key to identify organisms to orders. They also felt that this indicator clearly showed response to changes in management practices, was relevant, and had cross-linkages with other indicators.

Indicator 2.4. No significant variation of physical and chemical characteristics from the historic range of variability where records are available, alternatively time series could be employed.

This indicator makes use of physio-chemical parameters to determine water quality and the health of an aquatic environment (Australian Framework, 1998). It also determines the extent of industrial pollutants and environmentally damaging chemicals which may affect water quality. There are usually fixed and relatively constant factors which contribute to the nutrient levels in any system. Some of these factors include climatic conditions (e.g. weathering, erosion, rainfall and variability in runoff), catchment characteristics (e.g. surface geology and land form) and diffuse anthropogenic sources (e.g. agricultural surface runoff in areas where the soil or surface vegetation has been disturbed and/or fertilizers have been applied) (Dallas and Day, 1993).

PHYSICAL CHARACTERISTICS

Verifier 2.4.1. Turbidity

Turbidity is caused by suspended particle matter in water. In addition to the presence of suspendoids, turbid rivers are seasonally permeated by suspended solids that are either washed in during rainfall events or brought into suspension from the bottom sediments during spates (Dallas and Day, 1993).

It is important that this verifier be included in the water quality index since it is a characteristic which has vast impacts on physical, chemical and biological representations of a water body. Change in this verifier may also be an indication of increased erosion and runoff. The greatest impact of this parameter on the ecological functioning of a water body occurs when turbidity is present at abnormally high levels or for unusually long periods of time (Hellawell, 1989). The immediate visual effect of turbidity is a decrease in water clarity, which together with changes in water colour, may lead to impeded light penetration and declining temperatures. A decrease in penetration depth of surface light will limit the photosynthesis process of plants and decrease the visual range of aquatic animals.

Verifier 2.4.2. Temperature

Although natural physical features of running water are subject to the hydrological, climatological and structural aspects of the region and catchment area (Dallas and Day, 1993), change in temperature may also stem from anthropogenic causes, e.g. returning of irrigated water, stream regulation and changes in riparian vegetation. On clearing vegetation that affords shading to a river, the water is subjected to direct solar radiation, which leads to increased temperatures and greater temperature ranges and fluctuations (Dallas and Day, 1993).

It is important to include this verifier as one of the parameters which measure and monitor changes in water quality during the C&I process, since many water quality problems stem from fluctuations in temperature. The effects of temperature change on the ecological function of a water body may include, changes in population abundance and diversity, in addition to standing crop and productivity. Changes in temperature may also result in variations in dissolved oxygen, chemical toxicity and plant diversity (Dallas and Day, 1993). However, to adequately determine changes in water temperature, this characteristic would have to be monitored throughout the year. It would therefore, be impossible to include this verifier in a water quality index which rapidly determine changes in parameters as a result of variations in management practices.

Verifier 2.4.3. Colour

Pure water is not colour-less but has a pale green-blue tint when found in large volumes (Tebbutt, 1983). When monitoring changes in water colour it is necessary to differentiate between true colour due to materials in solution, and colour due to suspended matter. Water in upland catchment areas may have a natural yellow colour due to the presence of organic acids which are not in any way harmful. This may be a difficult verifier to measure in South African rivers since they are extremely varied in both physical and chemical characteristics, and their flow regime. Therefore, this characteristic was not considered as a suitable verifier of change in water quality.

CHEMICAL CHARACTERISTICS

Verifier 2.4.4. Suspended Solids

This is a useful verifier of water quality since not only does it show change in the chemical characteristics of the water body but the amount of suspended matter in rivers draining catchment areas usually reflects the degree of soil erosion (Department of Water Affairs and Forestry, 1996). Those activities which result in accelerated soil erosion will result in an increase in the suspended solid load. The environmental effects of an increase in suspended solids are similar to those given for turbidity, eg. a change in aquatic communities, decrease in light penetration and photosynthetic activity, an overall decrease in invertebrate numbers and a decline in the fish and filter-feeder populations (Dallas and Day, 1993).

Verifier 2.4.5. Deposited Sediments

The greatest source of sediments into a stream is that of soil erosion which can contribute up to 50 % of the residues found in a water body. This verifier is important to water quality since an increase in deposited sediments above natural levels may cause a decline in the health and ecological functioning of a system. Settling suspended solids in turbid water threatens the benthic aquatic communities by obscuring food sources, habitats, hiding places and nesting sites (Dallas and Day, 1993). Benthic invertebrates which prefer low-silt substrates (mayfly, stonefly, caddies) are replaced by silt-loving communities of oligochaetes, pulmonate snails and chironomid larvae (Dallas and Day, 1993). An increase in deposit sediment may also impact on the plant communities in the water body, with the primary-producer community declining due to decreased light penetration. Damage may also occur due to abrasion, souring and burying of aquatic flora. Since it would be difficult to quantify this verifier in the time allocated for the C&I process, it was rejected as a verifier of progress towards sustainable measurement of plantations.

Verifier 2.4.6. Water pH

The pH of water has a wide-ranging effect on water chemistry and therefore, on the ecological functioning of the system. It will determine which chemical compounds are found in the sample, particularly compounds such as proteins and other organic molecules which can exist either as bases or acids. The pH level will also determine which metals will be present and may therefore, alter the availability and toxicity of these substances. Non-metallic ions may also be affected by a change in pH eg. ammonium ions (Dallas and Day, 1993).

This was considered an important water quality parameter, since changes in pH from that normally encountered in unpolluted water may have severe effects on the ecological functioning of a water system, with the extent of acidification or alkalinization determining the degree of severity of these effects. Although it is not always possible to attribute it directly to lowered pH, acid streams do tend to reduce the number and diversity of invertebrates (Dallas and Day, 1993).

Verifier 2.4.7. Electrical conductivity

One of the most important measures of water quality is that of the total amount of materials dissolved in the water body. Human activities which impact on electrical conductivity include irrigating of crops, clear-felling of trees and return of sewage effluent to inland waters.

Two environmental variables which determined the communities of organisms living in a particular aquatic ecosystem are flow rate and salt concentrations, and it is for this reason that both of these verifiers were considered important when measuring water quality. The tolerance of organisms to total dissolved solids is species-specific. However, it is often the rate of change in salinity rather than the final salinity which is most critical in an aquatic ecosystem. Many organisms are able to adjust to slow changes by a process of physiological acclimation, which would not be possible if the change were rapid.

Verifier 2.4.8. Total Alkalinity

The alkalinity of water refers to the sum of carbonate, bicarbonate and hydroxyl anions of weak acids and the hydroxyl ions and bicarbonate in the water sample. If acid or alkali is added to pure water the pH may change rapidly, but if the water is not pure, the rate of change may be less rapid due to the buffering capacity of certain salts in the water.

The monitoring of this water quality characteristic during the C&I process will supply information of greater relevance than that of water pH, since buffering capacity shows the ability of a water body to neutralize the effects of the addition of acid or bases. It is therefore, this water quality parameter which determines the extent of pH change which will take place with the addition of acid or bases. This is a highly recommended measure of chemical change in water quality, and is therefore, vital to the C&I process.

Verifier 2.4.9. Dissolved Oxygen

One of the most important biotic factors relating to the survival of aquatic organisms is that of the concentration of dissolved oxygen in the water.

This verifier is vital to the ecological functioning of a system since a change in dissolved oxygen concentrations directly affect aquatic organisms, the extent of which will be determined by the dependance of the particular organisms on water as a medium. Organisms like fish which are totally dependant on water as the medium for survival will be very sensitive to low dissolved oxygen concentrations. Exposure to sub-lethal levels over a long period of time may result in changes in behaviour, blood chemistry, growth rates and food intake (Dallas and Day, 1993). Supersaturated levels of dissolved oxygen (〉 20 mg l^{-1}

but will vary with temperature) may cause gas bubble disease and mortality of fish but will have greater impacts on the less mobile life stages of organisms, e.g. eggs and fry. Other sub-lethal effects may include reduced reproduction, spawning, emergence and growth (Dallas and Day, 1993). Certain insects (e.g. mayflies, stoneflies, caddieflies) which respire though gills will be subject to the same stresses as fish.

Verifier 2.4.10. Total Nitrogen, Nitrate-N, Nitrite-N and Ammonia-N

Plant growth and reproduction requires nutrients which are made up of the elements; carbon, nitrogen, phosphorus, calcium, magnesium, sulphate and silica, as well as other elements termed micro-nutrients (Dallas and Day, 1993). Under low flow conditions, excess plant growth may follow nutrient enrichment, resulting in a change in invertebrate and fish community composition.

It is only nitrite and free, un-ionised ammonia which may have toxic effects on aquatic biotas. Toxic effects of nitrite on fish result when nitrites react with the haemoglobin to form methaemoglobin, a compound which lacks the capacity to bind oxygen. The effect is not apparent when the fish is inactive but may cause death due to anoxia during exertion. Un-ionised forms of ammonia affect the respiratory systems of many animals by inhibiting their cellular metabolisms or by decreasing the oxygen permeability of the cell membrane. Acute effects of ammonia toxicity may also induce reduction in hatching success, reduction in growth rate and morphological development, and pathological changes in tissues of gills, liver and kidneys (Dallas and Day, 1993). However, since most of the chemicals included in this water quality parameter are not toxic to aquatic biota, it is questionable whether measuring this verifier will supply any constructive information to the C&I process.

Verifier 2.4.11. Chloride ions and chlorine

Chlorine does not occur in nature but is found only as chloride ions (DWAF, 1996). Chloride ions are the major anion in many inland waters in South Africa, however, the levels found in natural water may exceed the preferred levels for plant growth (Rayment and Higginson, 1992). It is an essential constituent of living systems, being involved in ionic, osmotic and water balance of body fluids. The ions exhibit no toxic effects on living systems, except where they have impacts on the total dissolved solids in the water sample. Since this water quality parameter shows no adverse effects on the ecological functioning of a system, it was not considered an appropriate measure of sustainability and was therefore, not included in the water quality index.

Verifier 2.4.12. Phosphorous

Phosphate, limiting in freshwater aquatic systems, is a nutrient which may stimulate the growth of macrophyte and phytoplankton. An increase in the concentrations of these compounds allows plants to assimilate nitrogen in greater quantities. Higher concentrations of phosphorous are likely to occur in water that receive leaching and runoff from cultivated land (Dallas and Day, 1993). This water quality verifier was not included in the index as it was felt that it did not produce utilizable information relating to progress towards sustainable plantation management.

Verifier 2.4.13. Organic Material

Organic matter, either in dissolved or particulate forms are characteristically present in aquatic ecosystems. Organic enrichment of an aquatic system results in changes in both chemical (e.g. dissolved oxygen, nutrient levels) and physical (e.g. turbidity and suspended solids) characteristics, which in turn drive biological adjustments within the river (Dallas and Day, 1993).

The effects of organic enrichment of an aquatic system will depend on the river zone in which it occurs. An erodible upper reach or mountain catchment zone would be noticeably more sensitive to organic enrichment. Augmentation of an aquatic ecosystem with organic waste usually results in a decrease in species richness, diversity and the alteration of biotic community structure (Dallas and Day, 1993). Large increases in organic matter results in colonization of riverine systems by a greyish growth of "sewage fungus". Measurement of organic matter content during the C&I process, may supply useful information on the decomposition process taking place in a water body, and may also supply reasons for changes in biotic community structure especially in areas where harvesting has occurred. It is therefore, important to include this parameter in any water quality index which measures progress towards sustainable management.

Verifier 2.4.14. Organic pollutants

Biocides, organic pollutants, refers to herbicides, insecticides and fungicides. They enter the aquatic environment from various sources including industrial effluents (include disposal of agricultural waste), leaching, runoff from soils, and deposition of aerosols and particulates (Dallas and Day, 1993).

The nature, modes of action and toxicity of biocides vary considerably (Dallas *et al.*, 1992). Because biocides are so varied in nature and are toxic in minute quantities, their detection and quantification in aquatic systems is complex and expensive. Concentrations in the water column are often below detection limits, while they may accumulate in sediments and in the biota. It is therefore, questionable whether this verifier will give a true reflection of the organic pollutant content of a water body, and it therefore, doubtful whether it will be a constructive tool in the C&I process.

SYNTHESIS

The maintenance of water quality is critical for the conservation of the ecological values which underpin sustainable forest management. Since physical attributes and chemical constituents of natural fresh waters differ from region to region due to differences in climate, geomorphology, geology and soils, and aquatic and terrestrial biotas, it is often difficult to decided which water quality parameters should be evaluated and monitored when determining verifiers that could be applied as measure of progress towards sustainable plantation management. The ability to assess and define water quality is therefore, essential to the development, performance and evaluation of sustainable land use and management systems. Practical assessment of water quality under exotic timber requires the development of a basic water quality index of verifier which include physical, chemical and biological parameters.

Since, as yet, no verifiers have been developed at the FMU level, selection of verifiers which could be applied in industrial plantations was based on the impacts of this agricultural process on the natural resources of an area, and

Table 12: Outcome of the investigation into water quality and quantity verifiers.

Accepted Verifiers	**Impacts of change in verifier levels**	**Reason for acceptance**
Riparian buffer zones	Impact on both hydrological and ecological properties of an area	Can be directly linked to management practices and is easy to determine
Stream flow rate	Affects the ecological functioning of a water body	Plantations impact extensively on water hydrology
Bio-monitoring	Monitors the ecosystems response to disturbance	A sensitive measure, responds to changes in management practices and has cross-linkages with other indicators.
Turbidity	Impacts on the physical, chemical and biological representations of a water body	Impacts on more than one water quality characteristics.
Sus-pended sediments	Impacts on aquatic community composition, decreases light penetration, causes a decline in photosynthetic activities	Reflects change in the chemical characteristics of water and has cross-linkages with other indicators e.g. soil erosion
pH	Impacts on water chemistry e.g. determines which compounds are found in a water sample	Has severe effects on the ecological functioning of a water system
Electrical conduct-ivity	Impacts on species composition of a water system	Indicates changes in water chemistry
Total Alkalinity	Impacts on water chemistry	Shows the buffering capacity of a water body
Dissolved oxygen	Directly affects aquatic organism	Shows change in the ecological functioning of a system
Organic Material	Impacts on species richness and diversity, and may result in alteration of community structure	Can be directly linked to management activities i.e. in harvesting areas.
Rejected Verifiers	**Impacts of change in verifier levels**	**Reason for rejection of the verifier**
Temp-erasure	Impacts on population diversity and abundance, dissolved oxygen levels and toxicity of chemicals	Will required continued assessment which does not fit in with the C&I objectives
Colour	Show changes in the chemical characteristics of water	Rejected - South African rivers are extremely varied in both physical and chemical characteristics
Deposited sediments	Causes a decline in the health and ecological functioning of a system e.g affect the benthic communities	Rejected - difficulty and time required for measurement
Total N, NO_2, NO_3 & NH_4	Nitrite and unionized ammonia may be toxic to certain aquatic organisms	Rejected - not a useful measure of progress towards sustainable management and difficult to measure
Chlorine ions	Depending on the level, may impact on plant growth	Rejected - does not supply utilizable information on progress towards sustainable management
Phos-phorus	Stimulates excessive growth of macrophytes and phytoplankton	Rejected - does not supply helpful information on progress towards sustainable management
Organic pollutants	Impacts on the chemistry and biological function of a system	Rejected - difficult to measure.

those already selected by Stork *et al.* (1997) and Boyle *et al.* (In press). The relevance of each of these verifiers to the maintenance of water quality was examined, culminating in their rejection or acceptance for further investigation (Table 12). Those verifiers which were accepted from this vetting process, were presented to and evaluated by, environmentalists and forestry managers at a C&I workshop.

CHAPTER SEVEN

EVALUATION AND RANKING OF SOIL AND WATER VERIFIERS

It is important that the practicality of indicators/verifiers be assessed in a clear and rational manner and reasons for acceptance or rejection are objectively determined. Expert voting alone will not be adequate for scientific and instructive evaluation, since the decision to accept/reject an indicator/verifier may vary with a change in circumstance, for example a change in available resource and evaluating personnel. Evaluation of indicator/verifiers needs to be based on a comprehensive list of concerns, such as alternative options, cost, relation to management/stakeholder priorities, capacity to carry out the assessment, objectivity and uncertainties in using these data.

It was for this reason that both environmentalists and plantation managers were included in a C&I evaluation workshop which was run in conjunction with two of the largest exotic timber growers in South Africa, i.e. Mondi and SAPPI. At the workshop, the representatives from these companies were introduced to the concept of C&Is and the role that these processes could play in the South African framework. The original set of twenty-six soil and eighteen water verifiers was narrowed down into a subset of eleven each for soil and water (Tables 13 and 14). The sub-set of criteria, indicators and verifiers was by no means a conclusive set, but was selected based on how vital they were perceived to be in evaluating progress towards sustainable management of industrial plantations. The range of questions which was asked were also not conclusive, but was selected to closely mirror those chosen by Boyle *et al.* (in press).

Unfortunately, since the workshop was held before the completion of the previous two chapters, some of the verifiers presented should not have been included, while others which were accepted in the previous chapters have been omitted. There are therefore, small discrepancies between the verifiers accepted in the previous chapters and those presented at the workshop.

Table 13: Concise set of soil indicators and verifiers

INDICATOR	VERIFIER
1.1. No significant variation in the physical redistribution of soil	1.1.1. Area and Percent of land with significant soil erosion.
1.2. No significant variation in levels of soil organic matter and/or changes in other chemical properties	1.2.1. Total organic carbon and nitrogen.
	1.2.2. Soil pH
	1.2.3. Mineral nitrate and nitrite
	1.2.4. Available phosphate
	1.2.5. Exchangeable base cations.
1.3. No significant variation of soil physical properties	1.3.1. Bulk density
	1.3.2. Soil strength
	1.3.3. Aeration
	1.3.4. Water content
1.4. No significant variation in the accumulation of persistent toxic substances	1.4.1 Organic pollutants and heavy metals.

Table 14: Concise set of water indicators and verifiers

INDICATOR	VERIFIER
2.1. Area and percent of land managed primarily for protective functions	2.1.1. Width of riparian buffer zones
2.2. Stream flow and timing has not significantly deviated	2.2.1. Stream flow rate
2.3. No significant variation of biological diversity	2.3.1. Biomonitoring
2.4. No significant change in physical and chemical characteristics	2.4.1. Water turbidity
	2.4.2. Water pH
	2.4.3. Electrical conductivity
	2.4.4. Dissolved oxygen
	2.4.5. Total Alkalinity
	2.4.6. Nitrogen
	2.4.7. Phosphates
	2.4.8. Organic Pollutants

The participants of the workshop were asked to evaluate the sub-set of indicators and verifiers according to the nine questions listed below. Each verifier was appraised according to a scale of 1 to 5, where 1 was the negative extreme and 5 the positive extreme. Assessment of the verifiers was done in relation to the following aspects:

1. **Easy to detect, record and interpret**
   - **Difficulty?:** How easy would it be to collect these data?
   - **Analysis?:** How easy would it be to analyze the data?
   - **Accessibility?:** How accessible are these data? Have they already been collected?
2. **Relevance?:** Relevance to biodiversity conservation?
3. **Unambiguously related to the assessment goal?:** Is it closely related to its assessment goal?
4. **Precisely defined?:** Is the meaning clear? Is the definition precise?
5. **Diagnostically specific?:** Does the verifier tell us something about the indicator it relates to?
6. **Reliability?:** How reliable do you think this test is?
7. **Sensitivity?:** How sensitive is the verifier to impacts on ecological systems?
8. **Provides a summary or integrative measure?:** Does it sum up or integrate a lot of information?
9. **Accountability?:**Do you think your company is responsible for monitoring this indicator?

The scores obtained from the eleven workshop participants were totalled, with the maximum value obtainable being 55. A very simple analysis of the results was carried out, with no weighting of assessment categories. The scores for each water and soil verifiers are shown in Figures 6 and 7.

For each verifier, the scores of the questions were totalled and averaged, to determine which areas the delegates felt were unimportant to that particular verifier (Table 15 & 16). The assumption was made, that any question scoring below 2.5 (50% of the maximum), was considered by the delegates as an area of little interest or unimportant to the process. The coefficient of variation (CV) for each average score was calculated as a more useful measure of precision (Table 15 & 16) . Those questions which obtained a low value of CV showed a high precision of measurement, indicating that participants were in agreement on the importance/unimportance of the question. While those which obtained a high value of CV showed low precision of measurement, indicating that participants could not agree on the importance/unimportance of the question and it should therefore, be ignored. These CV values supply an additional statistical way of determining the perceived value of a verifier to the workshop participants.

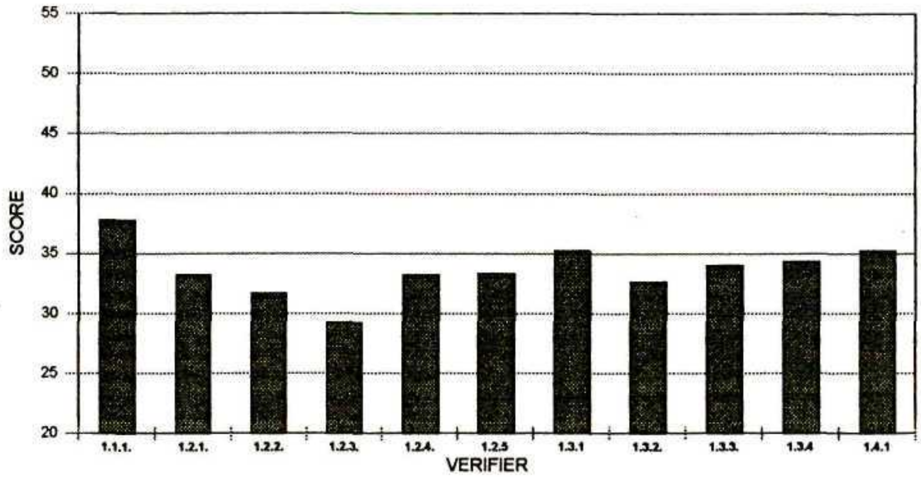


Figure 6: Score of soil verifiers as obtained at the C&I workshop

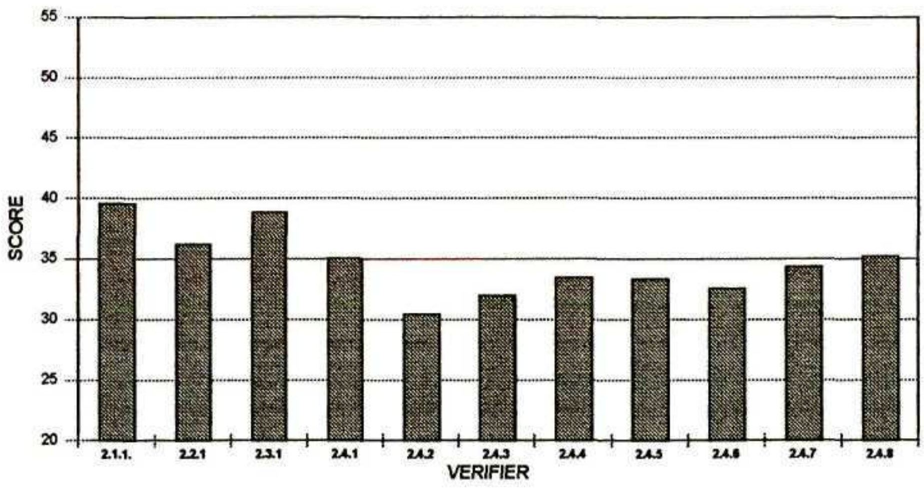


Figure 7: Score of water verifiers as obtained at the C&I workshop

Table 15: Average scores (n = 11) for each question of the different soil verifiers. Bolded figures indicate those questions which scored below 50 % of the maximum value (5). Bracketed figures indicate the coefficient of variance for each question, given as a percentage.

Question	Verifier										
	Erosion	Total C and N	pH	Mineral NO_3 & NO_2	Available P	Exchange-able cations	Bulk density	Soil strength	Aeration	Water content	Pollutants
Difficulty	3.36 (29)	3.27 (23)	3.45 (19)	3.18 (26)	3.18 (22)	3.18 (22)	2.91 (23)	3.36 (14)	3.27 (32)	3.45 (23)	3.27 (29)
Analysis	3.18 (26)	3.36 (19)	3.45 (19)	3.09 (29)	3.27 (23)	3.36 (23)	3.18 (26)	3.45 (26)	**2.45** (29)	3.45 (31)	3.36 (14)
Accessibility	2.55 (42)	2.55 (31)	2.73 (27)	**2.45** (32)	2.64 (29)	2.73 (27)	**2.45** (40)	2.73 (42)	2.55 (45)	2.55 (42)	**2.18** (33)
Relevance	3.64 (27)	2.91 (34)	2.73 (32)	2.36 (41)	3.09 (29)	3.09 (29)	3.36 (29)	2.73 (32)	2.73 (35)	2.91 (34)	3.27 (29)
Unambiguous	3.82 (19)	3.09 (17)	3 (28)	2.64 (29)	3.09 (26)	3 (20)	3.36 (19)	3.09 (22)	3.18 (18)	3.18 (18)	3.73 (12)
Precisely defined	3.73 (17)	3.27 (23)	3.27 (19)	3.27 (14)	3.36 (14)	3.36 (14)	3.55 (14)	3.18 (22)	3.45 (14)	3.55 (14)	3 (28)
Diagnostically specific	3.55 (18)	3.27 (26)	3 (38)	2.73 (35)	3.27 (29)	3.36 (23)	3.64 (21)	3.27 (29)	3.64 (18)	3.36 (32)	3.36 (19)
Reliability	3.27 (23)	3 (28)	2.91 (37)	2.82 (33)	3.18 (26)	3.09 (22)	3.36 (19)	3.36 (26)	3.36 (19)	3.09 (32)	3.55 (18)
Sensitivity	3.36 (34)	2.91 (23)	**2.36** (41)	**2.27** (42)	2.55 (42)	2.55 (31)	3.18 (22)	2.82 (14)	2.82 (20)	2.91 (23)	2.91 (31)
Integrative measure	2.91 (27)	**2.36** (27)	**2.18** (43)	**1.91** (35)	**2.36** (37)	**2.45** (32)	2.73 (27)	**2.45** (27)	**2.45** (27)	2.64 (29)	2.64 (24)
Accountability	4.45 (15)	3.27 (26)	2.64 (41)	2.55 (45)	3.27 (32)	3.18 (29)	3.55 (25)	3 (40)	3.09 (40)	3.27 (39)	3.73 (34)

Table16: Average scores (n=11)for each question of the different water verifiers. Bolded figures indicate those questions which scored below 50 % of the maximum value (5). Bracketed figures indicate the coefficient of variance for each question, given as a percentage.

Question	Verifier										
	Width of Riparian Zone	Stream flow	Biological diversity	Turbidity	pH	Conduct	Dissolved O	Alkalinity	N	P	Pollutants
Difficulty	3.55 (22)	3.36 (29)	3.09 (26)	3 (25)	3.09 (29)	3.27 (26)	3.18 (26)	3.36 (26)	3.09 (29)	3.27 (26)	2.73 (27)
Analysis	3.45 (29)	2.73 (39)	3.36 (23)	3.36 (23)	3 (32)	3.27 (26)	3.27 (29)	3.45 (23)	3.27 (32)	3.45 (26)	3.09 (26)
Accessibility	3.36 (32)	**2** (43)	**2.18** (33)	**1.91** (35)	**1.91** (35)	**2.09** (38)	**2** (37)	**2.36** (45)	**2.18** (43)	**2.27** (50)	**2.27** (42)
Relevance	3.73 (20)	3.82 (15)	3.82 (15)	3 (35)	2.55 (42)	2.91 (31)	3.18 (35)	2.91 (27)	2.82 (30)	3.09 (26)	3.82 (22)
Unambiguous	3.64 (18)	3.64 (21)	3.55 (14)	3.18 (29)	3 (20)	2.91 (23)	3.27 (19)	3.09 (17)	2.91 (18)	3.09 (17)	3.45 (19)
Precisely defined	3.64 (24)	3.18 (29)	3.73 (17)	3.64 (18)	3.18 (18)	3.18 (22)	3.18 (18)	3.18 (22)	3.09 (22)	3.45 (19)	3.45 (19)
Diagnostically specific	3.45 (19)	3.45 (23)	3.64 (18)	3.55 (25)	2.64 (33)	2.82 (25)	3 (25)	3 (25)	2.91 (23)	3.36 (19)	3.27 (23)
Reliability	3.45 (19)	3.36 (19)	3.73 (17)	3.18 (18)	2.73 (39)	3.09 (26)	3.36 (19)	3.18 (29)	3.27 (23)	3.27 (19)	3.18 (26)
Sensitivity	3.64 (29)	3.64 (24)	3.91 (17)	3.45 (26)	2.64 (37)	2.82 (33)	3.09 (22)	3 (25)	3 (25)	2.91 (23)	3.36 (19)
Integrative measure	3.36 (29)	3.18 (26)	4 (21)	3.18 (26)	2.64 (29)	2.55 (20)	2.73 (23)	2.73 (16)	2.82 (14)	3 (14)	3.27 (19)
Accountability	4.27 (22)	3.82 (19)	3.82 (22)	3.45 (26)	3.09 (35)	3.09 (35)	3.18 (32)	3.09 (32)	3.18 (32)	3 (35)	3.09 (35)

EVALUATION OF SOIL INDICATORS AND VERIFIERS

Indicator 1.1. No significant variation in the physical redistribution of soil

Issues

- A number of agents affect soil erosion i.e. fire, grazing, roading, harvesting and soil disturbance/cultivation;
- The measurement of this indicator is important for hydrology/productivity/carbon cycling and most ecosystem functions;
- Extreme events are fundamentally linked to deterioration of water quality;
- The existence of the sedimentation source will vary temporally, e.g. the first few years after harvesting soil losses will be significant, while roads will erode for decades;
- It is important to determine the relationship between erosion quantity and environmental effects;
- The definition of the term 'significant' must be agreed upon (Australian Framework, 1998).

Workshop results

Representatives at the C&I workshop were divided on the significance of this indicator. Those that felt it was an important soil quality parameter, suggested two reasons, i.e. it impacted on productivity and it was their moral responsibility to ensure that erosion be controlled. Those that felt that it was not a relevant indicator, cited the fact that plantations did not show significant soil erosion as the reason.

Verifier 1.1.1. Area and Percent of land with significant soil erosion

Methods

Spatial analysis using Geographic Information Systems (GIS).

Workshop results

Despite disagreement (shown by the varied CV values obtained for each question) on the significance of the indicator, the verifier obtained the highest score of all the soil quality parameters (37.81). Representatives voiced concern about; the number of measurements required for reproducible results, the scale of measurement, and the time required for the assessment of this verifier. From the evaluation of the questions, it was clear that the participants felt that it was important that their company be accountable for monitoring this indicator (the low CV value of 15 % shows that the participants were in agreement on the importance of this question to the verifier).

Indicator 1.2. No significant variation in levels of soil organic matter (SOM) and/or changes in other chemical properties

Issues

- Soil organic matter may change spatially and temporally, making measurement difficult;
- Since SOM is linked to nutrient and carbon storage, it affects soil physical and hydrological properties and provides a substrate for soil biotas. It is therefore, important to maintain and managed SOM cautiously. The use of this indicator as a surrogate measure of other forest values, (e.g., soil density and hydrological properties, diversity of soil organisms, potential forest productivity) should be explored;
- Issues such as soil measuring depth, number of measurements and scale of assessment have to be resolved;
- It is also necessary to establish links between SOM and other ecosystem processes;
- It would be impractical to measure this indicator at many locations, therefore methodologies should be developed to locate representative reference/monitoring sites (Australian Framework, 1998).

Verifier 1.2.1. Total organic carbon and nitrogen

Methods

The determination of the total organic carbon content of soils is carried out by wet or dry combustion (Jackson, 1958, Nelson and Sommers, 1982). Nitrogen testing has been based on measurement of organic matter content, nitrate content and the rate of nitrogen mineralization from organic matter. The design of an effective test for available nitrogen is difficult since climatic factors have a bearing on the release of these compounds (Jackson, 1958). The determination of this verifier is therefore, usually carried out in a laboratory.

Workshop Results

This verifier obtained a low score (33.27) relative to the other soil quality parameters evaluated. Some concern was expressed at the cost of measurement of this soil quality characteristic. There was also some debate as to whether this verifier supplied information relevant to sustainable plantation management. The investigation of alternative verifiers was therefore, suggested, e.g. rate of decomposition of organic matter. In the evaluation of the questions, representatives showed little interest in this verifier as an integrated measure of sustainability (scored below 2.5).

Verifier 1.2.2. Soil pH

Method

Soil pH is determined potentiometrically in a slurry system using electrodes and a pH meter (Tan, 1996,). Soils pH may be determined in a slurry of 1:2 soil/water mix or if the presence of soil salts is high then it may be measured in a mixture of soil and 0.01 *M* calcium chloride ($CaCl_2$)(Tan, 1996, The Council on Soil Testing and Plant Analysis, 1980).

Workshop results

This verifier obtained the second lowest value of the soil quality parameters evaluated during the C&I workshop. Representatives indicated that, since this verifier did not take into account the buffer capacity of the soil it was of little purpose to the C&I process. Suggestion was made that more applicable verifiers be investigated, e.g. buffer capacity of a soil. In the evaluation of questions the delegates considered the sensitivity and integrativeness of this verifier as unimportant (scored 2.45 and 2.36 respectively).

Verifier 1.2.3. Mineral nitrate and nitrite;

Verifier 1.2.4. Available Phosphate; and

Verifier 1.2.5. Exchangeable base cations

Method

These verifiers are usually determined in the laboratory, but soil field test kits may also be used.

Workshop results

This nitrate/nitrite verifier obtained the lowest score (29.27) of all the possible soil verifiers. Available phosphate and exchangeable base cations scored average results of 33.27 and 33.36 respectively. Simpler techniques of measurement were suggested, and again the problem of scale of assessment, number of sites, and time of measurement, were commented on. From the evaluation of questions, delegates considered the nitrate/nitrite verifiers as unimportant in the areas of accessibility of data, relevance, sensitivity of measurement and integrativeness. The exchangeable cation and phosphorus verifiers also performed poorly in the area of integrativeness (2.45).

Indicator 1.3. No significant variation of soil physical properties

Issues

- The consequence of physical changes in soil will differ spatially, e.g. change will have greater impact in harvested areas than in access/infrastructure areas (roads, tracks). It is therefore important to determine the proportion of the plantations which are taken up by access/infrastructure areas;
- Harvesting systems are crucial to the physical properties of the soil. Therefore, careful planning of harvesting may reduce the potential impacts of the process;
- Since soil moisture content will determine the extent of impacts of management practices on soil physical properties, damage may be minimized by avoiding traffic on wet soils;
- Links should be established between changes in soil physical properties, stand growth on different soil types, and processes such as; infiltration of water, establishment of new tree seedlings, and root growth (Australian

Framework, 1998).

Verifier 1.3.1. Soil Bulk Density

Method

Bulk density is calculated using the dry-weight and volume of a soil sample.

Workshop Results

Bulk density scored the second highest value (35.27) of all the soil verifiers. Although this verifier scored a high value, it performed poorly with reference to the question of accessibility of data.

Verifier 1.3.2. Soil Strength

Method

The degree of compaction of a soil can be measured by the number of blows or given weight required to drive a spike down a given number of centimetres (Leeper and Uren, 1993). Similarly, a penetrometer gives a measure of the resistance of soil to deformation or soil strength.

Workshop Results

This verifier scored one of the lowest values (32.64) at the C&I workshop. Measurement of this verifier is dependent on a number of factors, i.e. soil strength increases with an increment in bulk density and a declines in the soil water content, except where soils become very dry. This relationship between soil strength, bulk density and water content was also affected by the clay content of the soil and the levels of organic carbon present. Representative evaluated this verifier as unimportant with reference to the question of integrativeness of measurement.

Verifier 1.3.3. Aeration;

Verifier 1.3.4. Soil Water Content.

Methods

Porosity is determined by dividing the volume of pore spaces of a soil sample with the volume of the core sample itself. Water content is determined by dry and wet weight of a soil sample.

Workshop Results

The aeration verifier scored 32.64, while water content obtained a value of 34. Some concern was expressed relating to the complexity of sampling soil water content, e.g. it is often difficult to determine whether a soil is saturated. In the evaluation of questions, representatives considered the aeration verifier as unimportant with reference to the question of ease of analysis and integrativeness of measurement.

Indicator 1.4. No significant variation in the accumulation of persistent toxic substance.

Issues

- With increased runoff, erosion and sedimentation, this indicator may impact on water quality (Australian Framework, 1998).

Verifier 1.4.1. Organic pollutants and heavy metals

Methods

Levels of pollutants in the soil are usually determined in the laboratory but in some instances soil test kits may also be used.

Workshop Results

This verifier was rated as the second most important by the workshop representatives (35.27). Delegates considered this verifier as unimportant with reference to the question of accessibility of data.

EVALUATION OF WATER INDICATORS AND VERIFIERS

Indicator 2.1. Area and percent of land managed primarily for protective functions

Issues

- This indicator is associated with land which has multiple functions, e.g. in plantations where riparian zones and wetlands are protected for their role in maintaining water and soil quality;
- The indicator is linked to management actions, can be measured, is

relatively inexpensive to monitor, and can be replicated;

- Requires a database which is transparent and integrated;
- It is often difficult to differentiate between environmental and management determinants of temporal changes in protected areas;
- It is also often difficult to verify that management prescription led to protection of soil and water resources;
- May ignore or exclude areas which need to be protected (Australian Framework, 1998).

Verifier 2.1.1. Width of Riparian Buffer Zones

Method

Determination of buffer zones can be done using the Bosch model which provides three methods - computer models, manual procedures or quick methods to determine the minimum management widths.

Workshop Results

The representatives at the C&I workshop viewed this verifier as the most important (39.55) of all the water quality parameters. It was mentioned that the Bosch model was being reviewed and could possibly be discontinued. It was very clear from the evaluation of the questions that the representatives felt it was important that their company be responsible for monitoring this verifier (scored 4.27). This may be due to the fact that the verifier can be directly linked to management activities, and can be easily observed and monitored.

Indicator 2.2. Stream flow and timing has not significantly deviated

Issues

- There is significant temporal and spatial variation in stream and river flow. It is therefore, often difficult to attribute change to environmental factors or management practices;
- There are a number of different factors which affect this indicator. It is often not clear whether the indicator intends to measure the impacts of changes due to river regulation or due to changes in forest cover;
- It may be difficult to directly associate changes in flow with the management

of the plantation estate since alterations in management actions outside the estate will also impact on this indicator;

- This indicator must be considered in conjunction with changes in biological diversity, and changes in physical and chemical characteristics;
- Research needs to be carried out to summarize and analyse historical flow data of South African rivers (Australian Framework, 1998).

Verifier 2.2.1. Stream flow rate

Method

The simplest method of determining current velocity is to place a float (eg. an orange) in the water and measure the time it takes to travel a predetermined distance (Jones and Reynolds, 1996). This is a very simple and cheap method but only measures the velocity of the surface water. It gives crude results when there are eddies and fluctuations in the velocity of a stream. A more precise method of measuring stream flow is that of a flow meter, which converts the speed of rotations of impellers to current velocity and gives readings from a specific depth or part of a stream (Jones and Reynolds, 1996).

Workshop Results

This verifier was displayed as the third most important of the water verifiers (36.18). However, concern was expressed as to the scale of measurement of this verifier, and how variations in timing of flow could be linked directly to management practices. Concern was also expressed as to when measurement would be taken since flow varies seasonally. This verifier performed poorly against the question of accessibility of data (2.00).

Indicator 2.3. No significant variation of biological diversity

Issues

- South Africa is diverse in climate, geomorphology, geology and soils, which results in different regions exhibiting considerable variation in water quality. Since the species of organisms that comprise an aquatic biological community are determined by water quality, there is great regional variation in the aquatic biotas which make up riverine communities. It is therefore, difficult to use the biotas of an undisturbed stream in one area as a reference site of a disturbed stream in another;

- Since species have natural tolerance limits for any water quality variable, a greater and greater change in water quality will gradually alter the constituent species of a biotic community until it is no longer recognizable as the same community (Dallas and Day, 1993). It would be impractical to monitor and report changes in an entire suit of biological diversity therefore, a representative sub-set of biotas should be monitored as a surrogate;
- To establish baseline data and historical records which are required for the measurement of variances, a historical record of traditional usages/volume of use should be determined;
- This indicator should be linked to those indicators which measure changes in soil erosion and variance in areas preserved for their protective functions, when establishing the sensitivity of this indicator to natural and human impacts;
- This indicator should be developed as a diagnostic tool which can be directly linked to management impacts (Australian Framework, 1998).

Verifier 2.3.1. Biomonitoring

Methods

Biomonitoring makes use of the biological responses of aquatic organisms to assess change in the water environment. In South Africa the SASS (South African Scoring System) is used to determine and rate the presence/abundance of specific aquatic organisms.

Workshop Results

This verifier scored the second highest value (38.82) of the water verifiers. Both SAPPI and Mondi representatives acknowledged that their companies had contracted out the overseeing of water quality using Biomonitoring. Some concern was expressed that the information supplied from this process would not be relevant, since change in aquatic biotas could often not be directly linked to management practices in the FMU. From the evaluation of the questions, this verifier performed poorly with reference to the accessibility of data.

Indicator 2.4. No significant change in physical and chemical characteristics.

Issues

- Levels of sediments in a water body affect most of the physio-chemical properties;
- Reforestation of exposed soils may have a positive impact on water quality;
- Movement of chemicals through runoff may affect water quality. However, it is often difficult to link the source of chemicals directly to management of the FMU, since practices outside this area may also play a role;
- The levels of pollutant chemicals in water should be linked to the soil indicator which measures change in organic pollutants (Australian Framework, 1998).

Verifier 2.4.1. Water Turbidity

Method

Light penetration is usually measured by visual observation or using a light probe, spectrophotometer or turbidity meters. An old, much utilized method of determining transparency is that of the Secchi disc. The disc is lowered into the water and the depth at which it disappears (approximately 5 % sunlight penetrates) is measured. A turbidity meter quantifies the degree to which the light travelling though the water column is scattered by suspended organic and inorganic particles.

Workshop Results

This verifier scored an average value of 35 at the workshop. A suggestion was made that this verifier be linked with the soil erosion indicator since in many cases, increased sedimentation can be attributed to an increment in runoff and erosion. In the evaluation of question, the verifier performed poorly against the question of accessibility of data.

Verifier 2.4.2. Water pH

Method

The pH of water may be determined using indicator paper or electronically using a pH meter and electrodes (The Council on Soil Testing and Plant Analysis, 1980). The use of a pH meter allows the measurement of pH directly in the field.

Workshop Results

Water pH scored the lowest value (30.45) of all the water verifiers. Once again the representative felt that even though this parameter is easy to measure, it does not supply useful information. In the evaluation of the questions, this verifier performed poorly with reference to accessibility of data.

Verifier 2.4.3. Electrical Conductivity;

Verifier 2.4.4. Dissolved Oxygen;

Verifier 2.4.5. Total Alkalinity;

Verifier 2.4.6. Nitrogen; and

Verifier 2.4.7. Phosphates.

Methods

All of these verifiers can be determined by either using hand-held meters (e.g. electrical conductivity, dissolved oxygen), water test kits (e.g. total alkalinity, nitrogen, phosphates) or in the laboratory.

- Electrical conductivity may be measured using a conductivity meter (Rayment and Higginson, 1992).
- The alkalinity of a water body is measured in the laboratory by chemical titration of a sample with hydrochloric acid (Rayment and Higginson, 1992).
- Levels of dissolved oxygen may be determined chemically or using an oxygen electrode (Jones and Reynolds, 1996). The chemical methods are more accurate but more time-consuming.
- The level of total nitrogen in water is usually determined in a laboratory making use of the Kjeldahl digestion process (Rayment and Higginson, 1992).
- Ammonium and nitrate concentration may be determined by chemical analysis in the laboratory or by using electronic probes in conjunction with a pH meter, (Jones and Reynolds, 1996). This method is faster than chemical analysis but the detection limits of the probes may be too high to measure the low concentrations of ammonium and nitrate usually found in water.

- Water testing kits may also be used, but these are less precise and constrained to a narrow detection range with high detection limits.
- Total phosphorus levels are usually determined in the laboratory by a two procedural process; 1) conversion of phosphorus into dissolved orthophosphate by digestion and 2) colourimentric evaluation of the dissolved orthophosphate concentration.

Workshop Results

All five of these verifiers scored very similar values, ranging from 34.36 (phosphate) to 32 (electrical conductivity). Some concern was expressed as to the relevance of some of these verifiers and the costs involved in testing in the laboratory. From the evaluation of the questions, all these verifiers performed poorly with reference to accessibility of data.

Verifier 2.4.8. Organic pollutants

Methods

Levels of organic pollutants will have to be determined in the laboratory or using a water test kit. Biocide effects on aquatic ecosystems may be measured using a number of techniques e.g. residue levels, bioaccumualtion and tolerance limits (Dallas and Day, 1993). Residue levels are fixed indices of dynamic processes which provide useful information of the influence of biocide contamination on the aquatic environment. This technique identifies the biocides which are the major contaminants and provides useful measures of the relative influence. It may also indicate the types of organisms that are most likely to accumulate residues.

Workshop Results

This verifier scored quite high (35.18) for this particular indicator. Once again, in the evaluation of questions, this verifier performed poorly with reference to accessibility of data (2.27).

RANKING OF VERIFIERS

From the evaluation process of the C&I workshop, the soil and water verifiers could be ranked, starting with the one which was perceived as most important to the C&I process (listed as 1), to the one which was believed to be least important to this process (listed as 11) (Table 17 & 18).

Table 17: Ranking of soil verifiers using the results from the C&I workshop

IMPORTANCE	VERIFIER
1	Area and Percent of land with significant soil erosion
2 & 3	Organic pollutants and heavy metals, and Soil Bulk Density
4	Soil water content
5	Aeration
6	Exchangeable base cations
7 & 8	Organic Carbon and Nitrogen, and Available Phosphate
9	Soil Strength
10	Soil pH
11	Mineral nitrate and nitrite

Table 18: Ranking of water verifiers using the results from the C&I workshop

IMPORTANCE	INDICATOR
1	Width of riparian zones
2	Biomonitoring of aquatic biological diversity
3	Stream flow rate
4	Organic pollutants
5	Turbidity
6	Phosphate
7	Dissolved oxygen
8	Total alkalinity
9	Nitrogen
10	Electrical conductivity
11	pH

This ranking system could be used to conceptualize the testing of soil and water C&Is. Since verifiers which appear at the top of the lists are those which environmentalists and managers view as important in the assessment of progress towards sustainable plantation management, field testing should commence with these. The verifiers lower down on the scale, should either be further investigated to determine alternative means of measurement if they form an essential part of a suite of C&Is, or they should be discarded.

SYNTHESIS

A number of soil and water verifiers were evaluated by representatives from two exotic timber growing companies in South Africa. Delegates were asked to give each verifier a score between 1 and 5 when answering a number of questions. The results of the workshop were used to rank verifiers, commencing with the verifier which was classified as the most important to the C&I process, and ending with the one of least importance. Since this ranking system clearly shows those verifiers which environmentalists and managers view as important in the assessment of progress towards sustainable plantation management, this scale could be utilized to conceptualize the testing of soil and water C&Is. Those verifiers at the top of the scale should be field tested, while those lower down should either be re-assessed for alternative means of measurement if they are perceived to form an essential part of a suite of C&Is, or should be discarded.

RECOMMENDATIONS AND CONCLUSION

Development of criteria and indicators at a national scale

- Technical and financial assistance in support of the implementation of criteria and indicators for sustainable plantation management should be encouraged, improved and broadened by the South African government. In order to promote the development of C&Is there is a need to provide guidance and to facilitate scientific collaboration in new and ongoing initiatives, building on experience already gained;
- linkages should be established between international initiatives (i.e. Montreal, Helsinki, Tarapoto, Dry-zone Africa and ITTO processes) on C&Is for sustainable forest management and the different processes and policies relating to plantation forestry in South Africa. Close linkages could be forged with actions taken in response to Agenda 21 and within the framework of international Conventions to which South Africa is a signatory e.g. Convention of Biodiversity;
- there is a need to address the common understanding of the terms, concepts and processes related to the development and application of C&Is as soon as possible, e.g define the essential terms, determine the units of measurement and critical thresholds, decided on the method of data assembly, storage, accessibility and dissemination, determine methods for measurement and recording, and select indicators;
- research on the development of C&Is should concentrate on approaches to effectively gathering information relating to soil and water conservation; predicting impacts of human intervention on the natural resources; developing C&Is at the FMU level (i.e. planting exotics); developing methodologies for aggregating data from the forest management unit levels to higher levels; and determining impacts of different forest management systems on SFM.

Developing C&Is at the FMU levels for use in industrial plantations

- In choosing indicators of soil and water quality, information managers should: define the audience to be reached, its level of technical expertise, and its information needs. They should also determine not only what kinds of data should be presented through indicators, but also the number of indicators that are to be presented, and the degree to which indicator information should be aggregated and the reporting units to be used.

- further research is needed on those indicators and verifiers which obtained low scores at the C&I workshop. They should either be discarded or, if they are an essential part of a suite of indicators and verifiers then further investigation is required to determine alternative methods of measurement;
- indicators and verifiers which were accepted at the C&I workshop need to be tested in the field. Once indicators have been developed, information managers should vet these indicators with individuals representing a sample of the target audience(s). The objective of this step is to ensure that these indicators effectively answer users' questions (and also that indicators are understood, that the reporting units are appropriate, that thresholds and benchmarks are intuitive, etc.);
- researchers need to investigate the use of remote sensing and GIS as means of producing spatial estimates for some of the indicators;
- there is a need to develop relationships between management practices, environmental effects, and other ecosystem processes;
- determination of the spatial and temporal scale of measurement, and the method and duration of assessment is vital to the C&I process;
- scientists in conjunction with managers and major stakeholders need to determine the acceptable levels of change, the thresholds, targets and benchmarks that are to be used in constructing indicators;
- it is essential to develop methodologies to locate representative reference/monitoring sites;
- developers of C&Is need to consult with major stakeholders once the C&Is for plantations have been selected to determine that the presentation formats can effectively communicate information to this target audience.

Implementation of C&Is at the FMU level

- The primary consideration in the application of C&Is are the extent of the FMU and its internal variability. It is therefore, important to first compile as much information available on management plans, FMU boundaries, vegetation types, vegetation structure, historic and current areas of intervention, inventory data, contours, streamlines and other physical element, and roads, settlements and other infrastructural element;

- the basic set of C&Is which has been develop must be adjusted to suit the region or area. For different interventions there will be different suites of indicators;
- attention must be given to where these indicators are to be applied within the FMU;
- since most environmental indicators have only recently been developed they should be considered as being in an experimental phase. It is important that indicators be tested against the wider phenomena they are intended to represent or summarise so that they can be relied upon. As with any such process, this testing can be expected to lead to modification, refinement, or even the abandoning of some indicators if they are found to be unreliable;
- not all criteria will be measurable by indicators, and of those that are so measurable, not all can be measured directly. For example, in defining criteria to assess forest condition, some of these criteria might best be answered qualitatively (e.g., whether indigenous vegetation areas are "pristine"), others can be captured directly through indicators (e.g., plantations as a percent of total forest cover, as a measure of naturalness), and others can only be measured indirectly (percent of plantation covered by roads, as an indirect measure of human disturbance).

CONCLUSION

Criteria and indicators are useful tools, designed to support the improvement of the quality of forest management as an integral part of the sustainable development of the nations in which they occur. They accomplish this by providing a measure of the state of forests and their management, and therefore, may be used to assess progress towards the achievement of sustainable forest management.

The potential benefits of using C&Is are evident: (1) internationally they broaden the basis of information and understanding about the quality of forestry practices; (2) at a national level they are a guide in developing and revising policies and legislation, and in the formulation and refinement of national forest programs; and (3) at the forest management unit levels they assist in the assessment of the outcome of forest management and in providing a basis for its continuous improvement. It is important to include linkage between each of these levels when developing C&Is.

Many countries and organisations seek practical means and ways to sustainably manage all types of forests. These efforts include, the development and implementation of guidelines and criteria and indicators (C&Is) for sustainable forest management. Since South Africa lags behind in the development of C&Is for plantation forest, it is important that they concentrate on this process in their attempts to achieving the goal of sustainable forestry management.

The development and implementation of C&Is is a dynamic process. Indicators and verifiers must be continually refined in response to changing public preferences, new scientific information, growing experience within countries and the exchange of experience between them. Since adaptive management is an essential tool for evaluating and integrating the complex issues surrounding natural resource management it would be best to concentrate on incorporating these procedures in the formulation of C&Is. When properly integrated, the C&I process will be continuous and cyclic as it evolves from new information gained and with changes in social and ecological systems. As a result, the C&I processes will be flexible and innovative, outcomes will be more sustainable and have greater acceptance with stakeholders. The C&I concept will be a holistic management system, based on good science and include critical evaluation of each step of the process.

On evaluation of a number of soil and water verifiers by representatives from two exotic timber growing companies in South Africa, verifiers could be ranked with reference to; easy of assessment, relevance, ambiguity, reliability, sensitivity, integrative measure and accountability. Through the ranking process, representatives indicated that they viewed the area and percent of land with significant soil erosion as the most important to measuring change in soil quality. They also placed organic pollutants and heavy metal, soil bulk density, soil water content and aeration in the top half of the ranking of important verifiers of progress towards sustainable plantation management. With reference to water quality, representatives evaluated the width of riparian zones as most important, followed by biomonitoring, stream flow, organic pollutants and turbidity. This ranking system could be used to conceptualize the testing of soil and water C&Is. Since verifiers which appear at the top of the lists are those which environmentalists and managers view as important in the assessment of progress towards sustainable plantation management, field testing should commence with these. The verifiers lower down on the scale, should either be further investigated to determine alternative means of measurement if they form an essential part of a suite of C&Is, or should have to be discarded.

APPENDIX A

SASS 4 Score Sheet

Version 1 31/07/96

UMGENI WATER•AMANZI

River.. Date: / /9
Sample point no..................
Sample point description:..

Temp (C)................. DO:...............

Biotopes sampled:

SIC .... Time.................minutes
Marginal veg'n............ Dom. sp...
Aq. veg'n............ Dom. sp...
SOOC.................. Sand................
Mud................... Gravel..............
Bedrock.............. Other..

Flow regime:
low.........medium...........high.........flood.........

Turbidity:
low...........medium..........high...........

Riparian land use: eg. industrial, cattle farming, etc.

Disturbance in the river: eg. sandwinning, cattle drinking point, etc.

Signs of pollution: eg. smell of water, petroleum, dead fish, etc.

Other observations

✓	Taxon	Score	Abun
	Porifera	5	
	COELENTERATA		
	Hydra sp.	1	
	Planarians	5	
	ANNELIDA		
	Oligochaeta	1	
	Leeches	3	
	CRUSTACEA		
	Amphipoda	15	
	Crabs	3	
	Shrimps	8	
	HYDRACARINA		
	Hydrachnellae	8	
	PLECOPTERA		
	Notonemouridae	12	
	Perlidae	12	
	EPHEMEROPTERA		
	Polymitarcyidae	10	
	Ephemeridae	15	
	Baetidae 1sp	4	
	Baetidae 2 sp	6	
	Baetidae > 2 sp	12	
	Oligoneuridae	15	
	Heptageniidae	10	
	Leptophlebiidae	13	
	Ephemerellidae	15	
	Tricorythidae	9	
	Prosopistomatidae	15	
	Caenidae	6	
	ODONATA		
	Chlorolestidae	8	
	Lestidae	8	
	Protoneuridae	8	
	Platycnemidae	10	
	Coenagriidae	4	
	Calopterygidae	10	
	Chlorocyphidae	10	
	Zygoptera juvs.	6	
	Gomphidae	6	
	Aeshnidae	8	
	Corduliidae	8	
	Libellulidae	4	

✓	Taxon	Score	Abun
	HEMIPTERA		
	Notonectidae	3	
	Pleidae	4	
	Naucoridae	7	
	Nepidae	3	
	Belostomatidae	3	
	Corixidae	3	
	Gerridae	5	
	Veliidae	5	
	MEGALOPTERA		
	Corydalidae	8	
	TRICHOPTERA		
	Hydropsychidae 1 sp	4	
	Hydropsychidae 2 sp	6	
	Hydropsychidae > 2 sp	12	
	Philopotamidae	10	
	Polycentropodidae	12	
	Psychomyiidae	8	
	Ecnomidae	8	
	Hydroptilidae	6	
	Other moveable case larvae:		
	case types		
	1	8	
	2	15	
	3	20	
	4	30	
	5	40	
	> 5	50	
	LEPIDOPTERA		
	Nymphulidae	15	
	COLEOPTERA		
	Dytiscidae	5	
	Elmidae / Dryopidae	8	
	Gyrinidae	5	
	Haliplidae	5	
	Helodidae	12	
	Hydraenidae	8	
	Hydrophilidae	5	
	Limnichidae	8	
	Psephenidae	10	

✓	Taxon	Score	Abun
	DIPTERA		
	Blepharoceridae	15	
	Tipulidae	5	
	Psychodidae	1	
	Culicidae	1	
	Dixidae	13	
	Simuliidae	5	
	Chironomidae	2	
	Ceratopogonidae	5	
	Tabanidae	5	
	Syrphidae	1	
	Athericidae	13	
	Empididae	6	
	Ephydridae	3	
	Muscidae	1	
	GASTROPODA		
	Lymnaeidae	3	
	Melaniidae	3	
	Planorbidae	3	
	Physidae	3	
	Ancylidae	6	
	Hydrobiidae	3	
	Sphaeriidae	3	
	Unionidae	6	
	Sample score		
	No. of families		
	Score/taxon		
	Air breathers		
	Air breath score		
	HABS 1		

Other families present

Procedure: Kick stones in current (SIC) for 2mins. Sweep marg/aq. veg'n for 2m. SOOC kick +/- $1m^2$, sand/mud stir with feet for 30secs. Sample gravel & any other biotope for 30sec. Tip net contents into tray. Remove leaves, twigs & trash. Check taxa present for 15mins & stop if no new taxa seen after 5min.
Estimate abundances: A: 1-10, B: 10-100, C: 100-1000, D: >1000

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