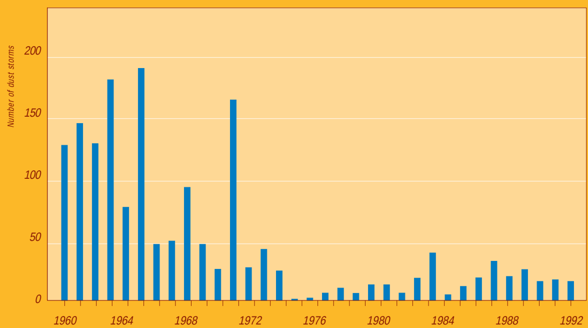
a guidebook to Environmental Indicators

CSIRO

Dust storms, dramatically captured in an urban setting, are an indicator of wind erosion. As shown, their number appears to be falling.



Source: McTainsh, G.H. and Reddan, S.P. 1995 (unpublished data).

A note on definitions

People who talk about indicators sometimes use the same words to mean different things. Key words are used throughout this booklet as follows:

Indicator is taken to mean a significant physical, chemical, biological, social or economic variable which can be measured in a defined way for management purposes. Some books give this meaning to the term attribute and an indicator is an aggregation of attributes related to the same issue.

Targets are specified levels or ranges for a measurable quantity that a group aims to achieve. Targets may be adopted by governments, industry, organisations or individuals. Targets are policy tools, but may have a scientific base. Australiaís commitment at Kyoto to restrict greenhouse gas emissions to 108% of 1990 levels by 2014 is an example of a target. Targets may be associated with one or many indicators.

A baseline tries to assess the behaviour of a system in the absence of some disturbing influence (a difficult task). For example, if the flow regime of a river were used as an indicator, the baseline would be the flow in the absence of any specified human influence (ie, without any dams, channels, weirs, or use of water). In most cases, the true baseline for natural systems cannot be defined or measured, so a particular condition at an agreed time is used as a substitute baseline.

A benchmark (or threshold) is the value for an indicator that has some defined environmental significance in the functioning of the natural system. One example is the number and size of fish that can be harvested from a particular fishery without endangering the species' capacity to renew its numbers. Another is the concentration of pollutants that can be tolerated without damaging health. Whereas targets have a basis in policy and reflect human values, benchmarks are scientifically determined.

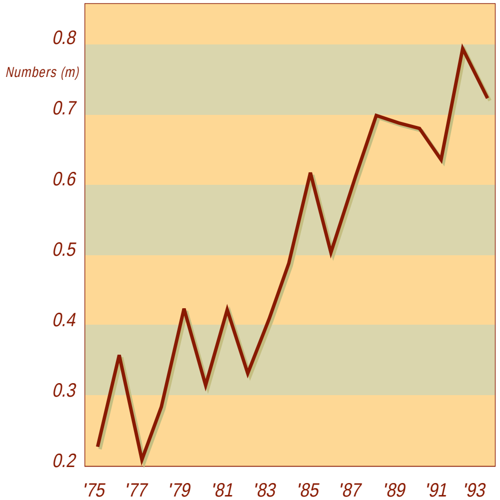
Environment management is used here to include not only formal management processes but also a range of environment-related activities of individuals and groups and those interested in environment programs, policies and outcomes. The word environment is directed particularly to physical environmental factors, but in the understanding that their effective management must take account of social and economic factors.

Contents

Environmental indicators are measures of physical, chemical, biological or socio-economic factors which best represent the key elements of complex ecosystems or environmental issues.

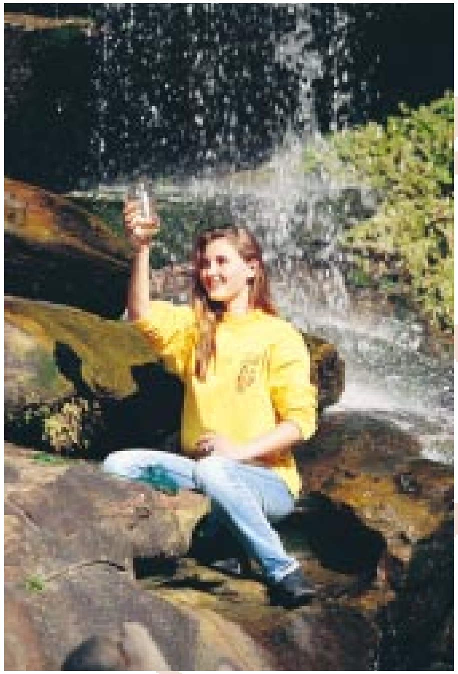
- They contribute to planning and management processes and are not just any piece of quantitative information.
- They can describe an environmental factor at some moment, show trends, or track progress to a given goal.

Increases in the number of saltwater crocodiles in the Northern Territory since protection began indicate successful management.



Note: These counts are from waterways surveyed by helicopter between 1975 and 1993. Source: Webb et al. 1994.

Why this booklet?



A well-designed monitoring program is essential to management and can serve important education functions. Here a schoolgirl is shown sampling water.

In our dynamic, complex world, the increasing scale of human activity is a major driver of change. Environmental indicators are becoming widely used as a simple way to view our complex environment and assess the impacts of our activities and our management responses. The move to a broader use of indicators is relatively new, with rapidly developing initiatives at all scales but a sense of inadequate consistency and continuity.

Interest is increasing in environmental indicators because society is more aware of issues influencing environmental quality, places more value on the environment, and demands better management and higher accountability from those responsible for both its use and its conservation.

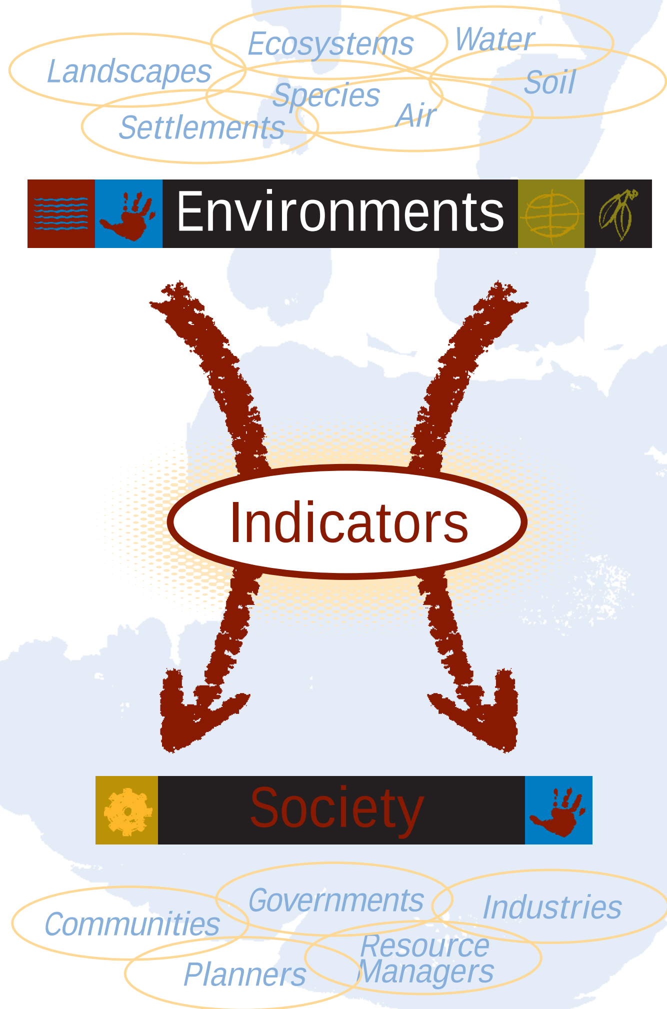
Good indicators encapsulate knowledge, providing an essential tool for understanding and for management purposes, from local to global. They are of great potential benefit as guides for action and to help measure its success, but must be designed with clear objectives and interpreted carefully. They are not an end in themselves.

To help the use of indicators for better environmental management, this booklet suggests a general framework and guidelines suitable for many users and uses. It aims to help by giving a general guide to the context and content of good indicators, but does not cover in detail the selection, development and use of any particular indicator.

It should provide an indicator starting point for those involved in resource management, industry, community groups, planners, policy and decision-makers at all levels of government, students and scientists.

Its framework ideas could be applied to many scales and purposes. For example, assisting property management; water quality monitoring and management; State of the Environment reporting; and in the meeting of corporate environmental management and reporting obligations.

What's happening in complex environments from local to global?



What's important to different users?

Environmental indicators are communication tools between environments and people.
They focus and condense information about complex environments for management, monitoring and reporting uses.
The indicator process can take account of social and economic information.
Properly designed indicators are useful tools for improving communication and management decisions.

Why indicators?

The Report *Australia: State of the Environment 1996* noted that:

"In many important areas, Australia just does not have the data, the analytical tools or the scientific understanding that would allow us to say whether current patterns of change to the natural environment are sustainable. We are effectively driving a car without an up-to-date map, so we cannot be sure where we are. Improving our view of the road ahead by enhancing the environmental data base is a very high priority. Our intended destination is a sustainable pattern of development, but it is not always clear which direction we need to take to get there."

As this quote makes clear, often we don't have the information to assist actions we want to take. We need data and understanding - and acquiring them may be expensive and time consuming. In some cases, we may have lots of data, but of variable quality, or not well related to the areas, time-frames or issues we are interested in.

In addition to gathering basic data, and developing understanding of the environmental factors to which it relates, we need ways to bring information to bear effectively on whatever environment-related decision we are contemplating, however small.

Salinity

Indicators can deliver the information to help make decisions. They often appear to be simple measures, but their success lies in accurately summarising and communicating key aspects of complex environments.

A good environmental indicator:

- has an agreed, scientifically sound meaning
- represents an environmental aspect of importance to society
- tells us something important, and its meaning is readily understood
- has a sound and practical measurement process
- helps focus information to answer important questions
- assists decision making by being effective and cost-efficient to use.

Indicators help define the nature and size of environmental problems, set goals for their solution, and track progress towards those goals.

This booklet aims to help development of effective indicators by describing how they link to environmental management activities, and reviewing factors which make up a good indicator.

Toxic algae

A generalised environment management cycle

Environmental managers all face differing realities, though similarities exist. This diagram represents a **generalised management cycle** in which the community, policy makers, managers and scientists all participate, taking the lead at different stages. Indicators can help groups, or an individual enterprise. Here we particularly assume that knowledge from science is required as one ingredient for success - as often it is.

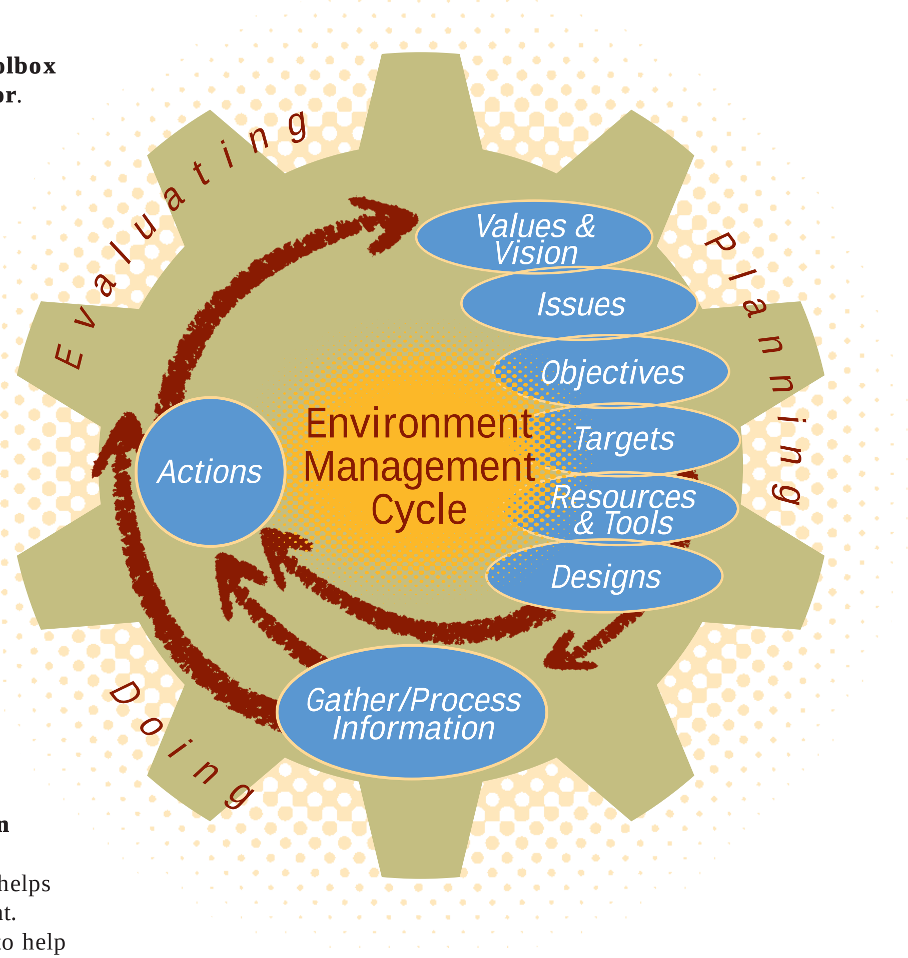
The **planning phase** begins with interaction between society identifying important environmental **values** and **visions** (e.g. conservation of key species), and policy makers establishing approaches which reflect those collective aspirations (e.g. ecologically sustainable development). Policy makers and managers then identify the related environmental **issues** (e.g. incidental catch of albatrosses by fishermen using long-lines).

Managers and scientists develop management **objectives** (e.g. reducing by-catch by redesign of nets), and associated **targets** (e.g. achieving negligible catch of albatrosses within 5 years). Managers then, through operational planning, identify and develop necessary **resources and tools**, and **design** the programs needed to implement the plan and to achieve the objectives and targets.

One tool in the manager's toolbox is the environmental indicator.

The design phase, and ensuing activities, involve and affect various people, both direct users and the wider community.

Often it is necessary to **gather and process information** although, sometimes, existing information and understanding is sufficient to start immediately on improving environmental actions. These **actions** may range from implementing policy changes, (e.g. new fishing regulations) to reallocating resources, to on-ground management (e.g. shifting farm fences). Critical to the success of the management cycle is **evaluation** of its steps and their outcomes, which completes the cycle and helps assure its continual improvement. Scientists are often well placed to help managers and policy makers in this evaluation.



Fitting indicators into the environment management cycle

'What do we need to know?'- this is the first guide in choosing the indicator.

Indicator development and use must be 'plugged-in' to the environmental management cycle. It must begin by addressing a question posed at some stage in the cycle and end by delivering answers back to the cycle. Questions from different stages of the cycle will motivate different types of indicators or ones that operate at different scales in time and space.

Indicator use can relate to any stage but typically begins at least by that of identification of tools and resources, and re-enters the cycle near the action and evaluation stages (which then feed wisdom to future management activity). Before beginning indicator design, it is essential to be sure about the questions being addressed, the stage of the management cycle to which the indicators link, and relevant local factors. Otherwise, there is a risk of adopting inappropriate indicators.

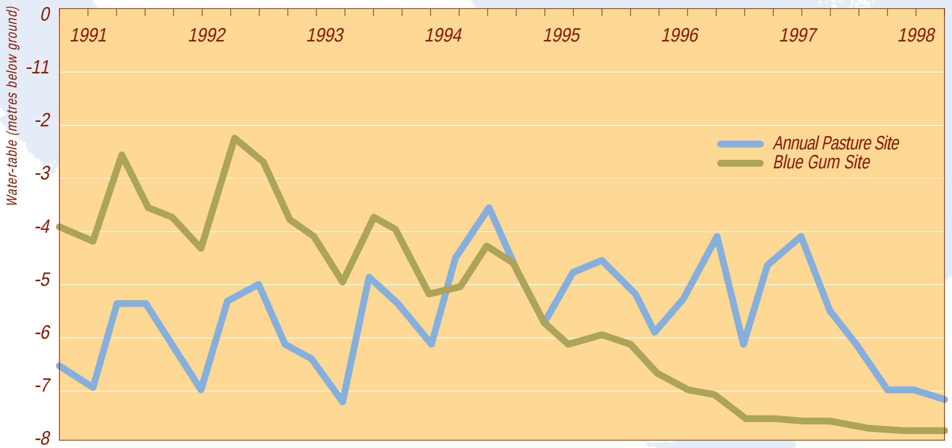
One vision that Australians (and others) have articulated is that of ecologically sustainable development. State of the Environment reporting is designed to help assess - or indicate - progress towards ecological sustainability: so, overall, it addresses questions such as 'what are the main environmental issues facing Australia?' and 'are problems getting better or worse?'. Another example is sustainable forest management where questions asked include 'is biodiversity being maintained: and are forest ecosystems healthy?' and where indicators are targeted at helping answer such questions.

Locally, a manager may plan to halt rising watertables by planting deep-rooted vegetation. Having set a measurable target for the area needing to be revegetated in order to use water before it enters the watertable, the manager might seek to indicate the answer to 'is the watertable rising or falling?' by asking 'how many plants have been successfully established?'

Indicators need to deliver information of use to managers or they won't respond. Few managers have the time or inclination to understand complex or obscure indicators. The science behind an indicator may be complicated: so, those developing it must provide clear guidance about its meaning and its levels of uncertainty.

Timeliness is another consideration; indicator data must be available when decisions are being made.

In sum, indicators must answer clear questions arising somewhere in a management cycle and be designed to feed back timely information which suits its needs and users. Indicators should help managers establish whether their objectives are being met.

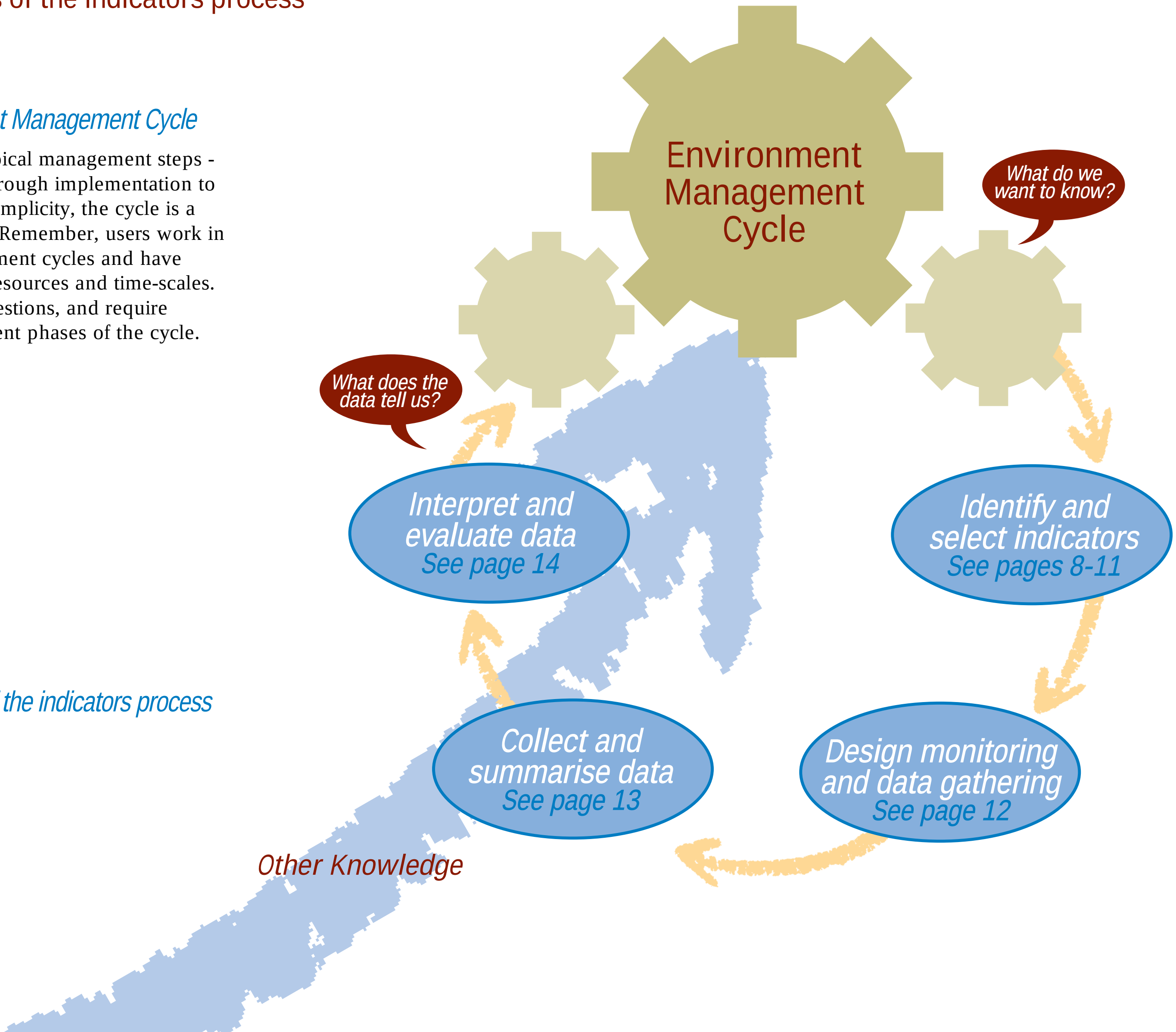


The graph indicates groundwater trends under annual pasture and a bluegum plantation in southwestern Australia. The picture above shows staff from Agriculture Western Australia monitoring groundwater.

Key elements of the indicators process

The Environment Management Cycle

Page 5, shows typical management steps - from planning, through implementation to evaluation. For simplicity, the cycle is a single step here. Remember, users work in differing management cycles and have different needs, resources and time-scales. They may ask questions, and require answers, at different phases of the cycle.

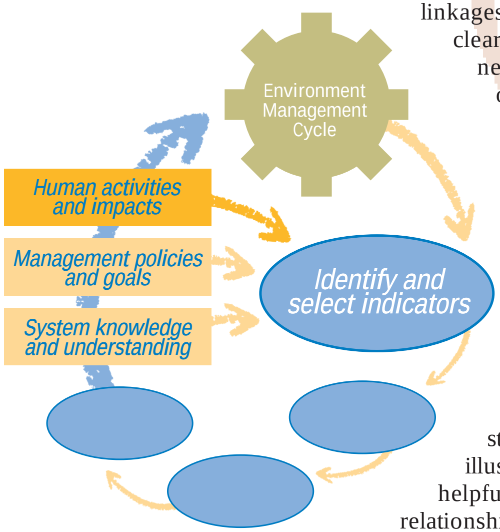


Key elements of the indicators process

Identifying and selecting indicators - human activities

Identifying potential indicators, and selecting the best to provide focused information for policy makers and managers, depends on several sorts of criteria. They can be grouped into those associated with human activities and impacts; the needs of society, policy makers and managers; and the scientific understanding needed. These are taken up in the next 4 pages, and the diagram below.

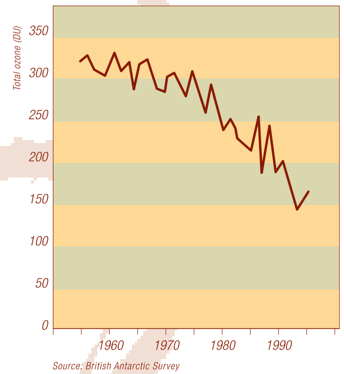
Good indicators generally rest on understanding the links between a human activity and its consequences. Sometimes indicators are associated with incomplete understanding: these should be used with care and efforts made to understand the linkages fully. The link between clearing native vegetation and negative effects on biodiversity, or the observation that exhaust from cars degrades air quality in major cities, are examples where there is scientific consensus about the relationships.



Where causal links between activities and effects are well understood, it may be possible to use indicators as **early warning signals**: stratospheric ozone depletion illustrates this. It will often be helpful to choose indicators with relationships to human activities since these are better understood and easier to measure, and alter, than many non-human processes. Unsurprisingly, the values helping guide indicator choice often reflect human-centred concerns such as health impacts.

While some human activities harm the environment, others are beneficial. Indicators often draw attention to harmful activities, but it is important to avoid the mindset that most human activities are negative. There are also useful indicators of natural factors which impact on human activities.

Indicator performance can vary depending on whether human impacts are acute or chronic, local or regional, and limited or cumulative in effect. Many activities, such as fishing, agriculture, and driving cars, have a continual effect on the environment. Others may fluctuate strongly: major shipping accidents, for example, can powerfully affect the environment, but are sporadic. The nature of the activities and impacts should be assessed as part of choosing indicators.



Ozone decline over Antarctica

Ozone depletion

Mario Molina and Sherwood Rowland warned in 1974 that man-made gases such as chlorofluorocarbons (CFCs) could damage the stratospheric ozone layer that screens out much of the sun's harmful UV radiation. Unfortunately, little attention was paid to this warning (except in the United States) until the mid 1980s, when a 'hole' was discovered in the stratospheric ozone layer above the Antarctic. This hole has since captured attention as an indicator of the state of the world's ozone layer.

This problem was addressed by phasing out production and use of CFCs and other ozone depleting substances. Because of natural variations and the time for existing CFCs to decompose, it is too early to confirm improvement in the ozone layer. However, declining production of ozone depleting substances and their concentrations in the atmosphere are excellent indicators of progress.

Identifying and selecting indicators - policies, goals and management

Indicators, in their role of assisting policy and management processes, must be conceived and used in ways which fit in with and influence policies, goals and structures. This important linking to the management cycle, imposes requirements on indicators.

Ownership by the full range of stakeholders is critical. Unless all interested parties agree the indicators represent sound information relevant to their needs, they risk being ignored or maligned. The best way to ensure consensus is to involve relevant groups in selecting indicators.

A range of scales in space and time apply to environmental management. Careful account must be taken of this when selecting indicators. The scale associated with the indicator will depend on the objective of management.

National State of the Environment reporting will use many continental scale indicators, reflecting the national needs it serves, while local government and individual landholders will mostly use indicators at a much finer scale. The same indicator may be relevant at both local and catchment scales; but, sometimes, different indicators will be needed for different scales.

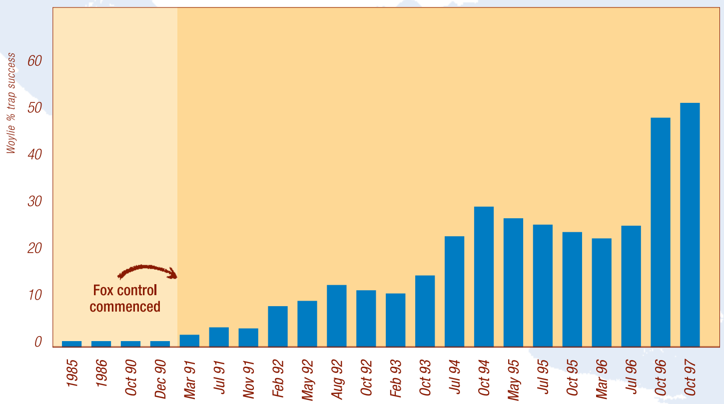
Both existing and new data can be used. Raw data are often expensive to collect, so it is important for indicators to make use, where possible, of all available data, even if collected for other purposes. On the same grounds, indicators that can be used for several purposes or by more than one group should be preferred to those with a single application. However, where new information is critical to the management goal, it must be collected.

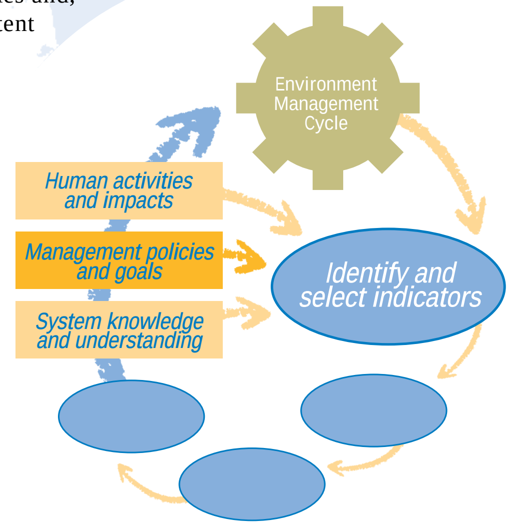
A monitoring program is often needed for indicators to establish the facts and the trends. A trade-off may be necessary between the cost of monitoring and the quality of the information acquired. The most cost-effective indicators should be chosen and the cheapest options are not necessarily the most effective.

Consistency across jurisdictions should be sought where possible. Within Australia, the same indicators should be used in all States and Territories and, where appropriate, be consistent with those used overseas. However, environmental and management variations will often make consistency a challenging goal to achieve.

Courtesy of Babs and Bert Wells.

Through management action, the Woylie or Brush Tailed Bettong (above) moved from the 'Endangered' to the 'Under Threat' list in Western Australia. Indicators have tracked the shifting numbers and have justified this changed status.





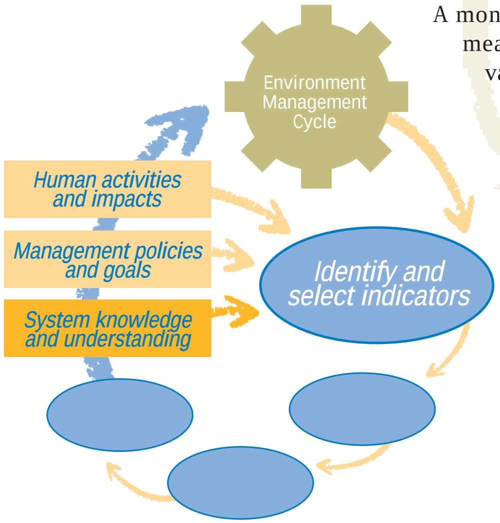
Identifying and selecting indicators - system knowledge and understanding

Questions of risk are involved:

- *how critical is the answer?*
- *is a surrogate or approximation acceptable?*

Environmental indicators are measures of physical, chemical, biological or socio-economic factors which best represent key elements of complex ecosystems or environmental matters. To achieve their aim of accurately and relatively simply reflecting often complex realities, indicators need to be based on system knowledge and understanding and be embedded in a well-developed interpretive framework. A monitoring program of repeated measurements of the indicator, in various places and times and in a defined way, will give the basis for detecting environmental change, through comparison with a benchmark set or condition.

The indicator must reflect the aspect of the system that is the objective of the monitoring.



- It may be a key species (such as koalas on Kangaroo Island) which provides information about the system and other species dependent on it.
- Or it may be a key process (like watertable change) which reflects changes in ecosystem, landscape or catchment scale processes.

An assessment of risks associated with the choice of indicators should be made. This will be based on how critical it is to monitor a particular system and whether the indicator will provide sufficient information about the changes in the system to manage them better. Where it is too expensive to provide a desirable level of accuracy, it may be necessary to trade-off maximum benefits and use a less accurate indicator (a surrogate): the fact that a compromise has been made should be made clear.

The level of gases in the air near industrial plants can indicate processes with potential impacts at various scales.

More on system knowledge and understanding

To understand what indicators mean, it is usually necessary to have good knowledge of how a system behaves. What is the range of natural variation? What happens if the system strays outside this natural range? Will natural functions be slowly degraded, or is there a point at which the whole system will suddenly collapse?

Without system understanding, it can be difficult to select and interpret indicators and to be sure they will provide useful, credible and statistically valid information. The better an ecosystem is understood, the easier to select the best indicators and assess what changes in them mean.

Normally, monitoring a complex natural system requires an integrated suite of indicators. The better our understanding of the system and the causal relationships within it, the smaller that suite can be. Understanding cause and effect relationships will also make it easier for managers to decide what action to take. For example, the relationships between the concentration of air pollutants in cities, emissions from vehicles and other sources, and weather events, are quite well understood. So, a manager could chose at some point to control industry emissions, use of wood stoves, or road traffic, based on weather indicators.

Some systems have **emergent properties** - of the system as a whole rather than individual parts. If emergent properties can be understood and measured, they are often better summaries of the state of the system than measures of individual components. For example, it is far easier to measure the pressure of a gas than to track the velocity of each molecule. Unfortunately, it is less clear how to identify and measure emergent properties of ecological systems. Suggested measures include the time taken to recover from disturbance, productivity trends, and biodiversity.

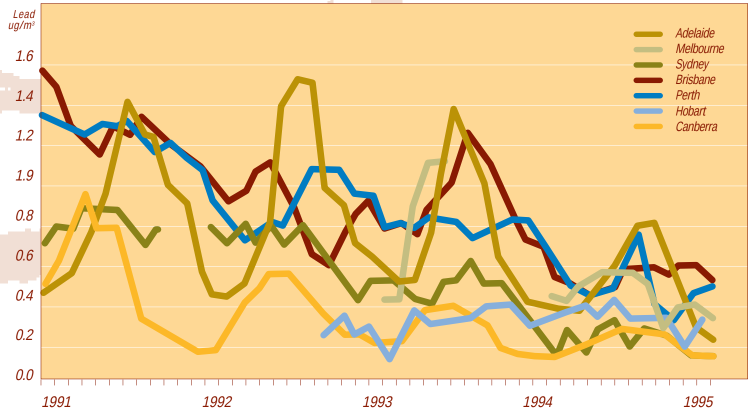
Pitfalls of using environmental indicators

Environmental indicators are windows to highly complex and variable systems. They are tools for extracting what is critical, for synthesising multi-dimensional information, or integrating the influences of many processes. However, these characteristics can be a weakness. As in many arenas, great care must be taken not to over-interpret the story which a simple measure tells of a complex system and not to misinterpret or confuse short and long term trends.

Because the scope of any one indicator is usually limited, they should be used in suites to give a more complete picture of a system.

There is danger associated with trying to combine indicators into a single index of a system (an environmental counterpart of the Gross Domestic Product), and basing decisions on that single measure.

Understanding the dangers of high atmospheric lead levels, and the contribution of lead from petroleum, has led to management actions which are reducing the problem.



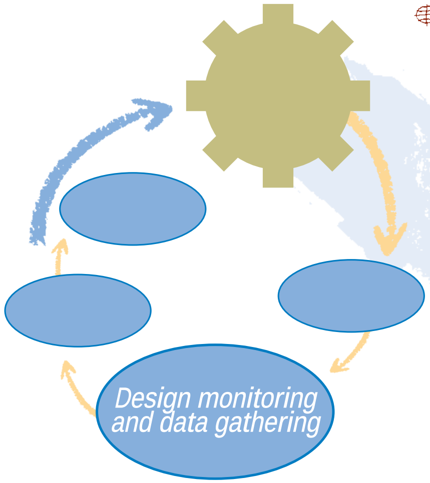
Source: State and Territory environmental authorities.

Design of monitoring and data gathering

Quantitative characteristics of indicators are often neglected in their development. Detection of change in an indicator is at its root a quantitative and statistical problem: so, effective use of an indicator depends critically on the design of its sampling program. That design has many aspects.

The statistical power to detect change in the indicator depends on the:

- natural variability and sensitivity to pressure of the component(s) being measured
- amount of change one wants to detect
- sampling methods
  - careful choice of placement and frequency of sampling
    - number of samples collected.



The scope of the indicator and scale of its sampling program have to be considered. The time and space scales of the sampling and the indicator must be compatible. For instance, it would not make sense to sample a slow-growing seagrass species weekly if the goal were to detect changes due to chronic influences of pollution over several years. Conversely, inventories taken at 5-10 year intervals may not detect harmful invaders soon enough to allow relatively simple eradication.

Indicator data are used to monitor natural systems, which have their own scales and boundaries, and support environmental management within designated regions. Sampling must be designed to match these differing boundaries if the data are to reflect the condition of the system accurately and be of most use to managers. It is not simple to reconcile the differing requirements of, say, bio-regions and administrative areas: catchments, for example, are well defined ecological units but their boundaries do not usually coincide with government jurisdictions.

Finally, the indicator's effectiveness and efficiency in representing the state of the system must be addressed. Is measurement of the indicator feasible in technological and logistic terms? Are measurements repeatable? Will the data give a statistically representative sample from the system? Is aggregation of the data within larger regions feasible? Can the indicator be combined with similar indicators collected in other regions? Expert assistance is often needed to help answer such questions.

Good indicator design is often neglected:

- *it is crucial to effective use of indicators*
- *indicators have to answer the questions asked and be cost effective.*

Corals, algae, reef fishes and starfish are monitored on the Great Barrier Reef as indicators of the health of the ecosystem. These data have been critical to Marine Park management. In designing the program, the factors on this page were taken into account.

Source: Great Barrier Reef Marine Park Authority

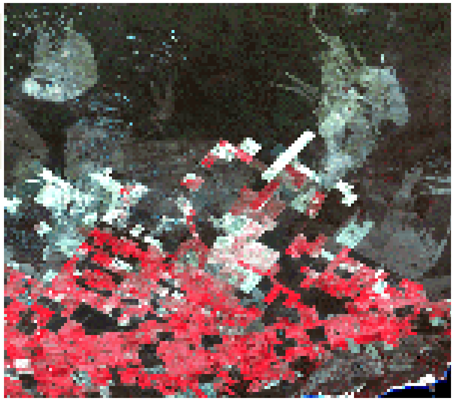
Collecting and summarising data

Field collection of indicator data often requires extensive planning, training of personnel, coordination of effort, and considerable resources. Coordination is particularly necessary when different collection processes in different areas and jurisdictions are involved. Field sampling programs may entail an on-going, long-term effort and, sometimes, complex equipment .

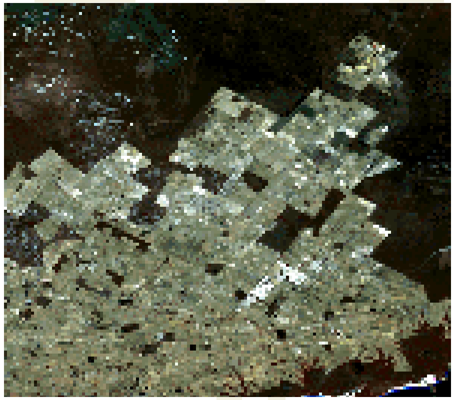
Once collected, initial low level clean up and summarisation of new data is usually required. This may occur in the database automatically. Indicator data must be screened to ensure they meet established data quality and compatibility standards. The data themselves should reside in a database which is easy to access and use. It should include, or be compatible with, tools used to process, aggregate, summarise and visualise the data.

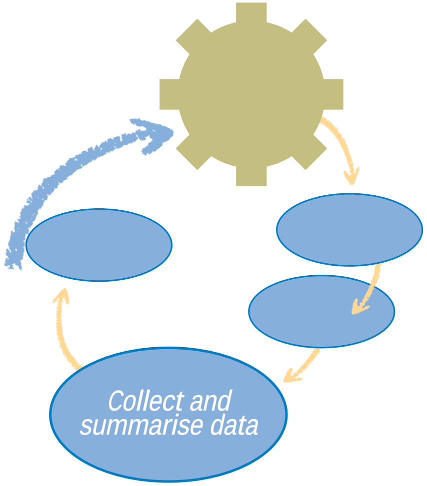
We should always presume that others after us may want to use the data for new purposes. Clear documentation and definition of the indicators, and of the data which relate to them, including methodology and units used, are essential both for current and possible future uses.

Exploiting existing databases also requires knowledge about location, reliability and collection methods, as well as computing facilities, considerable experience, and, in some cases, extensive processing.



Data collected by remote sensing, and skilfully interpreted, can powerfully indicate changes over time. These images, 13 years apart, show agriculture taking over bushland.

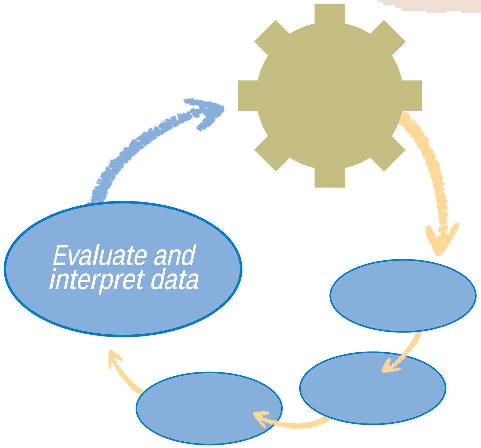




Interpreting and evaluating data

In the initial phases of indicator use, the scientific community may need to help managers to build their understanding.

As indicators become more routine, their interpretation by managers should become simpler, more confident.

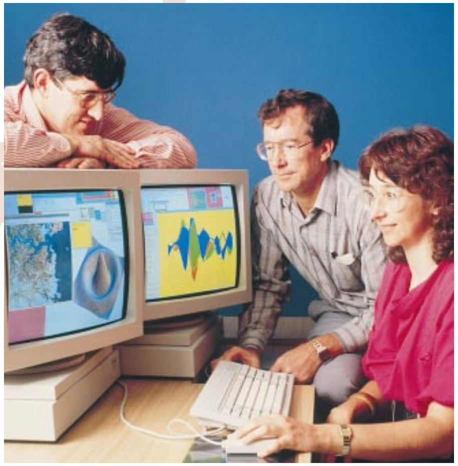


For greatest effect, indicator data should be linked to pre-established criteria in the management cycle, and tied to potential management actions. For example, if a series of satellite images indicated that the rate of decline in area of old-growth forest exceeded a threshold (say 1%/yr), this might raise an alarm and lead to logging reductions. Much as operational control criteria signal the need for adjustments in an industrial process, environmental indicators should monitor changes in, or impacts on, environments and point to the need for responses.

Often, indicator data will require sophisticated interpretation, such as through extensive statistical analyses, computer modelling, or expert assessment. Evaluation of potential management actions typically involves a variety of inputs, of which indicators are just one.

A range of tools and expertise can be used to select and focus this data pool on a particular management objective. Thus, deciding whether to respond to an algal bloom, and, if so, which remedial actions to take, will depend on more than mere indications of its presence. Other indicators may give insight into the state of water quality; additional sampling could establish the species causing the bloom; or an expert might provide an interpretation not available by other means. Indicators effectively point to the need for action - but other information is often needed to confirm this and to shape the responses.

Various means are employed to boost the power of indicators to convey the nature of a situation or trend. Communication to managers is the essential function of indicators. They can also convey information to a wider audience telling them, amongst other things, whether management of aspects of their environment is effective. So, the power to communicate and report is one factor to be considered in choosing, designing, using and interpreting indicators



Acting on indicator data - linking back to the management cycle

The best indicators trigger human action, or have the potential to do so. They might do this in several ways - including seeking confirmatory monitoring, or research. They may highlight an emerging or worsening environmental problem that needs to be addressed. For example, increasingly frequent algal blooms in a river may indicate problems. A drop in the area of a catchment covered by deep-rooted vegetation may point to the danger of increased soil loss or rising ground waters. Disappearance of a bird species from a country town might point to the declining condition of nearby remnant vegetation. In each case, remedial action is needed.

Some indicators may have trigger levels above which environmental action is recommended or required. For example, where the concentrations of pollutants such as ozone or carbon monoxide exceeds levels that endanger health, it is necessary to take steps to reduce them.

The best use will be made of indicators when they are explicitly built into management processes. Put the other way, management processes will often be better if they make explicit and thoughtful use of indicators in connection with agreed objectives. At present, many parts of Australia's environment are managed with minimum information and without well defined objectives or indicators. If indicators are to be of maximum benefit, managers and decision makers must build them into their thinking and decision-making, preferably by establishing links between indicator change and management strategies. Indicators must transcend politics.

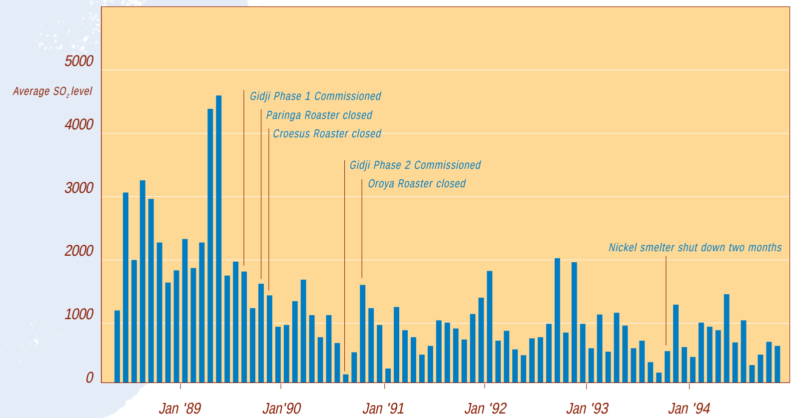
As the management cycle changes, the indicators which interact with it should be kept under review to ensure they remain relevant to management needs.

Diagnostic indicators

One strategy proposed for designing indicators is to build a 'diagnostic pyramid'. At the top of the pyramid would be a general indicator of the overall health of a system. Ideally, this would be a simple indicator which can be monitored cheaply. So long as this indicator continued to show that the system is healthy, no other indicators would be needed.

At the next level, a suite of more powerful, but more expensive, indicators might be developed. While more expensive to monitor, these would provide more information about the specific causes of decline in a system. A deterioration in the simple indicator of overall health would be the trigger to begin monitoring these more detailed indicators. However, simple indicators of overall health, used for early warning purposes, are often difficult to develop, except on small space scales, and are a problem needing further research. They are also far from the only sorts of indicators needed for policy and management purposes.

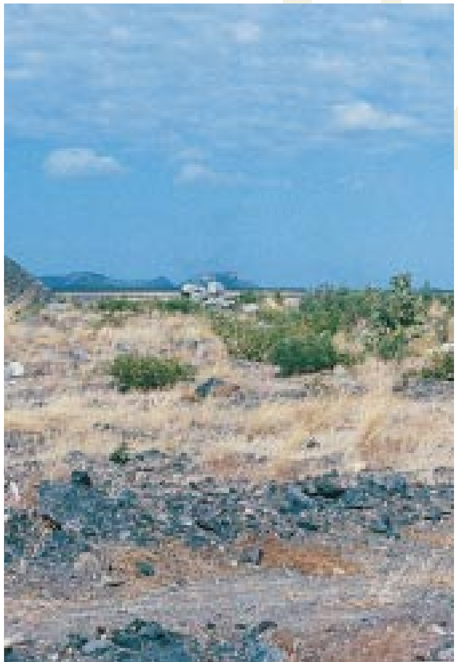
In Kalgoorlie, a reduction in sulfur dioxide levels has occurred following management actions.



Source: WA Department of Environmental Protection.

Minesite rehabilitation can be based on sensitive analysis of the landscape desired. Indicators can confirm progress towards the goals.

These photographs are 2 and 4 years after establishment of native tree species.



Scales in space and time

We seek information and manage natural systems at a wide range of scales in time and space and must take this into account when selecting indicators. For example, minesite rehabilitation occurs over fairly small areas, while ozone depletion has a global scale. Minesite rehabilitation may respond to management intervention within 5 to 10 years; but ozone depletion may take decades to respond to reduced use of depleting substances.

Some natural processes are extremely brief, but many operate on time scales from decades to centuries (for example, some trees live for 500 years). In contrast, environment management programs often operate on time-frames of a few years, making it difficult to select indicators to assess their success.

Often we will have to select indicators with an assumed link to environmental outcomes (for example, the success in establishing perennial deep-rooted plants to address rising water tables). For long-term purposes, the actual environmental outcomes should also be monitored (in this example, what actually happens to the water table).

Management decisions are often made on different space scales to the systems being managed. For example, local government boundaries may be the main basis of management of something that involves an ecological scale - such as a river catchment covering several local government areas or even crossing State boundaries. So, the indicator selected must be relevant at the catchment scale, but also meaningful at local and other government scales.

Some environmental issues must be assessed at each of local, state and national levels, but managers at these scales may need different information. For example, a farmer needs to know how much soil is being lost to erosion in a particular field, while a national agency needs to know the extent of erosion country-wide.

Different indicators may therefore be needed for managers operating at different scales. They may often be based on the same data, and finding reliable ways to aggregate, or disaggregate, data across space scales is a continuing and difficult challenge. The challenge is even greater when linking both space and time considerations. Expert assistance may be needed to underpin indicator-related action at local to global levels.

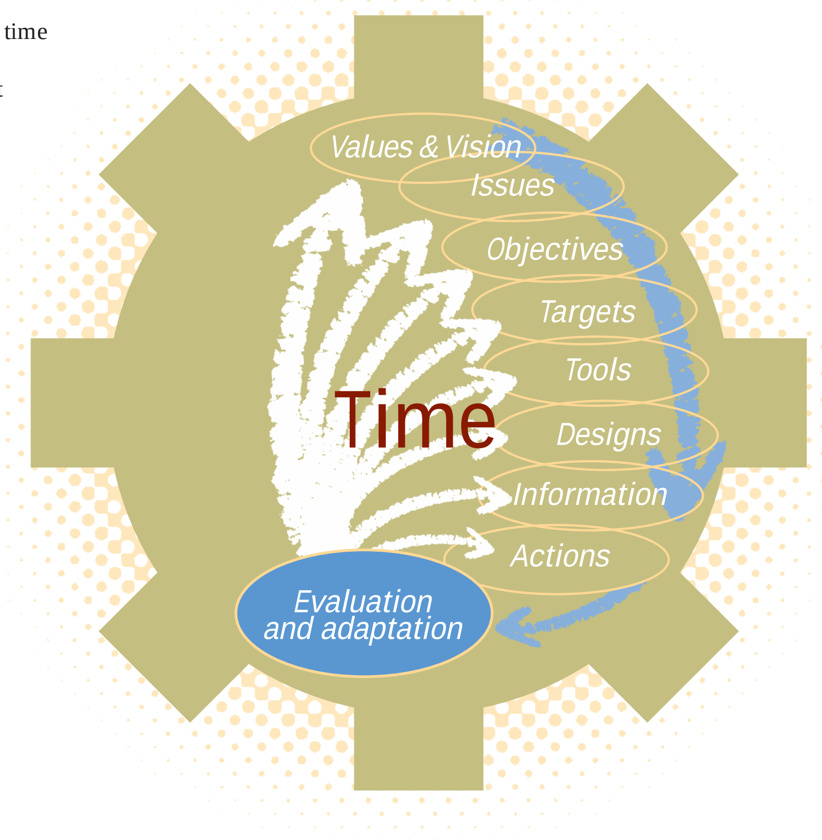
Feedbacks and modifications

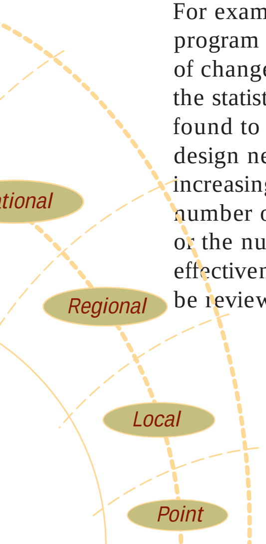
The effectiveness of management and indicator processes is greatly enhanced when processes, products and outcomes are evaluated, and those evaluations are used to modify the cycles. Environmental conditions change, human values alter, policies evolve, and understanding of systems improves - all of which demand that all aspects of management systems be flexible, dynamic and adaptive.

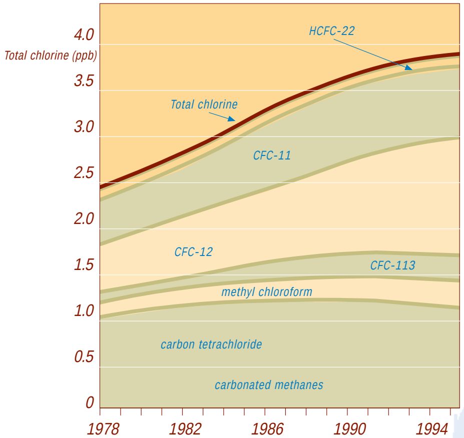
Adapting management actions to optimise outcomes is the most important reason for evaluation, but should occur at all stages in the cycle and at several scales.

For example, the ability of a sampling program to deliver the intended detection of change must be periodically assessed. If the statistical power to detect change is found to be inadequate, then the sampling design needs to be modified, perhaps by increasing the frequency of sampling, the number of samples collected at each site, or the number of sites. Similarly, the cost-effectiveness of the indicator process has to be reviewed.

Adaptation occurs on different time scales. The diagram illustrates that evaluation of management actions might lead to their modification within weeks or months, but that evaluation might contribute to modifying planning activities, such as setting objectives, only over several years. Evaluation and adaptation should be included explicitly as part of the management cycle and indicator design.







Source: CSIRO and Cape Grim Baseline Air Pollution Station

The baseline air monitoring station at Cape Grim in Tasmania and trends measured there of total chlorine in the atmosphere over time - important indicators based on ultra-sensitive measurement and long time series.

A checklist for the use of indicators for environmental management

Indicators must:

- be relevant to management objectives, be scientifically valid and fit in a policy framework
- be developed with all those involved in the management cycle, from stakeholders to those carrying out monitoring: indicators are unlikely to work successfully if imposed from above
- be credible, easy to understand and unambiguous
- reflect an essential, fundamental or highly valued element of the environment being monitored
- be part of the management cycle and not an end in themselves
- focus on the use of information, not on the gaining of it
- have a clear link to the environmental outcome being monitored
- be kept under review, and refined when necessary, as part of adaptive management
- provide early warning of emerging issues or problems
- be capable of being monitored easily to show trends over time
- use accepted and clearly documented methods, and units
- be as simple and cheap as possible (whilst still achieving their desired ends)
- be adaptable for use at a range of scales, wherever possible.

Other essential elements for indicator development include:

- partnerships between communities, government, companies and research agencies setting-up and running the process, and sharing information and experiences
- the provision of adequate resources (time, expertise, funds)
- a commitment to collect new data if required
- continuing research and development to provide the most appropriate indicators and to understand cause and effect relationships
- awareness of the links to wider social and economic considerations.

Some future directions

Indicators are being used increasingly as a tool serving better management–including through performance measurement. This is to be encouraged, but with care taken not to create an 'indicators industry' with indicators somewhat of an end in themselves instead of a powerful tool for judging the success or failure of our environmental actions. Distortion of the purpose and value of indicators will be avoided if a realistic view is maintained of their uses and limitations and of the need to develop practical, soundly-based methodologies for their development and use.

This booklet is one small step in that, providing a context and some guidelines for those developing and using indicators - but it is far from a blueprint. Above all, its message is that indicators must be embedded in whatever policy and management processes - and underlying aims - they are serving, and that managers must respond to the signals that indicators can provide.

Rigorous scientific underpinning of indicators is essential. As our understanding of environmental systems improves, it will be possible to select better, more cost-effective indicators. It is particularly important to improve our understanding of all elements of biological diversity if better indicators are to be developed. Through science, steady improvements in the underlying knowledge of systems will continue to occur, particularly in terms of understanding the interconnections between factors and between systems. One promising area for further research is 'whole of system' properties which may help lead to simpler indicator sets. Nevertheless, there will be a continuing need to recognise, and accept, the uncertainty in scientific and policy knowledge of what is happening and how to fix it.

Improved instrumentation will allow ever more sensitive detection and monitoring. Current trends are towards greater use of powerful remote sensing techniques, using satellite or aerial platforms, and better automated recording technologies such as automatic data loggers at remote sites.

Indicator data will be quicker and faster in both capture and analysis with more use of real-time measures and complex and powerful modelling and statistical techniques. These will also facilitate the aggregation of local, regional and national data, the more accurate reconstruction of historical data for trend analysis and the use of available data for multiple purposes, with related savings in collection costs.

Indicators will be able to be used more readily by managers and policy makers. The indicators process will be backed by powerful visualisation techniques.

Indicator use will feed to better reporting and communication.

At the same time as more sophisticated and complex techniques and technologies become available to scientists and managers, simple indicators and tools must be made available to community groups and individuals to enhance democratic participation in environmental understanding and management. The simple local level of activity will remain a cornerstone of effective environmental action.

As repeatedly stated, environmental indicators serve management processes. These vary widely in nature, scale and complexity but usually require the integration of a range of factors, of which the physical environmental are only one part. More and more it is realised that robust solutions require attention to each of social, economic and environmental factors. Indicators are being developed to better serve this broad ecological-social-economic sustainability approach.

Overall, the use of indicators in natural and human influenced systems is in its infancy and many steps to improved use will be taken over the next few years.

Reading list

Australian Conservation Foundation 1996. *Listening to the Land - A Directory of Community Environmental Monitoring Groups in Australia*. ACF, Melbourne.

Fairweather, P. G. and Napier, G. M. 1998. *Environmental Indicators for National State of the Environment Reporting - Inland Waters. Australia: State of the Environment (Environmental Indicators Reports)* Department of the Environment, Canberra.

Hamblin, A. 1998. *Environmental Indicators for National State of the Environment Reporting - Land Resources. Australia: State of the Environment (Environmental Indicators Reports)* Department of the Environment, Canberra.

Institute of Environmental Studies (ed) (1996). *Tracking Progress: Linking Environment and Economy through Indicators and Accounting Systems. Conference Papers. Proceedings of the 1996 Australian Academy of Science Fenner Conference on the Environment.* Institute of Environmental Studies, University of New South Wales, Sydney.

Moldan. B., Billharz, S., and Matravers, R., (eds) 1997. *Sustainability Indicators: a report on the Project on Indicators of Sustainable Development*. John Wiley & Sons, Chichester.

Montreal Process Implementation Group (1997). *Australia's First Approximation Report for the Montreal Process.* Department of Primary Industries and Energy, Canberra.

Organisation for Economic Co-operation and Development (1993). *OECD Core Set of Indicators for Environmental Performance Reviews*. Environment Monographs No. 83, Organisation for Economic Co-operation and Development, Paris.

Organisation for Economic Co-operation and Development (1996). *OECD Core Set of Indicators for Environmental Indicators. Biodiversity and Landscape - Draft working Paper*. Organisation for Economic Co-operation and Development, Paris.

Saunders, D., Margules, C. and Hill, B. 1998. *Environmental Indicators for National State of the Environment Reporting - Biological Diversity*. *Australia: State of the Environment (Environmental Indicators Reports)* Department of the Environment, Canberra.

State of the Environment Advisory Council (eds). *Australia: State of the Environment 1996 an independent report to the Commonwealth Minister for the Environment* CSIRO Publishing, Collingwood, Vic.

Tongway, D., Hindley, N., Ludwig, J., Kearns, A., and Barnett, G. (1997). *Early indicators of ecosystem rehabilitation on selected minesites*. Proceedings of 22nd annual environmental workshop. Minerals Council of Australia, Dickson.

Walker, J. and Reuter, D. (1996). *Indicators of Catchment Health - a Technical Perspective*, CSIRO, Melbourne.

Ward, T., Butler, E. and Hill, B. 1998. *Environmental Indicators for National State of the Environment Reporting - Estuaries and the Sea. Australia: State of the Environment (Environmental Indicators Reports)* Department of the Environment, Canberra.

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