Environmental Indicators

For National State Of The Environment Reporting

inland waters

Australia: State of the Environment
Environmental Indicator Report

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Preface

The Commonwealth State of the Environment Reporting system supports the *National Strategy for Ecologically Sustainable Development* and helps Australia meet its international obligations, such as those under *Agenda 21* and the OECD environmental performance reviews. The first independent and comprehensive assessment of Australia's environment, *Australia: State of the Environment 1996* was released by the Commonwealth Environment Minister in September of that year.

The next step in the evolution of the reporting system is to develop a set of environmental indicators that, properly monitored, will help us track the condition of Australia's environment and the human activities that affect it. To help develop these indicators, Environment Australia has commissioned reports recommending indicators for each of the seven major themes around which Commonwealth state of the environment reporting is based. The themes are:

- human settlements
- biodiversity
- the atmosphere
- the land
- inland waters
- estuaries and the sea
- natural and cultural heritage.

Clearly, none of these themes is independent of the others. The consultants worked together to promote consistent treatment of common issues. In many places issues relevant to more than one theme receive detailed treatment in one report, with cross-referencing to other reports.

Report authors were asked to recommend a comprehensive set of indicators, and were not to be constrained by current environmental monitoring. One consequence of this approach is that many recommendations will not be practical to implement in the short term. They are, however, a scientific basis for longer term planning of environmental monitoring and related activities.

These reports are advice to Environment Australia and have been peer reviewed to ensure scientific and technical credibility. They are not necessarily the views of the Commonwealth of Australia.

The advice embodied in these reports is being used to advance state of the environment reporting in Australia, and as an input to other initiatives, such as the National Land and Water Resources Audit and the Australian Local Government Assocation's Regional Environmental Strategies.

Summary

More than 200 possible environmental indicators for inland waters were considered as potential key indicators for use in national state of the environment (SoE) reporting. Of these, 53 are recommended for further evaluation, refinement and use: 6 relating to groundwater, 3 to human health, 13 to water quality, 12 to water quantity, 7 to physical change, 8 to biotic habitat quality and 4 to effective management. In all, 18 are indicators of pressures, 19 of condition and 16 of response. Recommendations are also made for research and development regarding SoE indicators. These fall broadly into the categories of further developing SoE procedures and outputs (especially data collation and indicator expression), and firming the scientific basis of how the indicators work.

Aims of the study

- present a key set of environmental indicators for inland waters for national state of the environment reporting;
- ensure that the list of indicators adequately covers all major environmental themes and issues;
- examine each indicator in detail to ensure that it is rigorously defined and measurable and in an interpretive framework;
- identify suitable monitoring strategies for each indicator – including measurement techniques, appropriate temporal and spatial scales for measurement and reporting, data storage and presentation techniques, and the appropriate geographical extent of monitoring;
- identify relevant data sources for each indicator, if these are available;
- define the baseline information that is needed to properly interpret the behaviour of the indicators.

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Background

Commonwealth State of the Environment Reporting

In 1992 Australia's *National Strategy for Ecologically Sustainable Development* (Council of Australian Governments 1992) was endorsed by the Commonwealth, all State and Territory Governments and Local Government. The objectives of this strategy are:

- to enhance individual and community well-being and welfare by following a path of economic development that safeguards the welfare of future generations;
- to provide for equity within and between generations; and
- to protect biological diversity and maintain essential ecological processes and life-support systems.

The strategy called for the introduction of regular state of the environment (SoE) reporting at the national level to enhance the quality, accessibility and relevance of data relating to ecologically sustainable development.

The broad objectives of state of the environment reporting for Australia are:

- to regularly provide the Australian public, managers and policy makers with accurate, timely and accessible information about the condition of and prospects for the Australian environment;
- to increase public understanding of the Australian environment, its conditions and prospects;
- to facilitate the development of, and review and report on, an agreed set of national environmental indicators;
- to provide an early warning of potential problems;
- to report on the effectiveness of policies and programs designed to respond to environmental change, including progress towards achieving environmental standards and targets;
- to contribute to the assessment of Australia's progress towards achieving ecological sustainability;
- to contribute to the assessment of Australia's progress in protecting ecosystems and maintaining ecological processes and systems;
- to create a mechanism for integrating environmental information with social and economic information, thus providing a basis for incorporating environmental considerations in the development of long-term, ecologically sustainable economic and social policies;
- to identify gaps in Australia's knowledge of environmental conditions and trends and recommend strategies for research and monitoring to fill these gaps;
- to help fulfil Australia's international environmental reporting obligations; and
- to help decision makers make informed judgements about the broad environmental consequences of social, economic and environmental policies and plans.

The first major product of this system was *Australia: State of the Environment 1996* (State of the Environment Advisory Council 1996) — an independent, nation-wide assessment of the status of Australia's environment, presented in seven major themes: human settlements; biodiversity; the atmosphere; the land; inland waters; estuaries and the sea; and natural and cultural heritage.

In *Australia: State of the Environment 1996*, each theme is presented in a chapter that follows the OECD (1993) Pressure-State-Response model (see also Commonwealth of Australia 1994). The OECD P-S-R model describes, respectively, the anthropogenic pressures on the environment, conditions or states of valued elements of the environment, and human responses to changes in environmental pressures and conditions. In the inland waters chapter of *Australia: State of the Environment 1996*, the pressures on inland waters were presented in detail, together with an account of the current condition of inland waters, and some responses to those pressures. In the present report, indicators of state or condition are routinely called "condition indicators".

Australia: State of the Environment 1996 is the first stage of an ongoing evaluation of how Australia is managing its environment and meeting its international commitments in relation to the environment.

Subsequent state of the environment reports will assess how the environment, or elements of it, have changed over time, and the efficacy of the responses to the pressures on the environment. The next national SoE report is due in 2001, consistent with the regular reporting cycle of four to five years. In order to assess changes in the environment over time it is necessary to have indicators against which environmental performance may be reviewed. As pointed out in *Australia: State of the Environment 1996*:

> "In many important areas, Australia 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".

The development of a nationally agreed set of indicators is the next stage of the state of the environment reporting system. This report recommends environmental indicators for inland waters. Indicators for land (Hamblin 1998), biological diversity (Saunders *et al*. 1998), and estuaries and the sea (Ward *et al.* 1998) have been developed in consultancies run in parallel with the development of indicators for inland waters. Indicators for atmosphere, natural and cultural heritage and human settlements have been developed about six months behind the first four themes.

Environmental indicators

Environmental indicators are physical, chemical, biological or socio-economic measures that best represent the key elements of a complex ecosystem or environmental issue. An indicator is embedded in a well-developed interpretive framework and has meaning beyond the measure it represents.

The set of key indicators must be the minimum set which, if properly monitored, will provide rigorous data describing the major trends in, and impacts on, Australian freshwater ecosystems. It should include:

- indicators that describe the Condition of all important elements in each biological level in the main ecosystems;
- indicators of the extent of the major Pressures exerted on the elements; and
- indicators of Responses to either the Condition or changes in the Condition of the ecosystems and their elements.

The selection criteria for national environmental indicators are listed below (from Commonwealth of Australia 1994) and selected indicators of inland waters should satisfy as many of these as possible. Thus, indicators should:

- serve as a robust indicator of environmental change;
- reflect a fundamental or highly valued aspect of the environment;
- be either national in scope or applicable to regional environmental issues of national significance;
- provide an early warning of potential problems;
- be capable of being monitored to provide statistically verifiable and reproducible data that show trends over time and, preferably, apply to a broad range of environmental regions;
- be scientifically credible;
- be easy to understand;
- be monitored regularly with relative ease;
- be cost-effective;
- have relevance to policy and management needs;
- contribute to monitoring of progress towards implementing commitments in nationally significant environmental policies;
- where possible and appropriate, facilitate community involvement;
- contribute to the fulfilment of reporting obligations under international agreements;
- where possible and appropriate, use existing commercial and managerial indicators; and
- where possible and appropriate, be consistent and comparable with other countries' and State and Territory indicators.

Scope of inland waters

The accepted definition of inland waters is the surface and underground water resources not associated with the seas (thus excluding estuaries and coastal lagoons). These waters are predominantly fresh, but can be more saline than seawater for natural or cultural reasons. Such water resources may be permanent or temporary. Inland waters constitute important inland ecosystems — including wetlands, rivers, lakes, streams, aquifers, ponds and floodplains.

Inland waters are diverse in type, source, quality and setting within the landscape. Yet for monitoring and reporting on the condition of inland waters there has to be some acceptable baseline against which change can be measured.

Conceptual and policy approaches to inland waters

Conceptual frameworks are important to guide the development of indicators. Two were discussed at the Inland Waters Workshop held in Canberra in April 1996 (DEST 1996). The older of these emphasises ensuring water is suitable for use by people, and has guided most water quality investigations in the past. The more recent framework is based on a concern for the health of aquatic ecosystems, thus freeing emphasis from merely anthropocentric concerns to embrace ecocentric ethics as well (Fairweather 1993). Because the environment has many non-human elements, the newer of these approaches will dominate the discussion that follows.

Four complementary management or assessment frameworks for inland waters, currently accepted by Australian governments, are relevant to developing indicators. These are the Wetlands Policy of the Commonwealth Government of Australia, the COAG water principles, the National Water Quality Management Strategy, and the National Land and Water Resources Audit.

The Wetlands Policy (Commonwealth of Australia 1997) brings together the different strands of Commonwealth policy regarding wetlands protection and management to fulfil Australia's obligations under the Ramsar Convention on Wetlands. This policy covers a particular habitat type relevant to inland waters, and is one of the few such policies in existence.

Internationally, the amount of water available for different uses is undergoing urgent audits (Gillis 1997). In early 1994, the Council of Australian Governments (COAG) agreed that we need to establish water entitlements for the environment to protect the health of Australian inland waters (Anon 1995). A set of 12 national water principles (ARMCANZ/ANZECC 1995) was developed, with the overall goal "To sustain and where necessary restore ecological processes and biodiversity of water dependent ecosystems". This is obviously consistent with a concern for ecosystem health.

The Commonwealth and all State and Territory Governments are participating in the development of the Australian National Water Quality Management Stategy (ANZECC 1992). The goal of this strategy is to achieve sustainable use of the nation's water resources by protecting and enhancing their quality while maintaining economic and social development. One of the aims of this goal is the protection of inland waters and the maintainance of ecological processes and systems. State of the environment reporting could be used to assess how this goal is being met. Thus, indicators of inland waters might be geared to this assessment. The water quality guidelines are currently under review — via a contract to the Environmental Research Institute of the Supervising Scientist (ERISS), see Carbon (1996).

The Land and Water Resources Research and Development Corporation (LWRRDC) is managing a National Land and Water Resources Audit (NLWA), resourced with $32 million. The NLWA aims to undertake an economic evaluation of environmental degradation and includes links to a National Water Resources Assessment (NWRA) as a major source of data. The NWRA should at least replicate the last national assessment of water done by the Australian Water Resources Commission (AWRC) in 1985 (DPIE 1985). SoE indicators will be useful for descriptive aspects of both the NWRA and the NLWA.

These management and assessment frameworks list a number of objectives and actions. Progress towards each objective needs to be monitored, and national SoE indicators could aid this assessment. Suitability for monitoring progress towards these national goals is an important consideration in recommending environmental indicators for inland waters.

Regionalisations and spatial scales for reporting on national environmental indicators

Regionalisations are an essential framework for focusing attention, summarising patterns, aggregating information, and developing indicators, as well as allocating priorities and resources (Thackway and Cresswell 1995). Indicators of inland waters must be reported using regionalisations that represent topographical, hydrological and ecological realities.

Most regionalisations in common use are constructs drawn up for social or political reasons; State, Territory and local government boundaries and statistical local areas are prime examples. While they may be important for political and social reasons, waterbodies and catchments are constrained by landscape evolution, climate, substrate, landform and a number of other ecological conditions and do not recognise these artificial regionalisations.

The most meaningful regionalisations for inland waters are generally those based on catchments. This is because surface waters are arranged spatially as a network throughout the landscape, effectively controlled by topography. Thus, catchments delineate watersheds with real biophysical boundaries for surface waters.

Important and useful regionalisations currently used in Australia are:

- the twelve drainage divisions used by AWRC since the 1970s and in *Australia: State of the Environment 1996* (see Figure 7.1 of State of the Environment Advisory Council 1996);
- the 77 water regions used for planning;
- the 245 river basins (mostly corresponding closely to real catchments and sub-catchments);
- the 61 groundwater provinces (i.e. hydrogeologically based); and
- the seven major groundwater basins.

Any of these is, in some ways, more biophysically consistent than State and Territory borders, and will return relatively few regions in the arid and semi-arid parts of the continent. The choice comes down toarguing about the primacy of geopolitics versus planning versus topography.

Currently, Environment Australia does not have digitised versions of the smaller, more numerous classifications listed above. For the purposes of this report then, the regionalisation used will be the twelve drainage divisions and the seven major groundwater basins, with reference to where a finer-scale resolution would aid reporting. The lack of digitised base-maps is addressed in the section below on research and development needs.

Some pressures and responses are more appropriately considered at the scale of expression, which is usually (but not always) the local scale. Therefore, indicators of these pressures and responses are expressed at the local scale, which for national state of the environment reporting is the Statistical Local Area. Most off-site impacts (e.g. salinity, eutrophication, chronic toxic contamination) have a regional component that is suited to aggregated scales of reporting. The issue of how to aggregate different types of information is further addressed in the section on research and development needs for SoE indicators.

Different regionalisations are appropriate for other, related aspects of the environment such as biological diversity and estuaries and the sea. Some of the main regionalisations and their relationship to drainage basins are discussed below.

The Interim Biogeographic Regionalisation for Australia (IBRA, see Thackway and Cresswell 1995) has been developed as a framework for setting priorities in the National Reserves System Cooperative Program that has as its primary aim the conservation of biodiversity. The IBRA is intended to define, map and describe the major ecosystems of Australia and is an integrated classification of biotic and abiotic variation. IBRA regions represent a landscape-based approach to classifying the land surface, including attributes of climate, geomorphology, landform, lithology, and characteristic flora and fauna. It has meaning to ecologists and land managers (Thackway and Cresswell 1995) and, subject to verification for particular indicators, should be useful for state of the environment reporting (State of the Environment Advisory Council 1996). IBRA incorporates boundaries based on the 12 drainage divisions as one of its first data layers, so these two are in broad agreement.

A potentially catchment-based scheme is embodied in the classification of rivers by the Australian National University's Centre for Resource and Environment Studies (CRES) on behalf of the Australian Heritage Commission for the protection and management of wild rivers under the relevant Commonwealth Act. During 1996 there was an attempt to broaden this approach to incorporate all rivers in the Murray–Darling Basin — under the rubric of CSIRO research sponsored by the Murray–Darling Basin Commission (MDBC). This is geared for use in work on environmental flows allocations and thus uses information about human-made river structures as well as natural features. Any river classification that results from this work is potentially useful in reporting SoE information. No report has yet appeared from this meeting.

Some existing inventories relate to State and Territory boundaries. For example, ANCA (1996) is an important listing of important wetlands throughout Australia, but has collated information about them for the eight jurisdictions plus external Territories and offshore islands, with a chapter cross-referencing these to IBRA. No doubt the use of expert officers from each jurisdiction who are most familiar with their estate makes this a more useful document than one written from afar.

Approach to selecting indicators

A myriad of attributes could be measured as indicators for inland waters. Virtually every aspect of the hydrology, chemistry, geomorphology and ecology of a waterbody can be (and has been) used to describe its condition. Almost all human activities associated with a waterbody and its surrounding lands can be considered as potential pressures, and a multitude of potential actions follow, as responses, from those two categories. The approach taken here has been to review the indicators that have been used in Australia and elsewhere and to add any novel indicators that show real potential. All these have then been evaluated against the set of criteria listed above.

Some indicators we evaluated can be considered in more than one category — e.g. nutrient contamination is often thought of as a condition regarding water quality per se, but is also a pressure on aquatic biota. We have noted such differing viewpoints in discussing a given indicator in this report. More generally, the concept of biological indicators of inland waters is relatively new for Australia and information is limited and nowhere near as complete as for physical or chemical water quality, where there are a series of measurements which are readily made and give a reliable description of some aspects of the condition of the water.

Indicators must be easily measured but also be representative of deeper processes for known boundary conditions. Where direct measurements are too difficult or costly, or where many elements might be represented by only a few critical aspects, the use of surrogates becomes crucial. Any decision on which level of surrogacy to use depends on the scale of measurement and reporting and the resources available. The greater the level of precision, the better the indicator. For national state of the environment reporting it will be possible, in some cases, to use some measures commonly adopted at local scales because they are available at a consistent level of detail.

Indicators of responses were the most difficult to develop during this consultancy. This difficulty may arise because the consultants are natural scientists rather than social or political scientists. Responses may include government policies, legislation, administrative structures, community education, direct management, setting targets, etc. Therefore, the approach taken here is that the level of activity needs to be addressed before assessing how appropriate or effective any response(s) might be. Some of the suggested indicators may seem strange or difficult to quantify, but that first impression is probably a measure of their novelty. In particular, we have to think about responses in new or unconventional ways. The alternative is to have very few indicators of response at all; this has been the case in the past (see Table 1 and State of the Environment Advisory Council 1996). One approach to developing response indicators and categories for their use is to employ expert panels to make subjective judgements. The expert panel approach is now used routinely in several States for choosing flow allocations (see Young *et al*. 1995).

One of the most important requirement for the selection of SoE indicators is the ability to represent the environment at the national level. There may be few indicators of inland waters that are able to do this. For example, while it is desirable for a study of a single, valued waterbody to include any suspected toxic chemicals within it, the sheer cost of doing so on a site-by-site basis across the whole country is too daunting and so precludes this as a nationwide indicator. So, efficient data collection is paramount. Other crucial selection issues are: the degree to which we understand the process of how the indicator operates; the desirability of knowing about some specific threat or the condition of some valued component of the inland waters environment; the ability to interpret what the indicator means (based also in an understanding of process); its utility in a variety of situations found across Australia; and its potential as a communication tool. These latter can be worked upon as part of the further research and development of the key indicator set.

We were not constrained to presently used data sets or to SoE indicators already used in various jurisdictions. Our emphasis here is on what should be monitored rather than on what has been done in the past. Thus quite a few novel indicators, especially of responses, are recommended by this report. One by-product of that outcome is an ongoing need to "sell" such novel indicators as well as refine them to the point of routine use. Suggestions for doing so are given in the later section on research and development recommendations.

Decisions about the indicator set were necessarily staged, with different amounts of time put into ones that are promising compared with ones that are too diffuse or difficult to develop very far. Some 200+ different proto-indicators were evaluated by this process. These were 58 pressure indicators, 109 condition indicators and 43 response indicators.

Indicators of inland waters taken from eight State of the Environment reports from Australia:

An examination of eight recent State of the Environment reports from around Australia showed that 134 different indicators were used for inland waters (Table 1). Only one of 46 indicators of pressure was common to all eight reports. Similarly, only four of 82 condition indicators were used in all reports and none of the six response indicators was used in five or more publications.

Given the importance of inland waters, the divergence amongst these limited sets of indicators shows the need for reassessment. Present indicators are clearly inadequate to assess condition and trends, particularly in relation to areas outside designated conservation catchments where pressures on inland waters are greatest and the most severe land-use conflicts occur.

Table 1

National: *Australia: State of the Environment 1996* (State of the Environment Advisory Council (eds) 1996)
ACT: *Australian Capital Territory State of the Environment Report 1994* (Australian Capital Territory, Canberra 1994)
SA: *The State of the Environment Report for South Australia 1993* (Department of the Environment and Land Management 1993)
NSW: *New South Wales State of the Environment 1993* (Environment Protection Authority 1993)
New South Wales State of the Environment 1995 (Environment Protection Authority 1995)
Victoria: *Victoria's Inland Waters State of the Environment Report 1988* (Office of the Commissioner for the Environment 1989)
Agriculture and Victoria's Environment: Resource Report, 1991, State of the Environment Report (Office of the Commissioner for the Environment 1992)
WA: *State of the Environment Report for Western Australia 1992* (Government of Western Australia 1992)

(A) Frequency of use of the 134 indicators of inland waters used in the eight reports.

Number of reports	1	2	3	4	5	6	7	8
Number of indicators	78	13	16	9	7	4	2	5

(B) The commonly used indicators. Only indicators used in four or more of the reports are listed.

Indicator of	Number of reports
Pressure	
Water consumption and withdrawal	8
Groundwater use	6
Water use patterns	5
Water storage in dams and reservoirs	4
Point sources of pollution — load, nature, frequency	4
Condition	
Stream flow characteristics	8
Surface water salinity	8
Surface water phosphorus concentrations	8
Surface water nitrogen concentrations	8
Groundwater levels	7
Surface water turbidity	7
Surface water temperature	6
Surface water heavy metal concentrations	6
Surface water resources	6
Extent and condition of riparian vegetation	5
Aquatic invertebrates	5
Surface water acidity (pH)	5
Surface water dissolved oxygen (DO)	5
Surface water pesticide concentrations	5
Groundwater salinity	5
Fish community status	4
Extend and condition of wetlands	4
Algal chlorophyll-a levels	4
Bacterial levels (drinking and surface waters)	4
Surface water biochemical oxygen demand (BOD)	4
Salinisation (irrigation and dryland)	4
Waterlogging	4
Response	
(none)	

It is notable that a number of indicators are relevant to different broad themes or issues as outlined above. Generally an indicator that can address more than one theme is more desirable than a single-issue indicator, but there must be trade-offs between generality of application and indicator precision (or specificity).

Grouping the indicators

The proto-indicators (i.e. the many suggested or potential indicators) evaluated are discussed under the seven following broad elements or issues: Groundwater; Human health; Water quality; Water quantity; Physical change; Biotic habitat quality; and Effective management. These categories were chosen to organise our deliberations about proto-indicators and do not represent a definitive typology. A brief rationale for each issue or element follows:

Groundwater: A broad distinction is often made between groundwater and surface waters (e.g. Commonwealth of Australia 1995). This is due to differences in how ground and surface waters are studied or assessed, and in the threats to them (especially in relation to their time courses). In this report we continue this division by considering all issues primarily associated with groundwater together, and grouping issues relating to surface waters under a number of different topics. However, we do emphasise that there are many instances where these two interact, e.g. irrigated salinity and elevated watertables, wetlands, river baseflows, etc.

Groundwaters flowing through porous media can travel large distances over long time periods. In many parts of Australia, baseflow in streams (including sizeable rivers like the Darling) is maintained by groundwater inputs. Therefore groundwater levels and their quality are valuable indicators of processes affecting the long-term viability of water systems. They reveal direct relationships between land use or development and hydrologic response, which may be invisible from surface water monitoring only. This allows prognoses of the longer term impacts of such pressures.

The timescales of groundwater reserves are also longer than those of surface waters, giving both slower action and, in places, an ancient resource. Thus, groundwater is the "future water resource", and effective SoE reporting (i.e. truly useful for natural resource management) must have an indispensable component of groundwater monitoring.

Human health: Human health is a paramount issue for the sustainability of any resource. Much concern about water quality in the past has been with the suitability of water for human use such as drinking, contact, recreation, raising foods, etc. Many other human health issues are addressed in the human settlements theme report, thus only three key indicators relating to human health are developed in this report.

Environmental water quality: There is a whole industry surrounding the measurement of environmental water quality (Aquatech 1995), but worldwide it has been described as suffering from the "data rich but information poor" syndrome (Ward et al. 1986). A lot of effort is expended in ways that are not necessarily optimised, and value for money is not readily apparent. Thus, this industry produces a lot of data that could, with further effort, be used to inform SoE reporting. The selection among these many possibilities is a key issue with a great range in ease of measurement (Jolly *et al.* 1996).

A better approach to water quality pressures might be to audit the materials that can contaminate waterways. This could be done by a process such as the National Pollutant Inventory (if extended to cover all sources) combined with judicious use of Australian Bureau of Statistics (ABS) and economic data on commodities of interest (e.g. pesticide imports or sales, fertiliser production, etc.) We can use these estimated expenditures as surrogate indicators of pressure. Another alternative is to document the classification from a potential-use perspective, e.g. the proportion of waters meeting ANZECC or equivalent criteria for potability, recreation, stock and domestic, or environmental protection purposes.

Surface water quantity: The COAG water principles represent a fundamental shift in how water will be allocated in the future. This shift embodies the broadening of concern from interest in the suitability of water for human use to valuing all the attributes of inland waters. Therefore we must be concerned with environmental flows, allocations across different environmental components and the way these allocations are conducted. This is a cornerstone, for example, of the Sustainable Rivers Program of the MDBC. There is much research activity under way (e.g. AWWA 1994). There is now a level of management and monitoring activity surrounding water quantity *per se* that may not rival the effort expended on understanding water quality but hopefully will be more cost-effective.

Physical change: The land affects the water flowing under and over it in many ways — providing particles and solutes, redirecting flows, modifying the timing and amount of runoff, etc. This crucial linkage must be a key feature of SoE reporting. This section is linked very strongly with the land resources theme, and several condition indicators in that theme are pressure indicators for inland waters. Many of these issues are manifest as physical instream changes to surface waters and the channels they flow through. However, chemical, biological or hydrological changes are discussed elsewhere, and indicators considered under this heading relate to physical changes in the land through which surface waters flow.

Biotic habitat quality: The most refined expression of the character of our waters may be the responses of the animals, plants and micro-organisms living in them. Aquatic organisms are the ultimate "end users" of our water management. Water quality monitoring now routinely uses assessments of invertebrates, fish and aquatic plants. As argued by Cranston *et al.* (1996), assessing river biota at any point integrates the ecosystem condition of all the catchment above and is thus a holistic assessor of catchment "health".

Effective management: Integrated management that addresses real issues is the key to avoiding problems in the future as well as fixing the problems we have now. Integrated or total catchment management (ICM, TCM) is addressed under this heading. Like many of the other response indicators dealt with in this report, these key indicators are novel attempts to use social and political information to assess management activity. They are not presently being monitored for SoE purposes and so are quite experimental.

Some categories used by other themes (e.g. for estuaries and the sea — integrated management, renewable products, cited species/taxa, ecosystem-level processes) were either not considered particularly useful for inland waters or covered within one or more of the seven listed above.

ANZECC Water Quality Guidelines

The revised ANZECC Water Quality Guidelines (Anon 1997a,b) will differ in their approach from the current ANZECC (1992) guidelines. More detailed environmental guidelines will be set, with increased consideration of ecosystem-based guidelines and four types of ecosystems described for fresh waters (lowland rivers, upland rivers, freshwater lakes and reservoirs, and wetlands).

The guidelines will be based on issues — such as "maintenance of dissolved oxygen" or "effects of pH changes". A risk-based approach will be employed, with the use of biological effects data to determine low-risk trigger levels. Generally the guidelines will be based on concentrations, but load-based guidelines are suggested as more appropriate for nutrients, solid particulate matter and biodegradable organic matter.

Guideline packages are presented for each issue, addressing:

- the environmental effects that may be observed;
- key indicators (of four types — condition; key stressor; modifiers; and performance indicators);
- the formulation of low-risk trigger levels; and
- the recommended approach for the overall use of the guideline package.

When trigger levels are exceeded, a process of further investigation is outlined using a "decision tree".

Trigger levels are the concentrations or loads of the key "performance" indicators, above which the risk of adverse biological (i.e. ecological) effect is considered unacceptable. The trigger levels will be ecosystem-specific, and there are two basic methods for determining the levels. The first uses biological effects data, which may be from the literature or derived from studies of local biota in local waters. The second relies on the use of reference system data — as in the Australian River Assessment Scheme (AUSRIVAS — see Indicator 6.1) — and may involve using the same ecosystem but removed from the possible impact (i.e. upstream) or another similar ecosystem within the same region. There are considerations for direct and indirect effects; the former would rely on toxicity data (preferably using extensive toxicity acute and chronic data and, if available, local ecosystem information). Indirect effects could be assessed through statistical approaches using reference systems and perhaps modelling packages, such as taking the 80th percentile or the mean plus one standard deviation of the reference distribution.

With the ecological risk assessment approach to guidelines, a rapid biological assessment procedure such as AUSRIVAS could be employed. An example of its use would be when the condition indicators are specified as being species composition and the abundance or absence of key species.

Another section of the new ANZECC guidelines will address for the first time the use of sediment quality guidelines. These interim sediment quality guidelines will complement the water quality guidelines, because it has long been recognised that sediments play an important role in aquatic ecosystems, especially as a source and sink for pollutants. The new guidelines have reviewed current knowledge of the environmental impacts from polluted sediments to set the interim guidelines, and also outline a procedure for the development of Australian guidelines.

Key Indicators for National State of the Environment Reporting on Inland Waters

This report recommends 53 indicators as the key indicator set. Table 2 lists the key indicators with their C-P-R categorisation and whether further research and development is needed on each indicator. Most require at least some further development.

Table 2

The key set of indicators of Inland Waters.

The category of each Key Indicator (C = Condition, P = Pressure, R = Response indicators) is shown against the issue or element descriptions; and whether further research and development is needed for this indicator (Y=yes, N=no, ?=some details need to be defined or refined).

Issue or element	C/P/R	Research and development needed?
Groundwater		
1.1 Depth to watertable	C	N
1.2 Groundwater salinity	C	N
1.3 Borehole capping	R	
1.4 Estimated resources	C	N
1.5 Net amount abstracted /discharged	P	?
1.6 People, stock and crops supported	P	?
Human Health		
2.1 Human criteria exceedances	C	Y
2.2 Swimming days lost	P	?
2.3 Wastewater treatment	R	N
Environmental Water Quality		
3.1 Guideline trigger levels reached	C	Y
3.2 Algal blooms	C	N
3.3 Nutrient loads	C	?
3.4 Chemical residues	C	Y
3.5 Pesticide exposure	P	Y
3.6 Pollution point sources	P	Y
3.7 Minesite remediation	R	Y
3.8 Bloom contingency plans	R	?
3.9 Polluter pays principle	R	Y
3.10 Pollutant detection	R	Y
3.11 Waterwatch participation	R	N
3.12 Zero-P detergents	R	Y
3.13 Instream salinity trends	C	N
Surface Water Quantity		
4.1 Resource versus demand	C	?
4.2 Surface water distribution	C	N
4.3 River flow regimes	C	Y
4.4 Environmental Flows Objectives	R	?
4.5 Flooding	C	Y
4.6 Alienated floodplains	P	Y
4.7 Water use	P	N
4.8 Irrigation extent	P	?
4.9 Water pricing	R	?
4.10 Irrigation efficiency	R	Y
4.11 River structures	P	?
4.12 River discontinuity	C	Y
Physical Change		
5.1 Vegetated streamlength	P	?
5.2 Extractive industries	P	N
5.3 Catchment clearance	P	?
5.4 Farm distance	P	Y
5.5 Riparian stock access	P	?
5.6 Fenced waterways	R	?
5.7 Stream sinuosity	C	Y

Table 2 (cont.) The key set of indicators of Inland Waters

Issue or element	C/P/R	Research and development needed?
Biotic Habitat Quality		
6.1 AUSRIVAS survey ratings	C	N
6.2 Frogwatch records	C	?
6.3 Fish kill records	C	?
6.4 Waterbirds	C	Y
6.5 Habitat loss	P	Y
6.6 Exotic pest flora and fauna	P	N
6.7 Wetland extent	C	?
6.8 Pest control	R	Y
Effective Management		
7.1 Consistency	P	Y
7.2 Management effort	R	?
7.3 Participation	R	?
7.4 Licensing	R	N

Table 3(a) summarises the total key set in terms of these categories and classes. Table 3(b) lists the dozen key indicators that do not require large amounts of developmental work; half of these are indicators of condition. Interestingly, there are no clear, simple triptychs of C-P-R indicators amongst these twelve.

Table 3

Key Set Summary.

(a) Key set summary of numbers of the recommended key indicators against their categories and types.

	Category			Total	R&D	
	P	**C**	**R**		**Y**	**?**
Groundwater	2	3	1	**6**	0	3
Human health	1	1	1	**3**	1	1
Environmental water quality	2	5	6	**13**	8	2
Surface water quantity	5	4	3	**12**	5	5
Physical change	5	1	1	**7**	2	4
Biotic habitat quality	2	5	1	**8**	3	3
Effective management	1	0	3	**4**	1	2
Total	**18**	**19**	**16**	**53**	**20**	**20**

(b) Subset of the 12 key indicators with the least research and development needed now:

Pressure	4.7	Water use
	5.2	Extractive industries
	6.6	Exotic pest flora and fauna
Condition	1.1	Depth to watertable
	1.2	Groundwater salinity
	1.4	Estimated resources
	3.2	Algal blooms
	3.13	Instream salinity trends
	4.2	Surface water distribution
	6.1	AUSRIVAS survey ratings
Response	2.3	Wastewater treatment
	3.11	Waterwatch participation
	7.4	Licensing

Issue or Element 1: Groundwater

Indicator 1.1: Depth to watertable

Description

Depth to groundwater aquifer or perched watertable.

Rationale

The depth of the watertable is important because if it is too shallow there is risk from waterlogging, salinisation or effects from any water-borne contaminants. A continually falling watertable, on the other hand, indicates that discharge exceeds recharge and thus there is pressure on the groundwater resource.

Analysis and interpretation

Two specific measures can be analysed for this indicator:

1. Area of land underlain by shallow watertables (as a measure of land degradation induced by irrigation or clearing). Shallow watertable is to be defined as less than *x* metres, where *x* may be regarded as regionally important on the basis of scientific studies — typically *x* = 1 to 4.

2. Trends in depths over time, e.g. rising or falling water tables over a period of 5 to 10 years. These indicate the potential for increased salinisation or waterlogging, or excess groundwater extraction with respect to rates of replenishment. This is a very direct measure of the sustainability of a groundwater system (and any surface water system relying on it for baseflow), and generally needs a long-term record (in order to account for the effects of year-to-year variations in rainfall). Rates of rise of centimetres per year can be a concern where the watertable is shallow.

Monitoring design and strategy

Depth to watertable must be measured locally with piezometers, wells or bore holes. In most catchments these are used now for local measurements; they should be configured into a national network. For complete interpretation, the following information for each well is also needed: depth of well; casing and screen intervals; and stratigraphy from hydrogeologists' or drillers' logs. Other useful information includes the year of construction, yield of the well, any water quality analyses, and the elevation (e.g. in Australian Height Datum) of the top of the casing of the well. Piezometric data could possibly be supplemented by electromagnetic (vehicle-mounted) surveys across larger areas where the watertable is shallow enough. Data are integrated and interpolated by geostatistics and Geographic Information System (GIS). Also important is an assessment of the change in baseflow of connected streams, where there are trends in groundwater levels. Time series of groundwater elevation (in relation to Australian Height Datum of the top of the bore casing minus the depth to watertable) provides valuable information for calibration of groundwater models (and is helpful for management).

Reporting scale

The reporting scale should be the groundwater basin or aquifer. For each region, report the area of shallow watertable or area(s) with changing watertable levels as percentages of the total land area and map accordingly. It is probably best to express all results with respect to different types of aquifer (e.g. surficial or confined; sedimentary or fractured rock aquifers).

Outputs

Maps of areas underlain by shallow watertables or with rising or falling watertables. Hydrographs of piezometers that are representative of hydrogeologic units or regions. Estimation of storage volume changes over long periods of time (e.g. 1, 5 or 10 years) at the same time of year.

Data sources

Watertable levels are assessed using different methods by landowners or the Department of Primary Industries and Energy (DPIE)/Australian Geological Survey Organisation (AGSO), water or land authorities in each State and Territory and the like. DPIE/AGSO are the only national data holders, but most data are recorded in State archives (held by water or land authorities). A fair amount of effort by State and Territory departments is put into regional estimation of watertable depths using models for research or planning purposes.

Links to other indicators

Estimated Resources (key indicator 1.4)

Indicator 1.2: Groundwater salinity

Description

Salinity of groundwater aquifers, as a particular measure of water quality.

Rationale

Nationally, salinity is the major water quality limitation on the environmental values (including potential beneficial uses) of groundwater. It is influenced by human action such as accessions of irrigation water, disposal of waste waters, seawater intrusion in response to excessive extraction from coastally linked aquifers, and the like. Excessive salinity in all groundwaters may limit their use and therefore the productivity of lands reliant on bores tapping saline groundwater. Some are too salty for human use, but lower levels can adversely affect vegetation growing in areas of shallow watertables. Therefore, in most parts of the country salinity generally defines the degree of protection required from diffuse and point-source pollution.

Where background salinities are moderate to high, salinity is a relatively poor indicator of anthropogenic pollution (except where poor well completion results in cross-contamination of aquifers). Other measures, such as nitrate (as nitrate-N) and *E. coli* are also common indicators of groundwater quality. Nitrate is a commonly accepted indicator of pollution of unconfined groundwater from agriculture, sewage, and waste management. Although *E. coli* is attenuated more readily in groundwater than some pathogenic bacteria and viruses of human origin, it has not yet been replaced as an indicator of faecal pollution in groundwater. In areas where other identified potential concerns relate to land use or affect the health of the population, other regionally specific indicators would be valuable — e.g. fluoride, agricultural chemicals, industrial chemicals, hydrocarbons, and other pathogens.

Analysis and interpretation

Trends in concentrations with time at observation wells should be plotted, and the proportion of samples within various land-use or physiographic categories falling within various salinity classes recorded. Please note that standards for the top few metres of watertables or from pumpable aquifers differ from those for surface waters (e.g. EC > 4000 is considered high for an aquifer). See ANZECC (1992), Commonwealth of Australia (1995), Anon (1997a,b) and other National Water Quality Monitoring Strategy (NWQMS) publications for these guidelines. These concentration data should also be compared with baseflow water quality in streams where this is relevant. Some aquifers are naturally saline — e.g. ancient seabeds, in areas with low rates of recharge, or in semi-arid and arid areas where watertables are shallow and evaporation from groundwater occurs.

Monitoring design and strategy

Regular monitoring of groundwater for salinity can be done in wells, boreholes or piezometers at sampling frequencies appropriate to anticipated rates of change, based on piezometric records. Salinity is measured by a variety of methods and units, but should be routinely expressed as EC (electrical conductivity).

Reporting scale

Data collected locally can be aggregated up to the level of a groundwater basin to summarise the changes. Point measurements would need to be made using the piezometers, wells and bores of key indicator 1.1. Modelling can perhaps usefully extend this at the larger scales, if need be.

Outputs

Maps of environmental value (i.e. salinity classes) for each aquifer or basin based on salinity classes (see Commonwealth of Australia 1995), yielding a region-scale or nation-wide map of (a) the unconfined aquifer system (for protection and planning) and (b) the lowest salinity groundwater at each location (for aquifer evaluation). Graphs of salinity level trends over time (see Williamson *et al.* 1997 for type of figure) will be useful as the database increases over time.

Data sources

Landowners collect some data, but this is very patchy. As for most other groundwater data, the main sources are the State and Territory land agencies, and DPIE/AGSO are the national data holders.

Links to other indicators

Shallow watertable
Groundwater rise

Indicator 1.3: Borehole capping

Description

Percentage of bores capped, by groundwater basin.

Rationale

Uncapped bores squander groundwater (as do bores watering or irrigating using open channels rather than poly-pipe, thus losing water through evaporation). Recent data from CSIRO Division of Wildlife and Ecology suggest that in rangelands native biota which do not require open water sources are disadvantaged by uncapped bores. Programs to cap bores may increase over the next few years (especially on conservation lands).

Analysis and interpretation

Count the number of boreholes capped as a percentage of (a) all bores or (b) those registered as being desirable to cap (the latter being part of government initiatives for borehole capping). These two proportions gauge (implicitly) the magnitudes of the task still ahead and the current effort.

Monitoring design and strategy

For each groundwater basin or State and Territory, count the number of bores capped each year, plus the total number of boreholes (thus adjusted for any bores that run dry or are otherwise terminated). An alternative could be the money spent on capping programs (e.g. via DPIE).

Reporting scale

By groundwater basin, reported as number of bores capped since the last SoE Report. Therefore, the base level of the number of bores now capped will be first reported in the next SoE Report.

Outputs

Tables by basin, State and Territory or borehole type.

Data sources

Data sources are State and Territory agencies responsible for groundwaters, and DPIE and AGSO (see e.g. PMSEC 1996 for the national picture).

Links to other indicators

Abstraction versus recharge (key indicator 1.5)
Piezometric levels in vicinity of capped bores

Indicator 1.4: Estimated resources

Description

Estimated resources of groundwater remaining per basin.

Rationale

To manage any resource it is necessary to know how much of it is potentially available for utilisation and consumption (Pimental et al. 1997). This is as true for groundwaters as for any other resources and perhaps more so, because their subterranean nature makes groundwaters less "obvious" than other resources. Quantity (and quality) of groundwater varies across Australia. Such information can be used directly in planning as well as being a fundamental aspect to document in SoE reporting.

Analysis and interpretation

The total amount of groundwater in each aquifer and basin needs to be estimated regularly so that trends can be calculated. This is essential information for planning purposes (e.g. letting licences).

Monitoring design and strategy

Calculated from measurements by piezometric levels using nationwide bore hole network (see key indicator 1.1).

Reporting scale

Because the absolute amounts are very large, trends are probably most important to report. It is appropriate to do so on the time scale of the SoE cycle (i.e. every 4–5 years).

Outputs

Maps of the basins across Australia showing reserves that are declining, increasing or steady. Some indication of how rapidly reserves are increasing or declining should also be given, preferably by colour-coding maps. Estimates of how long an aquifer will last at current rates of usage may also be useful, especially when combined with estimates of how pumping may become harder or more expensive over time. These latter measures should be tabulated.

Data sources

DPIE and AGSO for the national picture. Relevant State and Territory agencies are calculating relevant parameters to varying degrees across the country. ABS physical water account may collect similar information.

Links to other indicators

Depth to watertable (key indicator 1.1)
Groundwater utilisation
Groundwater discharge
Groundwater recharge

Indicator 1.5: Net amount abstracted/discharged

Description

Net rate of groundwater abstraction or discharge from aquifers per unit time (i.e. relative to the rate of recharge of those aquifers).

Rationale

Groundwater is utilised for a variety of human uses and this abstraction potentially places pressure on this important resource, increasing the cost of pumping, inducing more saline water into an aquifer, and/or reducing baseflow to streams or availability of water for riparian uses. Natural and induced recharge processes that return rainfall and other surface waters to subterranean aquifers alleviate this pressure. The balance between abstraction and recharge is the most effective way to gauge the pressure.

Our use and consumption of groundwater puts a strain on the resource available and also perhaps the quality (Pimental *et al*. 1997). This is so because the rate of abstraction is greater than the rate of recharge of aquifers in many parts of the country (McMahon *et al*. 1991).

Thus this indicator measures the net rate of groundwater abstraction from aquifers or discharge to surface waterbodies such as streams, lakes, and estuaries, and how this varies seasonally and over longer periods of time.

Analysis and interpretation

Estimating groundwater abstraction and its variation over long time periods is much simpler than estimating natural rates of recharge. Baseflow estimation is relatively reliable, but techniques for estimating groundwater discharge for ecosystem support of riparian vegetation are still in their formative stage. Hence the effort to determine groundwater balance must be focused on trends in piezometric head, and the objective of this measure is simply to record the main management variable that affects this balance (i.e. rate of abstraction) and the environmental consequences of trends.

If good estimates of recharge are available, then this indicator can be interpreted grossly in terms of whether abstraction/discharge exceeds recharge or vice versa. If a discrepancy is in the direction of over-use, then the resource will decline over the period measured. The magnitude of this discrepancy is also important for modelling how long the resource can last or, more realistically, how steeply pumping costs will increase as the resource is used. A finer analysis would examine trends in this ratio over time to gauge fluctuations in pressure and the quality of any remedial responses and overall management.

Monitoring design and strategy

Two possible forms exist for this indicator. The more achievable form requires three separate data types: (1) the rate of abstraction (amount of groundwater per unit time), normally measured from pumping rates and licence reporting; (2) baseflow in streams (see key indicator 4.3); and (3) area of vegetation and proportion of evapotranspiration demand that is met by groundwater. The second form of the indicator requires (1) plus the rate of recharge to the aquifer, which is more often estimated from models calibrated by relatively few measurements. Both of these estimates should be based on point estimates from each groundwater basin.

Reporting scale

By States/Territories and groundwater basins. Because groundwaters can potentially move great distances in an aquifer (admittedly over long periods), it is not feasible to measure either recharge or abstraction locally to arrive at a meaningful local estimate.

Outputs

Maps showing groundwater discharge to economic uses and environmental sustenance, in units of millimetres of water. This should allow a perception of environmental impacts of groundwater exploitation. These data can also be displayed as positive, neutral or negative relative rates, shown in different colours.

Data sources

AGSO, DPIE, State and Territory agencies (as per key indicators 1.1 and 4.3).

Links to other indicators

Estimated resources (key indicator 1.4)
People, stock and crops supported (key indicator 1.6)
River flow regimes (key indicator 4.3)
Groundwater utilisation
Groundwater discharge
Groundwater recharge
Groundwater abstraction

Indicator 1.6: People, stock and crops supported

Description

The number of people and stock, and the amount of crops, supported by groundwater.

Rationale

In arid and semi-arid areas of Australia (and in some more mesic climates with limited runoff), the main water resource for human activity is groundwater. Although continental groundwater resources are very large, this use puts a pressure on them. The number of people utilising groundwater as their main supply of water is a traditional indicator (e.g. see Commonwealth of Australia 1995). The number of livestock and area or value of major crop types supported by groundwater gives a better measure of its social and economic value. Stock need to be included to cover the extensive rangelands. This indicator should also include the spring and mineral water industries.

Analysis and interpretation

This indicator will be most useful when estimates are compared with estimates of the resource remaining, especially if trends are known. Known sources of surface water, rainfall, runoff and hydrology should also be considered when interpreting indicator behaviour.

Monitoring design and strategy

Estimates depend on the population size and the dominant agricultural activity of each reporting unit (State and Territory or groundwater basin).

Reporting scale

Australia-wide, but can also be reported for each groundwater basin (i.e. disaggregated). Available annual estimates of people, stock and crop supported should be aggregated up to the SoE cycle (4–5 years) for reporting purposes.

Outputs

Maps of the country showing estimates for different States/Territories or drainage basins, with total values tabulated.

Data sources

Combination of extant DPIE and ABS data, but neither authority currently presents data in this form.

Links to other indicators

Estimated resources (key indicator 1.4)

Issue or Element 2: Human Health

Indicator 2.1: Human criteria exceedances

Description

A novel composite indicator: percentage exceedances of water quality guidelines for a suite of bacterial and chemical water quality parameters for human health and recreation, per drainage division.

Rationale

Some water quality parameters are indicative of risks to human health, such as bacterial exposure through drinking water or physical contact. Water is often reused, so it is essential to monitor and limit the degree of contamination from its previous use and maintain a "healthy" water supply. Drinking waters are monitored for bacterial contamination (see ANZECC 1992 and NHMRC–ARMCANZ 1996) and many possible chemical concentration indicators (including NSW's Schedule 10 for 114 toxic, carcinogenic, mutagenic and teratogenic chemicals). Water supply amenity includes measurements of the natural concentrations of calcium carbonate (water hardness), magnesium, iron and manganese, and there are also chemical indicators such as aluminium, trihalomethanes and nitrate.

Analysis and interpretation

This indicator is a composite of a variety of human-related water quality measurements. Each separate water quality variable must be measured to make up this composite, but they are dealt with together to simplify discussion and avoid duplication of reporting. They should be reported both in composite and disaggregated form. This also allows for different jurisdictions to vary their measurements (in frequency or what is measured, rather than how) in accordance with the NWQMS.

Water Quality Guidelines (ANZECC 1992 or Anon 1997a,b) are used to indicate significant level of change for recreational purposes (primary and secondary contact), and drinking water quality guidelines (NHMRC–ARMCANZ 1996) are used to indicate any exceedance of the recommended levels (for various bacteria and chemicals) for potability.

Any exceedance of the local/regional trigger levels or other criteria is worthy of reporting and by itself a cause for concern. Thus this indicator should be reported both as the composite ("there were *x* trigger levels reached out of *y* measurements") and by specific causes ("trigger levels reached were *z* occasions for faecal coliforms, *v* for hardness and *u* for nitrates").

Monitoring design and strategy

Using standard methods for collection and analysis, data are acquired to assess two aspects:

1. Potability: Local monitoring by water suppliers (councils and water authorities) for faecal coliforms (*E. coli*, total coliforms and other bacteria) carried out weekly. In 100 mL samples the ANZECC (1992) guidelines require that samples should be free of faecal coliforms and 95% of samples in any year should not contain any coliform organisms. Chemical measurements are carried out daily, weekly or monthly by local councils and water authorities. Water quality guidelines for raw waters for drinking purposes: Hardness as CaCO3 maximum permitted level = 500 mg/L, Iron = 0.3 mg/L, Manganese = 0.1 mg/L (ANZECC 1992). NHMRC–ARMCANZ (1996) guidelines for aluminium 0.2 mg/L and ANZECC (1992) guidelines for trihalomethanes 0.25 mg/L and nitrates 50 mg/L (for infants <3 months) or 100 mg/L (for infants >3 months).

2. Primary and secondary contact: Monitoring for microbial guidelines for primary and secondary contact from water quality characteristics (ANZECC 1992). Over the bathing season, the primary contact guidelines require that the median bacterial level should not exceed 150 faecal coliforms/100 mL and 35 enterococci/100 mL. Secondary contact guidelines require the median bacterial counts not exceed 1000 faecal coliforms/100 mL and enterococci 230/100 mL. In addition, free-living pathogenic organisms should not be present. Frequency of monitoring is a minimum of five samples taken at regular intervals over one month. The level of change in the indicator is dictated by the ANZECC water quality guidelines.

Reporting scale

The spatial scale of data collection is local and the geographic extent is national. For reporting purposes, data should be aggregated to drainage divisions.

Outputs

Tables of the percentage of monitored samples that exceed water quality guidelines. Report summary statistics for each component (i.e. geometric means for each chemical and bacterium type). The geometric means of such data have been used due to historical reasons (i.e. relate to guideline values) and continued use overseas. They are thought to represent a more "typical" value than arithmetic averages (Macdonald 1991), being less affected by a few high values. In addition, bacterial data are usually log-normally distributed and the use of the geometric means would therefore appear appropriate (Macdonald 1991).

Data sources

Councils and relevant health or water authorities to carry out monitoring for microbial guidelines (ANZECC 1992) and other water characteristics such as algal blooms and pollution incidents (spillage). Federal health authorities do not carry a centralised database of this information.

Links to other indicators

Guideline trigger levels reached (key indicator 3.1)
Swimming days lost (key indicator 2.2)
Water treatment (key indicator 2.3)
Algal blooms (key indicator 3.2)
Pollution point sources (key indicator 3.6)
Supply amenity
Microbiological indicators
Microbes

Indicator 2.2: Swimming days lost

Description

The number of swimming days lost per year due to poor water quality in recreational areas, by catchment.

Rationale

Poor water quality can result in the closure of swimming areas. The record of swimming days lost due to the exceedance of water quality guidelines for recreational water quality and aesthetics (ANZECC 1992) would indicate the frequency of poor water quality and thus identify areas for improved water management. This represents the pressure on inland waters amenity value in an important aspect of Australian community life.

Analysis and interpretation

Any closure is a loss of amenity. Joint examination of the number of swimming days lost and the incidence of closure would indicate the frequency and the duration of those events, and hence the severity of reduced water quality. Comparisons with previous years could assess possible trends in water quality and therefore identify those areas that are improving or worsening. This, in turn, would influence water management decisions and strategies. The reason for closure (e.g. microbial, pollutants, blooms, etc.) should also be reported.

Monitoring design and strategy

Microbial characteristics should be assessed at least five times at regular intervals within one month, to comply with ANZECC (1992) guidelines. Swimming areas are closed when guidelines are not met. Record the number of swimming days lost due to closure of swimming areas for exceeding water quality guidelines for recreational water quality and aesthetics (ANZECC 1992).

Reporting scale

Spatial scale of the data collection is local — i.e. lake, dam or river reach — and the extent should be Australia-wide. Data should be collected locally and aggregated to catchments or drainage divisions. Annual reports are appropriate.

Outputs

Maps and tables of number of swimming days lost and incidents per location within catchments. Reasons for closure can also be tabulated and tallied for aggregation across time and space.

Data sources

Local councils (including the Australian Local Government Association), State and Territory environmental agencies, water or health authorities and managers of recreation locations carry such records. No central database could be found. Councils and relevant authorities to carry out monitoring for microbial guidelines (ANZECC 1992) and other water characteristics such as algal blooms and pollution incidents.

Links to other indicators

Human criteria exceedances (key indicator 2.1)
Algal blooms (key indicator 3.2)
Bloom contingency plans (key indicator 3.8)

Indicator 2.3: Wastewater treatment

Description

The number of water treatment plants and the levels of water treatment or filtration adopted, per drainage division.

Rationale

Untreated water, if reused for drinking or human contact, can cause disease or pollution. Treatment to primary, secondary or tertiary levels exerts different (progressively lessening) pressure on the receiving water environment. With the increase in population there is an increasing need for water treatment. The density of the population will also affect the level of water treatment required, as will the disposal options utilised for urban waters. The environmental indicator report on human settlements (Newton *et al.* in prep) is dealing with water treatment more generally and fully.

Analysis and interpretation

Assessing the number of plants (to each level of treatment) per catchment/region or per capita by catchment is reasonably straightforward. Comparisons over time or among locations provide the most useful analysis. Assessing the increasing population requiring certain levels of water treatment would also be useful, but very difficult. Capacity of the plants is another useful possibility, but often this is not utilised (i.e. spare capacity might exist). An assumption here is that all wasterwater treatment should be at tertiary (or equivalent) levels for the return of treated water to inland waters.

Monitoring design and strategy

The number of water treatment plants could be tallied from reports of local councils and other operators. This indicator needs to be monitored only infrequently (say every 3–5 years) to pick up changes in wastewater management.

Reporting scale

Regional, and aggregated to catchments or drainage divisions.

Outputs

Tables showing the number of water treatment plants per catchment and the level of treatment. Maps with pie charts can show the treatment levels (size of slices) and number of plants (size of the pie).

Data sources

State and Territory water authorities, environment agencies, local governments, and health departments all report on the capacity and level of water treatment facilities. The ABS collates information on population size served by water supplies at a range of treatment levels.

Links to other indicators

Swimming days lost (key indicator 2.2)
Human criteria exceedances (key indicator 2.1)
Water usage (key indicator 4.7)

Issue or Element 3: Environmental Water Quality

Indicator 3.1: Guideline trigger levels reached

Description

A novel composite indicator: proportion of samples exceeding trigger levels in the application of Australian environmental water quality guidelines for the protection of aquatic ecosystems (Anon 1997a,b or ANZECC 1992) for physico-chemical and toxicant concentrations, per drainage division.

Rationale

Environmental water quality is usually assessed against some criterion or guideline for each separate chemical or physical variable. The difficulty is in assessing and displaying these many variables, especially when there is no expectation under the NWQMS that all attributes of water quality will be measured routinely in every place (cf. local interests). Standard methods are employed to measure the various parameters of water quality, coupled with regular monitoring to ensure that these water quality guidelines are being met. Compliance data (for legal requirements) are generated by water consumers (e.g. industrial, agricultural and urban) reporting to regulatory authorities (i.e. State EPA or equivalent).

Many of the components of this composite indicator are themselves indicators of the condition of a waterbody from a purely water quality perspective, but obviously they can also act as major sources of pressure upon biota living within it.

Analysis and interpretation

This indicator is a composite of a variety of environmental water quality measurements. Each separate water quality variable must be measured to make up this composite, but they are dealt with together to simplify discussion and avoid duplication of reporting. They should be reported both in composite and disaggregated form (see below). This also allows for different jurisdictions to vary their measurements (in frequency or what is measured, not how) in accordance with the NWQMS.

Currently each of these variables has its own guideline for the protection of aquatic ecosystems under the NWQMS (ANZECC 1992 and the revision currently underway, see Carbon 1996, Anon 1997a,b), but the philosophy of that Strategy is that these are only guidelines and the regional or local implementation of them will vary depending upon conditions. Thus this indicator will aid in the development of more local/regional applications of the overall guidelines. Thus the shift (Anon 1997a,b) is away from monitoring exceedance of fixed and stated criteria and more toward a risk-based approach, including trigger levels for ensuing managerial actions.

Any occasion that a local/regional trigger level is reached is worthy of reporting and by itself a cause for concern. Thus this indicator should be reported both as the composite ("there were *x* trigger levels reached out of *y* measurements") and by specific causes ("trigger levels were reached on *z* occasions for DO, *v* for salinity and *u* for cadmium"). The reporting is disaggregated for trigger levels only, rather than all the measurements made. The emphasis here is on trigger levels *in toto* rather than any individual measurements per sample, because different water quality variables might have different effects on ecosystem components.

Monitoring design and strategy

There is a very large number of individual water quality variables, and the frequency of monitoring for each individual variable will vary. All are essentially point measurements made with site-specific considerations in mind.

At least the following classes need to be considered for inclusion (using standard methods for instream waters):

1. Turbidity (due to suspended sediments): This is often monitored by measuring optical clarity as Secchi depth, Nephelometric Turbidity Units (NTU) or mg/L. The Secchi disk (and its Waterwatch equivalent of a fixed viewing tube with a cross at the bottom) is the simplest technology that can be employed by anyone in any waterbody during daylight hours. Overseas, large-scale community monitoring events such as the Great American Secchi Dip-in (held each August) are based on this technique (see WWW site http://humboldt.kent.edu/~dipin/).

2. Salinity (see also key indicator 3.13): Monitoring of salinity levels in surface waters as EC (Electrical Conductivity) can be used as an indicator of salinity. Surface water quality guidelines for the protection of aquatic ecosystems (ANZECC 1992) are that salinity should not be permitted to increase above 1000

mg/L, which is equivalent to about 1500 S/cm. This concentration may need to be reduced depending upon other uses of the water. Frequency of monitoring would be daily or weekly. This can be monitored by various water users.

3. pH: Water quality guidelines for the protection of aquatic ecosystems (ANZECC 1992) = pH 6.5–9.0. Reported as trigger levels only. Awareness of daily fluctuations is essential, so considering the time of day is important when making measurements.

4. Toxic substances, such as those covered in the Water Quality Guidelines: Potentially this includes many different chemicals; for example, the recent ecological risk assessments by Sydney Water (Sydney Water Corporation 1996) had to measure 114 different chemicals contained on NSW's Schedule 10 listing. Measuring these is expensive and often labour intensive, requiring trained personnel and specialised equipment. Rather than setting individual guidelines for 70 000 such chemicals, Anon (1997a) attempts to derive a general approach to toxicants. Different regions are likely to measure quite different suites of chemicals, each of local interest. Potentially this makes any uniform reporting very difficult unless all such comparable measurements are aggregated. Thus this indicator will use whatever measurements are made locally. Increased heavy metal levels need to be measured, but reported only as trigger levels are reached (ANZECC water quality guideline for heavy metals) or perhaps used as case studies. Heavy metal loads in tonnes of heavy metals supplied to waterways as effluent are also possible. Pesticides and trace metals could be measured both as concentrations and toxicity (see Chapman 1997).

5. Dissolved Oxygen — measurement of dissolved oxygen concentration in surface waters: Standard methods are involved, either electronic probes or winkler titration methods. Spatial scale should be local. Frequency of monitoring depends on water usage, etc. The level of change that is likely to be important is reflected in the Australian water quality guidelines for the protection of aquatic ecosystems (ANZECC 1992); >6 mg/L (>80–90% saturation) measured over at least one, but preferably several, diurnal cycles. At < 4 mg/L fish can die or leave the location. Time of day is important when taking measurements due to diurnal cycles. The technique involves collecting data on dissolved oxygen from areas with previous records and making comparisons, revealing trends over time with repetition.

6. Water Temperature: Water temperature plays an important part in the functioning of an aquatic ecosystem. The Australian water quality guidelines set out procedures to assess increases in water temperature, but as yet there are insufficient data to establish acceptable reductions in temperature (ANZECC 1992). If measured at all, then the time of day must also be reported.

7. Any other chemicals that may be locally important, such as nutrients (see key indicator 3.3).

Reporting scale

The spatial scale of data collection must be local — i.e. river reach, wetland, irrigation area, etc. — and the geographic extent should be Australia-wide. Aggregate to drainage divisions, always retaining a record of the cumulative number of tests performed.

Outputs

Maps (of drainage division) showing the percentage of trigger levels reached and tables listing trigger levels reached (as under Analysis and interpretation p. 20).

Data sources

Data are collected at regular intervals by the various water authorities, councils, government agencies and departments (especially environment protection agencies), research organisation, private enterprises (including irrigation industries) and community groups (such as Waterwatch).

Links to other indicators

Nutrient loads (key indicator 3.3)
Chemical residues (key indicator 3.4)
Pesticide usage and exposure (key indicator 3.5)
Instream salinity trends (key indicator 3.13)
Pollution point sources (key indicator 3.6)
Waterwatch participation (key indicator 3.11)
Human criteria exceedances (key indicator 2.1)
Biochemical oxygen demand (BOD)

Indicator 3.2: Algal blooms

Description

Incidence of blue-green algal blooms, as defined by managerial agencies.

Rationale

There is a growing demand to use more freshwater for human consumption than is available without destroying the basic structure of the ecosystem. Eutrophication, massive toxic algal blooms, degeneration of ecosystems as manifested in loss of species, and shifts in species composition and abundance can make surface water unsuitable for drinking or recreational purposes. An alternative to the incidence of blooms is to examine their severity, e.g. whether they are toxic or not. Unfortunately, this is much harder to do on a national basis and not feasible here, because there is no simple field measurement for most toxicants. Toxicity is of more concern than the nuisance of plant blooms.

Analysis and interpretation

An example is the NSW Department of Land and Water Conservation's managerial guidelines for blue-green algae alerts. The cell numbers per millilitre of water range from Alert Level 1 at approximately 500–2000 cells per mL, through Alert Level 2 (2000–15 000 cell/mL), to Alert Level 3 where cell numbers exceed 15 000 cell/mL and one or more blue-green algal species are present. Low alert does not indicate an algal bloom, but there may be some taste and odour problems and an indication that an algal bloom could develop. At the medium alert level it is still not considered to be a "bloom", although water treatment (activated carbon) or the use of an alternative "safe" water supply is recommended. If environmental conditions continue and the cell numbers increase then a high alert status and bloom conditions apply. It is assumed at this stage that the bloom is toxic and action is taken accordingly. There is also a formal ARMCANZ guideline for recreational waters of 20 000 cells/mL.

Monitoring design and strategy

Monitoring should be conducted monthly or, ideally, biweekly (two weeks is the approximate minimum time for many blooms to form, G. Jones pers. comm.). Each State (at least Qld, NSW, Vic and SA) has documented its own protocols, the formulation of an agreed national protocol is possible (G. Jones pers comm.). The spatial scales on which data could be collected include: more than one site in large lakes and reservoirs and near point sources in rivers — including different ecological sections (upland, lowland) — on a catchment-by-catchment basis. The geographic extent of data collection should be national (most States monitor now), for all reservoirs, lakes and rivers, particularly lowland rivers. The frequency of monitoring could be fortnightly.

Reporting scale

Each State and Territory, and aggregated into drainage divisions.

Outputs

Maps of drainage divisions that suffer blooms at different frequencies. Aggregated data should be stored electronically on a commercially available database.

Data sources

This indicator is presently being monitored for some reservoirs in most States by each relevant water authority. The monitoring is conducted monthly or weekly. NSW is probably the most advanced State, with weekly data now available for the whole State for the last 5 years. There are logistical problems in the larger States with costs for appropriate sampling and transport to the laboratory for analysis. Local councils, water authorities, environment agencies, and community groups also hold data.

Links to other indicators

Bloom contingency plans (key indicator 3.8)
Nutrient loads (key indicator 3.3)
Total chlorophyll

Indicator 3.3: Nutrient loads

Description

The estimated amounts, or loads, of phosphorus and nitrogen in the waterways per year.

Rationale

High concentrations of nutrients in surface waters have been linked to algal blooms and poor water quality. The source of the phosphorus in our waterways is variable and poorly known (Donnelly 1994). But the measurement of nutrient concentrations alone is unreliable for interpreting nutrient conditions in Australian waters (Harris 1996). This indicator focuses on nutrient loads (amount per unit time), and would thus identify any key areas for inputs of degraded water quality from rural and urban sources. The measure of total nitrogen and phosphorus forms offers a conservative (over) estimate of eutrophication potential (Baldwin 1997).

This is an indicator of the condition of a waterbody from a purely water quality perspective, but obviously also acts as a major source of pressure upon biota living within it.

Analysis and interpretation

Flow data are used to determine the loads of nitrogen and phosphorus. If auto-samplers are to be used, then the determination of total nitrogen and phosphorus concentrations incorporates any transformation of the nutrients post sampling. Although not all the nutrients would have been bioavailable, the resultant measurements of total nitrogen and phosphorus would still give an indication of the eutrophication potential. It is also essential that adequate QA/QC (quality assurance/quality control) protocols be in place for both sampling and laboratory analysis.

Some Australian rivers (e.g. the Darling) seem to have a high natural phosphorus concentration (R. Davis, pers. comm.), and the biota may be adapted to these conditions. Hence interpretation would require the ratio of estimated natural load to current load.

Monitoring design and strategy

There has been a series of recent meetings and much discussion about which species of nitrogen and phosphorus tell us most about issues such as bioavailability. Some favoured forms are presently technically specialised or limited as measurement techniques. Following Baldwin (1997), we recommend that the most robust measures, total phosphorus and total nitrogen, be adopted for national monitoring.

The sampling strategy needs to be tested for the selection of sites, monitoring frequency, key indicators and appropriate analytical techniques. A suggested monitoring scheme (see Baldwin 1997) involves the selection of representative catchments/sub-catchments (1–100 km^2) which could ideally be fitted with gauged weirs and auto-samplers programmed for flow-weighted sampling. The flow-weighted monitoring (see Raisin 1996 for an example) of catchments would effectively overcome problems of spatial and temporal variability experienced with grab or spot sampling. Flow-weighted sampling will collect the highest flows and therefore the greatest loads. Loads are calculated from the product of measured concentrations with observed flows as a standard calculation.

The capital cost of auto-samplers is declining, and most State and Territory agencies now use them for monitoring their networks of key sites. Fully automated systems that also download data — such as the Qualtel machines (Greenspan Technologies Inc) — are also becoming more affordable. The maintenance/servicing of the auto-samplers can be coordinated by interested community groups, hence spreading ownership of the program to the local level.

Reporting scale

Yearly, per catchment, for estimates of total annual export of nutrients.

Outputs

Tables listing total loads.

Data sources

Data are held by State and Territory water authorities, EPA-like agencies, possibly Total Catchment Management (TCM) groups, Landcare, Waterwatch etc. Dedicated sampling is needed to extend the patchy coverage of this indicator. Most sampling is still done using grab samples (a method rejected by Baldwin 1997) with only "key" sites automated. Over time, all SoE sites should change to use auto-samplers.

Links to other indicators

Algal blooms (key indicator 3.2)
Guideline trigger levels reached (key indicator 3.1)
Eutrophication

Indicator 3.4: Chemical residues

Description

Chemical residues in aquatic biota or foodstuffs.

Rationale

A section of the valuable domestic and export food markets involves using water to maintain fish and shellfish stocks or for irrigated agriculture. Extensive monitoring programs, such as the National Residue Survey and National Food Authority (Market Basket Surveys) are in place to monitor the quality of produce, especially to assure limited contamination from chemicals.

It is also necessary to protect biota in the natural environment from adverse chemical contamination. Bioaccumulation is an avenue of transfer of toxins up food webs.

This is an indicator of the condition of a waterbody from a purely water quality perspective, but obviously acts also as a major source of pressure upon biota living within it.

Analysis and interpretation

Analyse samples for pesticides and chemicals of interest against the Maximum Residue Limits (MRLs) (Commonwealth Department of Human Services and Health 1995). Any exceedances of MRLs should be reported, as well as the total number of tests done.

Monitoring design and strategy

Selected foodstuffs are regularly analysed for chemical residues by the National Residue Survey. These include inland waters foodstuffs such as fish and yabbies, but indirect links such as algal toxins in foodstuffs from irrigated crops are not measured (PMSEC 1996). The Market Basket Survey selects foods deemed to be found in a "typical" Australian diet and analyses them for a core group of pesticides, metals and other chemicals of interest.

Reporting scale

Data are reported yearly (or every two years for the Market Basket Survey) on a national scale by individual commodities. Aggregate these (by separate addition of detections and total tests) to 4–5 years for the SoE cycle.

Outputs

Tables showing the number of hits and total number of tests for each chemical (National Residue Survey), per commodity.

Data sources

The National Residue Survey and National Food Authority are the prime national sources. Agriculture departments in each State and Territory collect commodity data. Quality control/quality assurance programs for individual commodities and marketing corporations also generate residue data, but these are likely to be treated as commercial-in-confidence. Testing for environmental purposes by universities, research institutions and State agencies (e.g. bioaccumulation studies or investigations after fish kills) may also be a useful data source. There could be some good case studies over longer periods (e.g. since 1970s), as there are for marine resources.

Links to other indicators

Toxic substances (part of Guideline trigger levels reached, key indicator 3.1)
Pollution point sources (key indicator 3.6)
Concentration of pollutants in fish

Indicator 3.5: Pesticide exposure

Description

Estimated contamination by pesticides in the riverine environment, per drainage division.

Rationale

The growth and economic viability of the agricultural industry relies on the use of pesticides (including insecticides, fungicides, rodenticides and herbicides) to ensure production of quality produce. There is also a widely held aim to maintain a "clean and green" image for local and export markets with better-practice management implementing lower pesticide usage and the use of more "environmentally friendly" chemicals (PMSEC 1996). The use of such a varied range of agricultural chemicals can inadvertently lead to contamination of nearby waterways (PMSEC 1996). Measures to ensure that there is minimum risk to the environment while sustaining agricultural production are therefore required. It is necessary to identify and assess those chemicals that are presently entering the riverine environment and to assess new pesticides that may be hazardous. This indicator focuses upon exposure *per se*, because pesticide use is dealt with in the environmental indictor report on the land (Hamblin 1998).

Analysis and interpretation

Pesticide concentrations in water should be compared with the Australian Water Quality Guidelines for the protection of the aquatic environment (ANZECC 1992). Many different chemicals must be included, and the best way to assess them is by the number of detections versus the number of tests. All such chemicals are biocides (and therefore toxic), and so should be reported if detected. The large number of chemicals — and even their chemical families — makes this an expensive indicator, but presently there is no alternative to take account of these very toxic biocides. The level of change at which the indicator would be deemed important could be determined by comparison with data from "clean" reference sites.

Monitoring design and strategy

At the national level, estimates of exposure should be made using data from *in situ* organic-solvent-filled passive samplers (dialysis bags), to be used Australia-wide with monthly collections during peak usage of chemicals. The spatial scale is all catchments used for intensive agriculture. Given the unavailability of information on use of pesticides, this is the best measure, although expensive and site-specific. The expense and site-specificity mean that this approach is best worked into a key or reference site network.

Reporting scale

National (also by State and Territory). Reporting frequency should be 4–5 years (i.e. the SoE cycle).

Outputs

Reports for catchments and drainage divisions, especially identifying those with irrigation districts.

Data sources

Presently this empirical technique has been used by researchers at the Centre for EcoToxicology/NSW EPA. Data on use of pesticides are not held centrally, but are occasionally estimated by the Australian Bureau of Agricultural and Resource Economics (ABARE), ABS, or agriculture departments.

Links to other indicators

Toxic substances (part of Guideline trigger levels reached, key indicator 3.1)
Chemical residues (key indicator 3.4)
Pollution point sources (key indicator 3.6)
Contamination in fish

Indicator 3.6: Pollution point sources

Description

Inventory of licensed point sources of pollution, as measured by number of point sources by source type per drainage division.

Rationale

Maintaining water quality relies on identifying and evaluating effluents from a variety of pollution sources, especially those that may adversely affect receiving water quality. Point sources can be identified more readily than diffuse sources, leading to quantification and targeted management. Similar indicators are being developed by the land resources, atmosphere and human settlements themes, with the proviso that here we are concerned with water rather than soil, air or urban pollution .

Types of sources include point sources identified in the NWQMS — e.g. from sewerage systems, cattle dips, piggeries, tanneries, wineries and distilleries, dairies, wool scouring sites, paper mills, mine sites, general industrial wastes discharging into waterways (under licence agreements etc.), and intensive rural industries generally.

Acid mine discharges are an identified subset of these sources. These are problematic because, although very common, few are treated. Many discharges are from closed mines, and such relics are rarely centrally documented. Exploration activities may also result in further acid mine drainage.

Analysis and interpretation

Licensed sources should have data on the type of pollution (i.e. the chemicals released) and their loads or volumes associated with each licence. No weighting and aggregation of this information is appropriate as yet, so the types will be recorded separately for future interpretation.

Subset — mine discharges: The main variable is the number of discharging mines per square kilometre of catchment or kilometre of river. The level of change to detect should be any increase in the number of mine discharges measured in this way. The level at which the indicator is likely to be important would be related to the change (improvement) in treatment needed for discharge to meet water quality guidelines, provided guidelines are regionally appropriate. Conversely, an increase in the number of discharges with demonstrable impacts on biological or chemical quality (i.e. for beneficial use or protected environmental value) of receiving water would be a significant deterioration. See ANZECC guidelines for protection of aquatic environment (some still in draft form). The raw data should be available electronically.

Monitoring design and strategy

Monitoring will require a mixture of data — from licensing of new ventures, through gathering historical records of past activities, to ground surveys of pollution incidents. Ideally, such data should include the volume of pollution for each point source, but these data will not be available for abandoned sites. Such sophistication could be worked into the indicator over time.

Subset — mine discharges: Monitoring should encompass either the number of discharges per kilometre of river or the percentage of rivers or river segments with mine discharges. Alternatively, the zones of decreased pH downstream (measured as kilometres affected) could be monitored. Monitoring will require better information on discharges from closed mines, as well as information on types of treatment and their performance. Data should be collected for river valleys, Australia-wide.

Reporting scale

By drainage divisions for a national picture.

Subset — mine discharges: The spatial scale on which these data could be collected could be in hundreds of metres of stream length, to be collected Australia-wide. The frequency of monitoring could be once every 5 years.

Outputs

Report the numbers of point sources of each type, by area (per catchment). Maps compiled from historical and current sources are probably the best method of display.

Subset — mine discharges: In the case of mine discharges, the reports should include monitoring (compliance) data from active mines. Report using maps — a colour document that grades discharges by their level of treatment and/or impact. The electronic data should be stored in public domain by State and Territory agencies, but with a nationally coordinated set of standards. At present this indicator is being monitored by various States and Territories.

Data sources

The National Pollutant Inventory will be the central database of such sites. Presently, information is held by State and Territory departments of mines or mineral resources, agriculture, rural/urban development and planning, environmental protection etc., and local government. Recently there have been task force investigations in many States and Territories into abandoned cattle tick dipping sites and other small-scale but intense problem areas. This approach is slowly expanding across a wider range of sources, in part as a component of the NWQMS.

Subset — mine discharges: Information from the State environmental or mining agencies. Many environmental agencies have licence information for current discharges. Mines departments often have dispersed information on previous workings.

Links to other indicators

Guideline trigger levels reached (key indicator 3.1)
pH (part of Guideline trigger levels reached, key indicator 3.1)
Toxic substances (part of Guideline trigger levels reached, key indicator 3.1)
Minesite remediation (key indicator 3.7)
River discontinuity (key indicator 4.12)
Source density

Indicator 3.7: Minesite remediation

Description

The number of mines discharging drainage that are remediated per year.

Rationale

This is the response indicator corresponding to the pressure indicator minesite discharges (part of key indicator 3.6). Many old and disused mine sites leak acidic waters, with associated mixtures of heavy metals, into waterways. The remediation of these sites is important in improving the quality of receiving waters. There is a need for both government and community groups to act on this, and there is a question of who will carry out the task of remediation. This is of national importance because there are many such sites, each affecting many kilometres of river. Nearly all gold or base metal mining areas from the last century or the early part of this one can leak acidic, metalliferous waters (at least after rain resulting in runoff). Those fed by groundwater are perpetual sources of contamination.

Analysis and interpretation

Remediation works carried out within the year should be analysed. Comparisons should be made with monitoring of remediated sites to ensure success of the works. Ratios of pH and metal concentrations in water before and after remediation should be studied.

Monitoring design and strategy

Records of minesite remediation works carried out over the year should be kept, as should monitoring data from before and after remediation work to assess changes in the quality of receiving waters. Each remediated case should then be removed from the mine subset of key indicator 3.6.

Reporting scale

Collect data at local (catchment) scale or use State and Territory records to aggregate to drainage division.

Outputs

Yearly reports on minesite rehabilitation works. After all remediation work is completed, a final tabulation of completed minesite remediation works should be produced.

Data sources

State and Territory departments of mines, energy, or natural resources produce annual reports that usually showcase the few recent examples (as mandated by current regulations). Older sites are essentially abandoned. Universities, research organisations and community organisations are involved in some remediation works, but records are more difficult to access.

Links to other indicators

Pollution point sources (key indicator 3.6)
Guideline trigger levels reached (key indicator 3.1)
pH (part of Guideline trigger levels reached, key indicator 3.1)
Toxic substances (part of Guideline trigger levels reached, key indicator 3.1)

Indicator 3.8: Bloom contingency plans

Description

Contingency plans for algal blooms.

Rationale

There is a need to implement various programs to minimise the effects of algal blooms, manage blooms, manage the causes of blooms, educate and raise awareness and carry out research. There are various State and Territory committees — such as the New South Wales State Algal Coordinating Committee (see e.g. SACC 1996), Victorian Blue-green Algae Project Team, South Australian Algal Task Force etc. — which coordinate the implementation of strategies for the control of algal blooms.

In NSW, the implementation of components of the strategy includes: eight regional algal coordinating committees (including the Riverwatch program along the Barwon–Darling River); the upgrading of water supplies by State and local government; implementation by the Department of Land and Water Conservation (DLWC) of a program to subsidise construction of stock and domestic bores to provide alternative water supplies to those affected by blue-green algae; and establishment of the State algal toxins database. Similar strategies exist for the other States and Territories.

Analysis and interpretation

The existence of bloom contingency plans is the first attribute to document. The effectiveness of the various strategies, such as nutrient control or flow management plans, might be gauged from the number of algal blooms effectively controlled (usually reported annually).

Monitoring design and strategy

Implementation of strategies is usually at a national and/or State level with coordination via State and Territory committees. Therefore, how many States/Territories have such plans? Do local government areas have local contingency plans? Tabulations of such information form the basis of this response indicator.

Reporting scale

State and Territory, aggregated to drainage divisions or catchment-based (depending on data source).

Outputs

Tables for each State and Territory, stratified by drainage division.

Data sources

Yearly reports from State and Territory Algal Coordinating Committees, with links to the MDBC (Algal Management Strategy), CSIRO (Algal Research Program) and ARMCANZ (WRMC Algal Program), local government environmental plans or SoE reports.

Links to other indicators

Algal blooms (key indicator 3.2)
Nutrient loads (key indicator 3.3)

Indicator 3.9: Polluter pays principle

Description

Adoption of the polluter pays principle, as measured by the number of statutes or regulations espousing it.

Rationale

There is growing concern over the lack of responsibility for pollution being taken by the major contributors, despite a move towards cleaner production that benefits the environment while maintaining productivity. There is an ethical argument that somehow those responsible for pollution should alleviate some of the degradation while continuing to pollute. The polluter pays principle is a recognition that individuals and companies are responsible for pollution and should pay for the privilege (a licence) to pollute, while the funds generated are used towards general monitoring and clean-up works. Thus there is an incentive for industry to adopt or initiate research and development into "cleaner" production processes and to recycle and/or improve effluent quality.

A polluter pays principle is embodied in appropriate taxes to reflect: industrial polluters (cost of clean-up and rehabilitation not undertaken by polluter); recreational users (riverside home owners, boaters etc., reflecting environmental maintenance) and; users of polluting products.

This is one of those response indicators that corresponds to an appropriate response but may be too difficult to measure. The experience gained in attempting to compile the indicator for the first time should either make it easier to use or lead to it being discarded.

Analysis and interpretation

Over time, trends in the number of contributors would indicate changes in practices and management, and hopefully the implementation of lower-pollution strategies. Allocation of generated funds for various environmental programs would indicate areas that are improving and others that need more attention in the future.

Monitoring design and strategy

Several questions need answers:

1. How many jurisdictions have policies and levies in place that embody "polluter pays"?
2. How many industries make contributions to government agencies?
3. How large are the funds generated by the polluter pays principle (thus indicating the extent and severity of pollution sources and the use of those funds for various schemes and monitoring programs)?
4. Will there be tradeable pollution licences in the future?

Reporting scale

Regional, aggregated to State and Territory.

Outputs

Tallies, tabulated by jurisdictions, of responses to the questions listed above.

Data sources

Annual reports of State and Territory environment departments, plus policy statements, laws, regulations etc. at State and Territory and local government levels.

Links to other indicators

Pollution point sources (key indicator 3.6)
Pollutant detection (key indicator 3.10)

Indicator 3.10: Pollutant detection

Description

The ability to detect pollutants as measured by declines in limits of reporting (LOR) or detection limits (DL), or the number of sensitive state-of-the-art machines in the country.

Rationale

The quality of monitoring depends in part on the sensitivity of analytical equipment and sampling frequency. Are we putting enough effort into looking for pollution? For example, some pollutants, such as organic contaminants, are very expensive to test. Hence this is a response indicator separate from the actual number or type of detections made.

This is a completely novel indicator not used for SoE or other reporting. As such, it needs considerable development and refinement before routine use.

Analysis and interpretation

A list of state-of-the-art machines and techniques needs to be defined and updated over time. Value judgements are inherent in this indicator, but that is also true of many other indicators. What is "state-of-the-art" is reasonably well known to specialist chemists and can be defined for each pollutant. Therefore frequency of monitoring need be only every five years.

A possible surrogate could be the ages of the machine in use, but this would need to be examined carefully for the type of pollutant because technology is changing at different rates for various types of chemicals.

Monitoring design and strategy

By State and Territory, and collected annually. Aggregate to SoE cycle units (4–5 years).

Reporting scale

National by chemical. Also by States/Territories to indicate gaps in measurements or their sensitivities.

Outputs

Tables showing trends in the number of state of the art machines by chemicals. Graphs of DL or LOR over time (years to decades).

Data sources

State EPA-like agencies and other monitoring groups (including universities and research organisations).

Links to other indicators

Guideline trigger levels reached (key indicator 3.1)
Toxic substances (Part of Guideline trigger levels reached, key indicator 3.1)
Chemical residues (key indicator 3.4)
Pollution point sources (key indicator 3.6)

Indicator 3.11: Waterwatch participation

Description

Proportion of the population involved with Waterwatch.

Rationale

Waterwatch is a community-based water quality monitoring program, initiated in response to the general concern over declining water quality and issues of increased salinisation and algal blooms. Originally developed as an educational program, it is now a national monitoring program, generating locally useful water quality data.

Community groups collect data that are passed first to regional/catchment coordinators, and then to State coordinators. Use can also be made of data from Waterwatch's periodic surveys, with information collected from the various community groups about who they are, where they operate, etc.

Analysis and interpretation

The percentage of the population involved, and trends observed, are the most important considerations. Because the techniques involved are meant to be robust and therefore tend toward being rudimentary, they are not as sensitive as scientists would like (Baldwin 1997). So this is more important as a participatory and awareness-raising activity than as a scientific exercise.

Monitoring design and strategy

Records of community groups participating in Waterwatch monitoring.

Reporting scale

By drainage division or State and Territory, by type of group (school, Landcare, etc.)

Outputs

Reports on the number of groups/number of people involved. The number of TCM, Landcare, etc. groups with Waterwatch attached and/or utilised should also be reported.

Data sources

Waterwatch office in Canberra (within the Biodiversity Group of Environment Australia) and the State and Territory offices of Waterwatch.

Links to other indicators

Guideline trigger levels reached (key indicator 3.1)
Pollution detection (key indicator 3.10)

Indicator 3.12: Zero-P detergents

Description

Market share of zero-P detergents nationally.

Rationale

Phosphorus sourced from detergents is thought by some to be a key link in P nutrient loads and algal bloom causation, especially when sewage is treated "properly" (i.e. considerable P is coming from detergents). Advertising is paid for by governments and TCMs encouraging the use of low- or zero-P substitutes for the high-P detergents of the past. Hence this indicator shows the response from this raised community awareness.

Analysis and interpretation

The sales of zero-P detergents as a percentage of total detergent sales and assessment of trends in the market. Upward trends would show an encouraging tendency, whereas downward trends might indicate less awareness or care about this issue. Over time, the component of total P loads coming from detergents versus other sources will become better known and so the importance of interpreting this response indicator may change.

Monitoring design and strategy

Sales records of various detergent products will be the raw data, and "monitoring" will be done by compiling such data. Data collection probably on a State and Territory basis.

Reporting scale

National, the trend is the most important aspect.

Outputs

Reports tabulating the market share of zero-P detergents nationally. Graphs over time.

Data sources

Detergent/chemical industries and maybe the ABS shopping/commodity data.

Links to other indicators

Nutrient loads (key indicator 3.3)
Algal blooms (key indicator 3.2)

Indicator 3.13 Instream salinity trends

Description

Trends in salinity levels in surface waters.

Rationale

Instream salinity is one of the components of the composite indicator Guideline trigger levels reached (key indicator 3.1), but here we are more concerned with national trends in concentration (rates of increase) than with levels in relation to guideline figures. With whole drainage basins threatened by rising salinity levels, this is such a major problem for water usage by Australian people and the environment that it cannot be left as merely a component of key indicator 3.1.

As an ancient continent with many ancient seabeds beneath it, Australia is prone to salinisation even without the anthropogenic influences of poor irrigation practice and tree clearance. Concern has been raised about the increased salinity of some of Australia's rivers, especially the River Murray, where salt loads have increased. For example, the MDBC has looked at salt trends in the Murray–Darling drainage division and found that levels of salt (both as concentrations and loads) are increasing in most streams over reasonably long time periods (Williamson *et al.* 1997). Continued monitoring is needed to assess the extent of the problem and the effectiveness of implemented management practices for salt reduction.

This is an indicator of the condition of a waterbody from a purely water quality perspective, but obviously also acts as a major source of pressure upon biota living within it.

Analysis and interpretation

Trends in salinity over time should be assessed, with comparisons made with previous records to ascertain rises or falls in general levels, and possibly to predict future trends. If flow is also measured (see key indicator 3.3, Nutrient loads), then salt load could also be calculated (perhaps only at a subset of sites). The number of catchments per drainage division with rising salinity trends would be another useful variant of this indicator (and lends itself well to national interpretation and display via maps).

Monitoring design and strategy

Salinity should be monitored as point measurements of EC (electrical conductivity). A network of suitable sites needs to be used, possibly tied into each State and Territory's water quality monitoring, or at least the AUSRIVAS test sites. The rate of change of stream salinity could be assessed in two different ways: firstly, across a catchment, e.g. from headwaters to estuary; and secondly, compared with historical records. Both are useful to report because they convey different information. Spatial scale of monitoring — i.e. for selection of sites — could be at river reach or irrigation area (as two different types with likely different trajectories), then scaled up to drainage division.

Reporting scale

National, aggregated to drainage basins.
Each catchment (and its land usage) probably needs separate reporting.

Outputs

Maps of salinity levels within drainage basins at key points along the watercourse. Graphs of trends over time (for formats, see Williamson *et al.* 1997).

Data sources

State and Territory water authorities, irrigation industries, local government, MDBC, research institutions, universities and community groups all measure salinity routinely. Therefore, many sources are possible for such a basic measure. Williamson *et al*. (1997) is the model for reporting on this at a regional level.

Links to other indicators

Guideline trigger levels reached (key indicator 3.1)
Groundwater salinity (key indicator 1.2)
Depth to watertable (key indicator 1.1)
Nutrient loads (key indicator 3.3)
River flow regimes (key indicator 4.3)
Waterlogged soils
Rainfall

Issue or Element 4: Surface Water Quantity

Indicator 4.1: Resource versus demand

Description

The ratio of the water available to the perceived needs for water in any drainage division.

Rationale

Much of the recent pressure on water resources has come from a drive to overcome perceptions of a lack of security of water resource. This is driven both climatically (e.g. our rainfall variability) and politically (e.g. amongst competing uses). The sorts of questions that resource managers want answers to are: Is there enough water for all the desired uses, including the needs of the environment? Is allocation efficient or is there capacity for unmet demand in the system? This will vary across the continent.

This indicator is novel in the ratio form recommended here; at present, the resource (supply) and demand aspects are often reported separately as quite basic inventory items. Demand is the harder to gauge.

Analysis and interpretation

A value less than one (McMahon *et al.* 1991) for this indicator suggests that water is in danger of being over-allocated or that the system of allocation needs to be reviewed and overhauled. Values greater than one indicate that water is presently under-allocated (if the component for the environment is included according to the COAG principles and indicator 4.4). Trends over time can be interpreted as adjustments to the overall system (for increases or modest declines toward unity) or increased pressures on water resources (for steep declines)

Monitoring design and strategy

Two sources of data are needed for this indicator: first, estimates of the amount of water available (see key indicator 4.2); and second, estimates of the present abstractions, uses, etc. plus requests for further diversions, environmental (unmet) needs and planned future schemes. The latter can be gauged by requests for allocations of water made to water-distributing authorities in addition to present commitments.

Reporting scale

Aggregate State and Territory information into drainage divisions.

Outputs

Graphs over time for each drainage division.

Data sources

Mainly water authorities in each State and Territory, but also local governments or other agencies involved in permitting water abstraction and usage. The two parts are often reported by these agencies but not often explicitly compared.

Links to other indicators

Surface water distribution (key indicator 4.2)
Environmental Flows Objectives (key indicator 4.4)
Licensing (key indicator 7.4)

Indicator 4.2: Surface water distribution

Description

The distribution of our surface water resources by drainage division.

Rationale

Knowing how much water we have, and where, is fundamental knowledge for resource management purposes. Since the days of AWRC in the 1970s we have been assessing where and how water is available to Australia.

Analysis and interpretation

As an inventory of what is available, this indicator is most useful for detecting long-term trends in resources and their allocations. Because of relatively slow rates of change in this indicator, it need only be measured at long intervals (say 5–10 years). As a fundamental baseline measure, this indicator underpins many others to do with water quantities. Therefore it is essential for interpreting these other indicators.

Monitoring design and strategy

Given the good background we have on this (e.g State of the Environment Advisory Council (eds) 1996), it is necessary to update data only every 5–10 years or so. Reserves may change due to climatic shifts (e.g. drier or wetter periods) and decrease due to overuse.

Reporting scale

Aggregate to drainage divisions (as seen in AWRC reports from the 1980s).

Outputs

Maps of the country showing the total volume of surface water per drainage division, and the amount developed and possible to develop.

Data sources

DPIE and all State and Territory water authorities hold this information. Pulling it together was a major task of AWRC; since then, occasional updates have been necessary. The ABS physical account for water will use much of this information.

Links to other indicators

Water use (key indicator 4.7)
Resource versus demand (key indicator 4.1)
River flow regimes (key indicator 4.3)
Environmental Flows Objectives (key indicator 4.4)

Indicator 4.3: River flow regimes

Description

Alterations to river flow regimes from the historical record as measured by incidence of extreme flows from hydrographic records.

Rationale

River regulation has altered the flow characteristics (water level fluctuations, water balance) of most rivers across the continent (McMahon *et al.* 1991) so that the amount, timing (seasonally) and duration of flows no longer correspond to what was naturally the norm. This has been a hot topic of research over the past 15 years and so our understanding of the changes is now greater than ever (e.g. Walker 1996). What is less clear is the minimum set of conditions needed to restore, but still make most beneficial change to, the aquatic ecology (Young *et al.* 1995).

Analysis and interpretation

Interpretation is to be made against the historical record (as an "internal standard"), where gauging records extend into the past. Therefore, express the recent performance (e.g. over the first SoE cycle of 4–5 years) as a percentage of the corresponding historical value. There may be value in also recording the short-term durations of these flows as well as the levels reached. This is currently a keen topic of research by hydrologists (e.g. Prof. Tom McMahon at University of Melbourne) for Australian rivers and is likely to be even more easily interpreted in the near future.

Monitoring design and strategy

Two aspects of the hydrograph (constituting the indicator) are most crucial for the variable flow conditions of Australia: the baseflow value (i.e. lowest value of flow that is reached, which may equate to groundwater input only or no flow); and extreme high flows (e.g. as represented by the 90th percentile of flows). These are preferred to median flows which represent an "average" condition that may rarely be reached in variable systems and also have relatively less impact upon other aspects of the environment than extremes of flow. Each can be derived from examination of a series of hydrographs or from a flow-duration curve derived from data over the same period. Raw data will be the hydrographic record over the SoE period of interest (e.g. the lowest and 90th percentile flows per year), and these should be compared with the complete historical record for the river. These data are standard hydrographical information. The longer the gauged period the better; e.g. the River Murray record now extends back at least 110 years. Shorter periods yield fewer extreme events, but this is partially balanced by the record being more definitely within this climatic period.

Reporting scale

Extreme and baseflow values are derived from records of point measures made at stream gauges. The actual values are difficult to aggregate unless via cumulative frequency distributions or the number of places passing some criterion by river (catchment) and then drainage division.

Outputs

Tabulations and graphs summarising the probability distribution of the per cent alterations from historical flow, per drainage division (these are therefore standardised for long-term differences in flow rates across rivers). Trends over time are less informative unless standardised against weather records.

Data sources

Water authorities and others in States and Territories that engage in stream gauging. Annual or irregular reports for particular catchments or river reaches are now produced for many of these.

Links to other indicators

Flooding (key indicator 4.5)
Environmental Flows Objectives (key indicator 4.4)
Rainfall
Southern Oscillation Index (SOI)

Indicator 4.4: Environmental Flows Objectives (EFOs)

Description

Proportional adoption of COAG principles of water allocation for the environment.

Rationale

Since the 1994 COAG decision to ensure that the environment is considered a valid user of water, many jurisdictions have begun to grapple with what objectives should be adopted for environmental flows (sometimes termed "water for the environment"). This may have the greatest effect on surface waters in Australia of any policy change since the Snowy Mountains Hydroelectricity Scheme, and its potential is even more wide reaching. Because this is a COAG initiative, it applies to all governments in Australia. Therefore it is of national importance to assess the degree of application of these principles. The most direct proof of this policy change is in the number of jurisdictions and regions that have set flow objectives. In NSW at least, environmental flow objectives are linked to a set of water quality objectives (neither of which had been finalised by December 1997.

Analysis and interpretation

For each jurisdiction, count the number of policies and regulations that seek to implement EFOs. These can be tallied as a series of thresholds corresponding to affirmative answers to a series of hierarchical questions such as:

- Are EFOs part of the dominant resource management philosophy?
- Are EFOs within expressed policy?
- Do plans invoking EFOs exist?
- Are quantitative targets set for EFOs?
- Are these targets agreed to by stakeholders (including processes for achieving them)?
- How actively are they pursued?
- Is performance against these targets monitored and reported?

All these issues are relevant to this novel indicator.

Monitoring design and strategy

This is an example of an important issue that does not lend itself readily to measurement as an indicator, but will change the face of water allocation over the next few years and thus demands attention. Examination of policy documents and processes to see how the COAG water principles (Anon 1995; ARMCANZ/ANZECC 1995) are being developed and applied in each State and Territory is the most promising monitoring strategy. This is essentially a tallying exercise for different approaches and practices.

Reporting scale

Primarily for political units, but these could also be translated into the drainage divisions or catchments insofar as these correspond with political boundaries.

Outputs

Tables listing the number of jurisdictions against the categories embodied in the continuum of questions listed above. Separate entries for the different political levels from MDBC (or other "shared" catchments across State borders) down to Local Government Areas (LGAs).

Data sources

Water authorities and agencies in each State and Territory are responsible for this issue, although some EPA-like agencies are also involved in "whole of government" approaches (e.g. NSW). MDBC also plays a role in this within the Murray–Darling Basin, as do some research and management facilitators such as LWRRDC.

Links to other indicators

River flow regimes (key indicator 4.3)
Alienated floodplains (key indicator 4.6)
Flooding (key indicator 4.5)
Irrigation extent (key indicator 4.8)
Irrigation efficiency (key indicator 4.10)

Indicator 4.5: Flooding

Description

The frequency and extent of flooding per drainage division in relation to the historical record.

Rationale

River regulation and development on floodplains has led to much less flooding, except for the largest river flows (McMahon *et al.* 1991). This, in turn, is crucial to the many riverine and floodplain biota that rely on occasional floods for reproductive cues, opportunities to feed or habitat provision. Many native species have probably declined due to such an effect (see Young *et al.* 1995 for a review).

Analysis and interpretation

Because floods are discrete events in time, each can be summarised in some meaningful way and those summary statistics tallied for the region. The historical record is crucial to determining what our expectations should be. For example, small floods may be less common than before river regulation but big floods may be as common and bigger. Therefore, the basic values need to be expressed in terms of the historical average. We have such data only for the major rivers in Australia going back perhaps 100 years or less.

Monitoring design and strategy

Flood frequency and seasonal timing (which varies greatly across the continent) can be compiled from any temporal and local record of flooding. The size (volume of water) of a flood can be estimated from gauging records in the source river. The area inundated can be assessed using Landsat data, but these need to be checked against local records to assess whether the satellite pass coincided with the peak of the flood event. Also, perhaps the money lost through damage can be used as a surrogate of flood size where no gauging exists.

Reporting scale

Stratify by the size of flood and season. Aggregate by drainage division as the number of events and frequency distributions of their sizes.

Outputs

Tables and graph showing flood size and frequency as a percentage of corresponding historical values.

Data sources

Event-based records are kept by water authorities, emergency services and insurance companies (for claims lodged). National compilations are made by ABARE and ABS on an irregular basis. More promising is the ability to remotely sense floods in the future and immediate past using Landsat (Campbell and Wallace 1998).

Links to other indicators

River flow regimes (key indicator 4.3)

Indicator 4.6: Alienated floodplains

Description

The percentage of floodplains per drainage division that are alienated from their river sources.

Rationale

Floodplains should be inundated intermittently during times of flood, but development on them is usually facilitated by disconnecting them from river pulses. It is now well established that both floodplain and river biota are dependent on the river occasionally "breaking out" over the stream bank. River regulation has removed small and medium-sized floods, but generally has little or no effect upon the highest floods. The construction of levees, bundwalls, raised roads etc. — even out on the floodplain where elevation may range by only a few centimetres — has kept floodwaters back from these normally productive areas. Alienation from their rivers is one of the largest-scale and most dramatic changes that have occurred to our floodplains across the country.

Analysis and interpretation

Express alienated floodplains as a percentage of stream length or, where historical data are available, derive the percentage area of floodplain that is no longer flooded. The latter variable (at least) has to be scaled to a flood (river flow) of a particular size.

Monitoring design and strategy

Examine river lengths for levee banks, bundwalls etc. that alienate a floodplain. This can be done as a topographic map exercise, ground-truthing or with sensitive digital elevation models (DEMs). This indicator is probably not amenable to remote sensing except to detect structure on the floodplain during the course of flood rise (and therefore timing of the satellite overpass is crucial).

Reporting scale

Tabulation by catchment or drainage division. This indicator probably needs to be compiled only every 5–10 years.

Outputs

Tables or histograms of aggregated data.

Data sources

Presently this is poorly documented. Apart from some dedicated surveys by agencies such as DLWC in NSW, a variety of sources may give some insight into these changes. Possible sources includes public works or engineering departments of State and Territory and local governments, land and water authorities, emergency agencies involved in flood mitigation and other works, agriculture departments, and the like.

Links to other indicators

Flooding (key indicator 4.5)
River flow regimes (key indicator 4.3)
Changed river channels

Indicator 4.7: Water use

Description

The amount of water abstracted or developed each year by purpose and drainage division.

Rationale

To manage a resource, we need to know where it is going. In water management, a useful distinction can be made (Pimental *et al.* 1997) between water consumption (where water is abstracted once for exclusive ownership) and water use (where at least some water is returned to the hydrological cycle and reuse is possible).

Analysis and interpretation

Trends over time, as well as absolute proportions of the resource diverted, are of most importance. Although data are probably collected annually, the most useful scale for detecting change is probably at intervals of several years.

Monitoring design and strategy

Sum all new water allocations with the previous amount. These include water licences, the storage capacity of new reservoirs that have been built or enlarged, and any increases in rights to pump water during high flows.

Reporting scale

Nationally, by State and Territory, by irrigation district and, most importantly, by drainage division. Also aggregate the time steps from annual up to 3–5 years.

Outputs

The consumption and use *per se* of water should be displayed by industry type — e.g. irrigation (approx. 70% of water development), industrial, urban, domestic, etc. The source of water (either surface or groundwaters) should also be identified.

Data sources

Water authorities routinely maintain these sorts of records. At several times in the past (e.g. by AWRC in 1980s), these have been collated for a national report. Both the Land and Water Audit and ABS's water physical account will do this again in the near future. Remote sensing may be particularly useful to estimate the number of farm dams.

Links to other indicators

Resource versus demand (key indicator 4.1)
Water pricing (key indicator 4.9)
Average household water consumption in cities
Growth in water storage capacity
Growth in capacity of major storage reservoirs
Number of farm dams

INDICATOR 4.8: IRRIGATION EXTENT

Description

Growth in the area under irrigation per drainage division, by crop type.

Rationale

Irrigation is the greatest user of water resources (approx. 70% of abstraction from all sources; McMahon *et al*. 1991; State of the Environment Advisory Council 1996), and so we need to track growth in this main use. Understanding where irrigation is growing is essential to anticipating the locations where water resources will come under increasing pressure for allocation away from the environment and also the type (e.g. surface or groundwaters) that is most at risk in different parts of the country. Irrigation in many parts of the country uses considerable groundwater to supplement any available surface waters. Therefore, this key indicator is not merely a subset of key indicator 4.7 and needs to be estimated independently to give a complete picture of pressures on our total national water resource.

Analysis and interpretation

Trends over time are the most informative aspect of this indicator. Given the intention of capping water extraction and giving some back to the environment, any increase in area irrigated must be a concern (unless the efficiency also increases dramatically, see key indicator 4.10). Combining this information with key indicator 4.10 and comparing with the messages of key indicators 4.1 and 4.7 will yield enough information to assess trends in the pricing of water (key indicator 4.9).

Monitoring design and strategy

Raw data are available from annual reports of the agencies listed below at the scale of whole irrigation districts. Annual estimates are appropriate. Surface and groundwater sources should be kept distinct.

Reporting scale

Aggregate data from irrigation districts into the appropriate regionalisation (e.g. drainage division).

Outputs

Graphs of cumulative area over time for each drainage division. Stratify by both irrigation district and commodity type.

Data sources

Irrigation districts and areas have been formally controlled by the water authorities in each State (although this is changing under privatisation or corporatisation to irrigation boards and companies). Each State usually produces annual reports detailing the growth or shrinkage in areas irrigated during the previous year(s). Checks should be available though agriculture departments, water (irrigation) licences, and managing bodies such as the MDBC.

Links to other indicators

Irrigation efficiency (key indicator 4.10)
Water use (key indicator 4.7)
Resource versus demand (key indicator 4.1)
Water pricing (key indicator 4.9)
Abstraction versus recharge (key indicator 1.5)

INDICATOR 4.9: WATER PRICING

Description

The current price of water as a proportion of the true cost of providing it.

Rationale

The present costing of water for irrigation, domestic or industrial uses generally represents a considerable subsidy to the user because the true costs of that provision are rarely charged. This is so because the considerable infrastructures of, say, the Snowy Mountains or the Ord River Schemes are rarely passed onto the direct consumers of the water. As part of the COAG water principles, this will gradually change as economists routinely estimate the true costs of water provision. If it does not, then there seems little prospect of ever renewing or even maintaining much of this infrastructure well into the next century. Also, there is some pressure to incorporate costs of the environmental changes that are also wrought by water abstraction, storage, delivery and bulk usage. These consequences are less easy to translate into dollar terms, but they remain no less real.

Analysis and interpretation

Comparison of prices paid to the real costs should be made as a ratio, with the expectation that in many regions this value will be closer to zero than one. Values near one are closer to the break-even point. There are various economic or political arguments explaining why this ratio need never reach one (e.g. development for the greater common good, sharing across electricity and primary production sectors, socialisation of farmers' enterprises etc.). Any values over one indicate a clear profit for water suppliers that may be more appropriate for the coming age of privatised water companies. An adjunct to this indicator might be an assessment of the cash reserves put aside by such companies to offset future maintenance and renewal of infrastructure (these latter data may not be available on the grounds of being commercial-in-confidence).

Monitoring design and strategy

Monitoring effectively requires up-to-date costings of the water, including the costs of delivery, infrastructure, opportunity costs associated with environmental change and the like. These have been estimated for a few irrigation schemes in the past but generally not for extensive water schemes across the country. Specialist economic input is needed. Pricing is reviewed annually in many States and Territories, and these values may not be changing very rapidly. Thus measurements may be made infrequently (e.g. every 4–5 years). This will reduce the costs of gathering the economic information necessary to monitor this indicator properly.

Reporting scale

Data should be collected at the user scale (e.g. irrigation district) and then aggregated to the drainage division or State and Territory levels.

Outputs

Tables of values of the price:cost ratio or graphs of the same versus the theoretical break-even point of a value of one.

Data sources

Water companies and authorities in each State and Territory that are in the business of providing water (annual reports may contain such figures). The infrastructure is often costed as part of budgetary summations (therefore Treasuries and Finance Departments are a source). ABARE also calculates many of these figures for different resource sectors (i.e. commodity groups), and some agencies (e.g. MDBC) do so for irrigation as a whole.

Links to other indicators

Irrigation efficiency (key indicator 4.10)
Irrigation extent (key indicator 4.8)
Water use (key indicator 4.7)
Resource versus demand (key indicator 4.1)

Indicator 4.10: Irrigation efficiency

Description

The proportional adoption of "best practice" irrigation technology.

Rationale

As the greatest user of abstracted water, the irrigation sector is also one the greatest wasters of water (McMahon *et al.* 1991). Much more is lost to evaporation, runoff and deep percolation (during delivery and application) than is taken up by crop plants. These proportions are difficult to measure exactly to determine "leaks" in the system, but there are sets of equipment and practices that actively seek to minimise such losses. Not surprisingly, these have been developed in arid areas (including Australia). Combined with more realistic pricing of water, these technologies will achieve more efficient use of allocated water. Increased irrigation efficiency has the greatest potential for improving our water use (Pimental *et al.* 1997).

Analysis and interpretation

Data are probably best calculated on an areal basis (i.e. area under best practice management as a percentage of total area irrigated). Using water volume estimates, the total water use can be assigned to each set of techniques. Trends in this indicator are most important for interpretation. This partitioning may be useful also for estimating efficiency *per se*, i.e. return from the crop divided by the water used. Other methods, such as water use efficiency *per se*, are too hard to calculate.

Monitoring design and strategy

Definitions of what constitutes the "best practice" technology need to be updated every few years. Currently techniques such as piped delivery, dripper systems and micro-irrigation combined with an accurate assessment of the water needs of plants fall into this category, as opposed to older methods of spray, furrow or flood irrigation. But this is also defined differently for each crop (e.g. Beecher *et al.* 1995; Anon 1997c), and so agronomic or irrigation specialist knowledge is needed for this definition. Measurement relies on knowing the areas (or some other quantitative measure) under each type of irrigation.

This indicator could be defined as the proportion of irrigation units that have adopted best practice for that crop. The smallest feasible spatial scale is the individual farm, but such information is usually held for whole irrigation districts or areas.

Reporting scale

Essentially collected by irrigation district, these values can be aggregated to large irrigation schemes or drainage divisions.

Outputs

Tables of summarised values against location or type of commodity. Graphs of trends over time.

Data sources

Departments of agriculture in each State and Territory usually hold such information as part of their normal activities. Water authorities or the boards of irrigation companies/agencies are also useful sources (including their annual reports).

Links to other indicators

Irrigation extent (key indicator 4.8)
Water use (key indicator 4.7)
Resource versus demand (key indicator 4.1)

Indicator 4.11: River structures

Description

The degree of fragmentation of hydrology by river structures, as measured by the number of structures per kilometre of river, by type and drainage division.

Rationale

Dams, weirs, locks and other structures upon a river are used to regulate its flow for storage, diversions and navigation, but also lead to fragmentation of the river and serial discontinuity (see key indicator 4.12). Many ecological processes are disrupted (AWWA 1994; Young *et al.* 1995). Thus we need to estimate the number of such structures per kilometre of river. A single dam can disrupt fish migration, so reporting the number of rivers with even a single dam is also relevant.

Analysis and interpretation

Data can be expressed in two ways:

- as the number of structures of different types per length of river for each river; and
- as an estimate of the average river length without structures as a ratio of the total river length (to pick up changes since pristine condition).

Trends in these two measures are important because they can pick up the response of removing weirs etc. that are no longer needed (e.g. many are silted up and no longer perform their function).

Monitoring design and strategy

Simply count the number of structures and measure river lengths; all calculations can be made from such raw data (see above). Structures should be divided into a few major types (e.g. large, medium and small dams, weirs etc.) that affect river continuity differently and so can be linked to key indicator 4.12. Instances where fish ladders are in place can be treated as "transparent" to fish migrations, assuming the ladders are functional. The types to be distinguished should at least include large dams, weirs and locks for navigation.

Reporting scale

One value of each measure per structure type per river (catchment). Aggregate these then up to drainage division, State and Territory and national levels.

Outputs

Tabulations and frequency histograms per structure type or drainage division.

Data sources

The MDBC (for that drainage division) and other water authorities (in each State and Territory) with control over river operations keep inventories of the structures under their control. Local governments also operate small dams and weirs associated with off-take for domestic supply. Older weirs and some smaller, disused structures may not be effectively managed by anyone.

Links to other indicators

River discontinuity (key indicator 4.12)
Alienated floodplains (key indicator 4.6)

Indicator 4.12: River discontinuity

Description

Longitudinal disruption of river channels and processes as measured by Ward and Stanford's discontinuity distance and parameter intensity indicators.

Rationale

Dams and other river structures are major obstacles to any longitudinal exchange of water and materials (e.g. energy flow, nutrient cycling, fish migrations) that occur along a river. Thus river regulation has dramatic instream consequences; Ward and Stanford (1983) called this the serial discontinuity concept. In a more local context, it is clear that weirpools that back up behind weirs and locks on our rivers tend to stratify and so act more like (slow-flowing) lakes than lowland rivers for much of the year (especially during the irrigation seasons). This then leads to problems with algal blooms etc. This is, therefore, the indicator of condition that corresponds to the pressures indicated by key indicator 4.11.

Analysis and interpretation

Two metrics used to measure this indicator are defined (Ward and Stanford 1983) as:

DD = the downstream (+) or upstream (-) shift of any variable due to the presence of a dam or other river structure (e.g. a weirpool is water of no or low flow behind a weir and so water velocity is decreased upstream of the weir).

PI = the upstream versus downstream differences in values of variables due to a dam or other river structure.

Values for different types of structures should be aggregated separately (see key indicator 4.11).

Monitoring design and strategy

Measurements must be taken at a variety of distances up and down stream from a dam. The most obvious measurements are flow rate or stage height, but others related to dams (such as water temperature, dissolved oxygen, turbidity, salinity and biological communities) are also possible. Data would be two indicators (DD, PI as per above) per variable per dam (or equivalent). Measurements should be repeated yearly, at a similar time of year.

Reporting scale

Aggregate the data by catchment or drainage division. It is also possible to stratify by size of the dam or structure.

Outputs

Tables and graphs of measures versus distance may be the best way to capture this information. Graphs of the linear extent of weirpools and other effects may be useful as case studies with summaries at the national level (e.g. frequency distributions for each drainage division).

Data sources

Water authorities running dams usually have river heights above and below dams and weirs. For other measurements, some dedicated sampling may be needed; this might be carried out (either now or in the future) by water authorities or EPA-like agencies. The indicator is used more in North America than in Australia.

Links to other indicators

River flow regimes (key indicator 4.3)
Rainfall and/or Southern Oscillation Index (SOI)

Issue or Element 5: Physical Change

Indicator 5.1: Vegetated streamlength

Description

The percentage of total streamlength with riparian vegetation, per drainage division.

Rationale

Riparian vegetation protects waterbodies from pollutants travelling overland in runoff (i.e. acts as a buffer strip), and strengthens banks against erosion from water flow. Riparian vegetation is also an important energy source (through litterfall) for the aquatic ecosystems within the stream. LWRRDC (1996) gives a number of reasons for maintaining healthy riparian zones.

Analysis and interpretation

This indicator should be expressed as a percentage of the length of streams that have riparian vegetation beside and overhanging them (hence two measurements are needed, the total streamlength and the distance with vegetation). A ratio near one would be considered healthy in forested or woodland areas (e.g. river red gums), whereas smaller values would be expected in semi-arid and arid regions. Any values near zero would be a concern, probably representing severely degraded riparian habitat. Trends over time (especially years to decades) would also be useful in indicating if the state is worsening or improving.

Monitoring design and strategy

The extent of riparian vegetation could be sensed remotely, especially from airborne scanners that can distinguish tall vegetation from paved areas, bare ground or pasture. Satellite imagery may also be applicable but at a fine scale (Campbell and Wallace 1998). A strategy of focal catchments in each State and Territory or drainage division should be considered to initiate more routine reporting against this indicator (see section on research and development needs, p. 59).

Reporting scale

A single value can be estimated for any stream, so these can be aggregated to the catchment or drainage division level. There is an argument for stratifying reporting by stream size (e.g. order); various theories about river function (see Young *et al.* 1995 for a review) suggest that riparian inputs are more important for smaller streams (i.e. low orders of 1 through 5). Therefore low values (near zero) of this indicator for streams of order 1 or 2 would be seen as degraded, especially in drainage divisions 1–6 and 8–9.

Outputs

Outputs should include maps of drainage divisions giving ranges of values (probably as frequency histograms), tables, and trends over time as graphs.

Data sources

Some data are held by water and land authorities (e.g. DLWC in NSW). Otherwise, data should be specifically captured from Landsat images and aerial photography.

Links to other indicators

Stream sinuosity (key indicator 5.7)
Riparian stock access (key indicator 5.5)
Fenced waterways (key indicator 5.6)
Bank erosion

Indicator 5.2: Extractive industries

Description

The number of extractive industries per kilometre of river or area of wetland.

Rationale

Sand and gravel extraction is widespread in rivers; sediment is mined for a number of uses (from landfill, gravel, sand, and diatomaceous earths to gems), and peat is mined from wetlands. Such extractive industries are responsible for many of the instream changes (i.e. not resulting from catchment modification although these can also interact). There is a very strong interaction with the abstraction of water (see Water Quantity issues). A pressure indicator to allow an independent assessment of these instream agents of change is thus required.

Analysis and interpretation

Two measurements are needed for this indicator: the total length of rivers or areas of wetlands; and the corresponding values for mining and other extractive uses. Failing measures of distance/area for the latter, the number of permits granted might substitute. Expressed as a percentage, these values might also be stratified by the type of extraction. Ideally these activities should be assessed for what has been done in the past, as well as what is currently occurring, because their impacts can persist for many years.

Monitoring design and strategy

All the activities under this indicator require permissions and licences. Thus the records of the permitting agencies should be accessed to determine the number of waterways that have been subject to extraction.

Reporting scale

Each catchment returns a single value per time step for this indicator, so these can be aggregated up to the level of drainage division. If data are only available on a State and Territory basis then that may already constitute the aggregation step. Assessed for each year, the timescale can also be aggregated, if desired, but many extraction operations may move on in less than a year.

Outputs

Summarised values can be tabulated for each drainage division or State and Territory, possibly stratified by the type of extraction.

Data sources

Data sources are State and Territory departments of mines and mineral resources, local government, and water authorities. Data may be available in Geographic Information System (GIS) form; otherwise annual reports will have to be examined. Where this information is in a variety of forms or formats, collation will be needed and possibly some standardisation.

Links to other indicators

River flow regimes (key indicator 4.3)
Stream sinuosity (key indicator 5.7)

INDICATOR 5.3: CATCHMENT CLEARANCE

Description

The degree of clearance in the catchment, as the percentage of original tree cover remaining.

Rationale

Catchments that have been cleared show very different hydrological characteristics to uncleared catchments. This is important for erosion potential, and delivery of material (salt, sediment, pollutants) to the stream. This landscape property is potentially one of the most important and permanent changes human activity can make to the integrity of a catchment (Jones *et al.* 1996). Obviously, a number of catchments have not had tree cover within historical times, in arid and semiarid Australia in particular. These should be omitted since, where the base is zero, the indicator is not calculable; cases should be appropriately noted. This indicator is most relevant to forested or woodland areas in upper catchments, but is still important nationally because of links to erosion and effects on water quality further downstream.

Analysis and interpretation

Calculate the percentage of the catchment currently cleared and compare with historical values as a function of the original tree cover. Trends over time (years to decades) are also important. The desirable current values will vary regionally, but the time-related percentages are more readily interpretable (low values near zero indicate large changes).

Monitoring design and strategy

The measurements needed are the total area of the catchment (or part) being considered and the area under trees now and in the past. Remote sensing (satellite and aerial photographic; Campbell and Wallace 1998), topographic mapping and local observations can be used for the former two measures and historical records are needed for the third. These data are amenable to GIS mapping and storage.

Reporting scale

There is only one value per catchment or part catchment, so the indicator can be aggregated by summation and averaging to drainage divisions, or State and Territory level.

Outputs

Outputs should be maps of Australia showing ranges of current values (as frequency histograms) and graphs of trends over time.

Data sources

Imagery generated by the CSIRO Office of Space Science and Applications (COSSA) or via Environment Australia will be a prime source (Campbell and Wallace 1998) of data. Land departments in each State and Territory may hold similar information. No dedicated surveys for this specific purpose were discovered.

Links to other indicators

Clearing rate
Removal of native vegetation
Tree cover
Stream sinuosity (key indicator 5.7)
Land resources Indicator 1.3, Per cent change in impervious area of catchment (as the obverse of the same question)

Indicator 5.4: Farm distance

Description

The distance from farms to watercourses.

Rationale

If activities upon farms can have detrimental effects on various waterbodies (e.g. as a source of pollutants, erosion, unintentional spillages, damage from stock, etc.) then the distance from farm activities will be a useful surrogate for the risk from these activities.

This is a novel indicator, requiring measurements from imagery or maps.

Analysis and interpretation

If buffer strips are to work then there should be some separation of farm activities from waterbodies. There are two different measurements possible — plots of either average distance versus activity type, or distance against frequency — which need to be interpreted against problems in particular case study waterbodies.

Monitoring design and strategy

Ideally this should be remotely sensed by measuring distances from farm buildings or crop fields to watercourses.

Reporting scale

By drainage divisions and farm types.

Outputs

Outputs should be tables (e.g. average distance) and graphs (of analysis data).

Data sources

Remote sensing imagery corrected for parallax, so that distances can be measured, is required. There are no current data sources.

Links to other indicators

Buffer strips
Catchment clearance (key indicator 5.3)
Stream sinuosity (key indicator 5.7)

Indicator 5.5: Riparian stock access

Description

The percentage of streamlengths with access for stock.

Rationale

Unlimited access of stock to streams can cause increased erosion and declines in water quality in rivers and wetlands.

Analysis and interpretation

The ratio of stock-accessible waterway to the total length of waterways should be recorded. High values (i.e. close to one) imply that stock access is relatively unrestricted; low values (closer to zero) imply that the overall pressure is less, although it may be concentrated at points with access, potentially exacerbating effects such as erosion. These latter areas may be worthy of more intensive examination.

Monitoring design and strategy

Two measurements are needed for this indicator: the total length of stream (also needed in other indicators) and the length that stock have access to. The latter is probably best assessed via ground-based observations rather than remote sensing.

Reporting scale

The scale of reporting should be from local (i.e. river reaches) to drainage division.

Outputs

Outputs should be frequency histograms as tabulations. Maps with averages and ranges of the indicator values may also be useful summaries.

Data sources

Water authorities or agriculture departments in each State and Territory may hold some data of this type, but data are patchy and collated for large-scale reporting purposes. If these data are not suitable, it will be necessary to implement dedicated sampling programs, which are probably most effective at a local scale.

Links to other indicators

Fenced waterways (key indicator 5.6)
Vegetated streamlength (key indicator 5.1)
Grazing

Indicator 5.6: Fenced waterways

Description

The percentage of the streamside with fencing to keep off stock.

Rationale

This is the response indicator corresponding to the pressure of key indicator 5.5. Fencing stock and providing alternative sources of drinking water can lessen the environmental impacts of stock. Despite considerable farmer resistance to limiting stock access, there is growing evidence from a number of small studies across the country that fencing waterways also makes good sense economically (in part because the capacity of the land to support grazing is less concentrated and so extended beyond proximity to natural water sources).

Analysis and interpretation

The ratio of fenced waterway to the total streamlength should be recorded. Low values (i.e. close to zero) imply that stock access is relatively unlimited; high values (closer to one) imply that the overall pressure from stock is lessened, although it may be concentrated at points with access (potentially exacerbating effects such as erosion). These latter areas may be worthy of more intensive examination and treatment.

Monitoring design and strategy

Similarly to key indicator 5.5, two measurements are needed: the total length of stream (also needed in other indicators) and the length that is fenced. The latter is probably best assessed via ground-based observations rather than remote sensing.

Reporting scale

The scale of reporting should be from local (i.e. river reaches) to drainage division.

Outputs

Outputs should be frequency histograms as tabulations. Maps with averages and ranges of the indicator values may also be useful summaries.

Data sources

Water authorities or agriculture departments in each State and Territory may hold some data of this type. Otherwise, dedicated sampling programs will be needed and these are probably most effective at a local scale. The ABS agricultural surveys might also yield some information.

Links to other indicators

Riparian stock access (key indicator 5.5)
Vegetated streamlength (key indicator 5.1)
Buffer strips

Indicator 5.7: Stream sinuosity

Description

The degree to which the streams are sinuous per drainage division.

Rationale

Streams that are not confined by bedrock naturally meander across the floodplain (especially in lowlands). This indicator measures the degree of channelisation and other engineering works (including erosion control using riprap, etc.) that are a pressure hydrologically, and often biologically. This standard of the geomorphic "naturalness" of a stream is relatively easy to measure from maps or aerial photos, while representing more complex modifications to river channels (e.g. the habitat simplification that comes from channelisation, removal of aquatic vegetation or undercut banks, de-snagging of fallen timber, dredging, levee bank construction, bank erosion etc.).

This is a relatively novel indicator for SoE use. Thus far it is only measured for scientific study sites rather than in more general surveys. Therefore, new measurements will be needed and some development is necessary.

Analysis and interpretation

The ratio of thalweg distance (path of deepest part of stream, including meanders; Gordon *et al.* 1992) to valley distance (path of the landform, including any floodplain) should be measured. Values larger than one are expected in undisturbed lowland rivers (i.e. meandering evident). Values close to one show that the stream has been channellised, i.e. straightened to cut meanders off.

Monitoring design and strategy

Relevant parameters are easily determined from aerial photography or topographic mapping. There is potential to measure large areas from satellite imagery. Measurement is necessary only every 5–10 years because of the slow rates of change.

Reporting scale

This indicator yields a single value per river (catchment), and can therefore be aggregated by summation and averaging up to the drainage divisions level or perhaps State and Territory level. Data collection is only relevant in areas with naturally unconfined channels.

Outputs

Ouput should be in the form of graphs showing trends over time and maps with colour-coding showing degrees of change (especially values close to one versus much higher).

Data sources

Remote sensing data sources, maps available from mapping authorities, and data from geological organisations will provide the raw materials from which measurements can be made. This measure is not currently used as an indicator.

Links to other indicators

Vegetated streamlength (key indicator 5.1)
River flow regimes (key indicator 4.3)
Extractive industries (key indicator 5.2)
Flooding (key indicator 4.5)
Percentage of river length impounded
River engineering
Infilling rate

Issue or Element 6: Biotic Habitat Quality

INDICATOR 6.1: AUSRIVAS SURVEY RATINGS

Description

Assemblages of macroinvertebrates in rivers as assessed by AUSRIVAS (AUStralian RIVer Assessment Scheme) sampling protocols and computer models.

Rationale

AUSRIVAS was developed as part of the Monitoring River Health Initiative (MRHI) of the National River Health Program (NRHP). At present, it comprises a set of sampling protocols for riverine macroinvertebrates and habitat variables, and a predictive modelling system (with standard software platform). AUSRIVAS provides regionally relevant assessments of the degree of impact on macroinvertebrate communities at river sites by comparing the taxa found to the taxa that would be expected were the site un-impacted. It is based on the British RIVPACS system (River InVertebrate Prediction And Classification Scheme), but is envisaged to contain additional components for detailed habitat assessment and algal community assessment

Benthic macroinvertebrates have been used in assessing water quality for many years. This particular approach attempts to use macroinvertebrate sampling plus physico-chemical measurements in a predictive manner to assess changes in water and habitat quality. An outline of the approach is given by Norris (1995) and the overall NRHP–MRHI effort is summarised by Schofield and Davies (1996). For each region, a list of macroinvertebrate taxa from high quality (that is, low human impact) reference sites is established. This reference condition provides a standard against which a series of test sites can be judged. AUSRIVAS has been under development since 1993, and more than 1500 reference sites across Australia were sampled during 1994–96 to build the initial predictive models. Further refinement of those models is anticipated during 1997/98.

AUSRIVAS is being used during 1997–99 to perform the First National Assessment of River Health (FNARH), with some 6000 new sites to be sampled and assessed using the existing models.

Analysis and interpretation

Analysis uses computer models to predict what macroinvertebrates each test site should contain. Application in the SoE context requires:

- a national set of test sites that are re-sampled in each iteration of SoE reporting in order to assess changes in ecological condition (defined as proximity to the reference condition expected for that site); with
    - sites selected in a random or stratified/random manner; or
    - sites selected in relation to regional impacts of specific interest (e.g. instream salinity).

Test sites are not yet chosen, so SoE might influence where they are located in each State and Territory.

AUSRIVAS will assess change based on variability amongst sites, e.g. how different invertebrate composition at a new site is to the reference sites. This is measured by the ratio of the number of taxa found at a site to the number of those expected (O/E scores). A decline of more than 20% in O/E scores is considered significant. AUSRIVAS, however, also places a site's scores into one of four bands equivalent to reference conditions and representing increasingly significant departures from the reference condition (see below), which could be interpreted as the degree of impact. AUSRIVAS also generates a second index called SIGNAL O/E that is based on the observed and expected sensitivity to pollution of the macroinvertebrate community at the site (Chessman 1995). The combination of the two indices, O/E and SIGNAL O/E, adds considerable diagnostic power to the bioassessment. The actual figures involved will need further ground-truthing against known impacts to become even more diagnostic, which is likely during the next iteration of the AUSRIVAS process.

The AUSRIVAS outputs will be used in conjunction with independent data on water quality to diagnose the ecological problems at a river site. The maintenance of water quality monitoring at test sites is important where poor water quality is believed to be a significant cause of impact on river biota. An AUSRIVAS analogue is being explored for estuarine benthos.

The FNARH currently monitors macroinvertebrates, but there are plans to incorporate a detailed habitat assessment and assessments using benthic diatoms or fish into AUSRIVAS.

Monitoring design and strategy

A great advantage of the AUSRIVAS indicator is that it has been developed on a national basis utilising Standard Operating Protocols (SOPs). Sampling methods are both standardised and rapid (Davies 1994); sorting and handling methods are uniform, with emphasis on achieving and maintaining high levels of quality control and assurance during AUSRIVAS development and the conduct of the FNARH. These processes need to be managed so that continual improvements in sampling or analytical techniques can be incorporated while still making use (and sense) of earlier data.

Field sampling for the FNARH began in 1997 (with 2000 test sites expanding to as many as 6000 by 1999) using the SOPs developed to date. Sampling for the FNARH is being conducted annually. The AUSRIVAS models have been developed for both one and two sampling events (in different seasons) per year.

The focus in the initial three years of the MRHI was on choosing and sampling reference sites to build the AUSRIVAS models rather than on sampling test sites for reporting — which is now the focus of the FNARH. The geographic range for macroinvertebrate sampling in the FNARH (test sites) and during AUSRIVAS development (reference sites) so far has been nation-wide. In the FNARH, some States have concentrated efforts on regions where management problems are most likely to arise or are seen as a priority. The spatial scales are focused on a 100–200 m river reach for each site, with any overall assessment at a catchment or regional scale based on numbers of sampling sites.

The use of AUSRIVAS for SoE reporting would require planning of sites specifically for SoE purposes, if the emphasis is on documenting trends. The present reference site network in each State and Territory may already be useful for determining expected faunas in test sites for the next SoE Report, and care will be needed in selecting groups of sites for repeated sampling for future SoE reporting.

The frequency of measurement for this indicator depends on:

- the nature of the pressure or impact (5 years may be good enough for mitigation of nutrients from sewage plants, but too short a time span for acidic rock drainage); and
- the temporal variability of the fauna — including (especially in Australia) responses to major droughts and floods. This issue is being specifically addressed under commissioned MRHI research, and will also be one of several subjects of a sensitivity analysis to be conducted on the AUSRIVAS models.

The latter is a big issue for SoE reporting of all biologically based indicators. Rigid adherence to a once-every-5-years timetable might mean measurements coincide with severe natural events making comparisons with previous SoE assessments difficult. Interpretation is thus needed via other indicators such as flow regime or the Southern Oscillation Index.

Reporting scale

Data collected will be site-specific, ideally with sites chosen to be useful and meaningful for iterations of SoE. Spatial scales of sets of test sites for SoE usage should be at least as fine in resolution as the AWRC River Basins and sets should be from as many basins as possible. Data should be reported nationally, and could also be stratified by broad classes of, say, pressure type or land use. There is not necessarily much value in sprinkling SoE sites uniformly across the nation to get some "average" picture, unless it is used merely as a snapshot for the next report.

Outputs

Data are stored electronically. AUSRIVAS outputs consist of ratios of observed/expected (O/E) taxa. O/E and banding output from the first AUSRIVAS survey is the most appropriate way to report data for SoE purposes. Maps with differently shaded river reaches corresponding to different bands have been mooted as a useful SoE reporting output.

In the SoE context there are probably two phases of outputs. The first phase would be the initial assessment, which will show how far sites are from the expected composition. Most probably, this will be reported using the "banding system" rather than actual O/E ratios: e.g. Band A — good condition/equivalent to reference conditions; Band B — slightly impaired; Band C — moderately impaired; Band D — grossly impaired. In the second phase, more emphasis can be placed on how the selected test sites have improved or declined relative to the first assessment.

Data sources

The main data source is the FNARH, launched in February 1997, using the AUSRIVAS computer models for regions and States/Territories. This is a federally coordinated program involving all States and Territories and a large number of commissioned researchers, and jointly managed by the Land and Water Resources Research and Development Corporation and Environment Australia. Presently the FNARH information is being collected by various State agencies nationwide. The reference site sampling is conducted twice yearly, and data stored in the computers of the contracted authorities in each State and Territory. Each jurisdiction retains joint ownership, with the Commonwealth, of its own data — which are used to develop models for each jurisdiction and regions within it. Each State agency will probably continue to store its own data and outputs, but the models and software will ultimately be managed as a centrally maintained, down-loadable package on a World Wide Web site. A functioning AUSRIVAS website has been developed at the Cooperative Research Centre for Freshwater Ecology for use during the FNARH. The maintenance and support of both the data and the software over time is an important issue that is currently being addressed.

Links with community-based programs such as Waterwatch are being actively pursued through the development of training resources for community groups and plans for their involvement in FNARH.

Links to other indicators

Various Water Quality and Quantity indicators (elements 3 and 4, respectively)
Frogwatch records (key indicator 6.2)
Waterbirds (key indicator 6.4)
Later versions of AUSRIVAS based on fish, diatoms, or other biotic groups

Indicator 6.2: Frogwatch records

Description

Populations of frogs in surface waters and wetlands within each drainage division.

Rationale

Amphibians are good indicators of aquatic habitat quality, in part because they are sensitive (e.g. they rely on water, at least in the early life stage, and breathe partly through their skin). The calling of males for mates makes monitoring frogs relatively straightforward, albeit only seasonally or after rain. Frog spawn and tadpoles are easily censused visually.

This indicator is very amenable to community-based monitoring programs. Australian Frog Week (an initiative of the Frog and Tadpole Study Group of NSW), where community groups take tape recordings of frog calls, is conducted every year. Frogs are presently being monitored in some States by various organisations such as Frog and Tadpole Study Groups (NSW, Vic and SA), frog societies (Qld), herpetological societies, naturalist societies, Landcare groups etc., all involving community participation.

Analysis and interpretation

Data are required on the numbers and presence or absence of various species (from tape recordings) for catchments, Australia-wide. The information from the various frog monitoring programs provides a valuable database from which to assess or detect any long-term changes in water quality and habitat health. These changes could be assessed by detecting sustained trends over time in numbers and/or species of frogs. Comparisons with distributional maps (e.g. Cogger 1992) and previous records will aid interpretation. Most trends documented so far are declines (i.e. undesirable).

Monitoring design and strategy

Amphibians can be monitored through their distinctive calls, and commercial tapes with which to make comparisons are available. Monitoring should be annual, timed at the appropriate season (late winter–spring) or after rain (when frogs are calling). Tape recordings by the public are sent to experts for assessment of species present, along with date, location and timing (nocturnal or daytime).

Reporting scale

The reporting scale should be catchments, reported for each State and Territory and aggregated to drainage divisions. Annual data should be aggregated to the SoE cycle (4–5 years) for any observed trends in total numbers and species (i.e. report each occasion and derive any longer term trends).

Outputs

Outputs should be maps of frog species distribution from each State that can be compared with earlier records. Information can be obtained from maps placed on the GIS database (i.e. South Australian Frog Census). Data are stored electronically. "Frog Census" is available through the Internet, http://www.epa.sa.gov.au/frogs, with contact person Peter Goonan, Email: goonanp@dep.sa.gov.au. Frogwatch records (seasonal) are available as a yearly report.

Data sources

Data sources are: Frog Census (SA Environment Protection Authority), Frog and Tadpole Study Groups, State and Territory environment departments, universities, and research organisations (including museums).

Links to other indicators

Wetland extent (key indicator 6.7)
Rainfall
Southern Oscillation Index (SOI)
Wetland condition
Amphibian populations

Indicator 6.3: Fish kill records

Description

Registers of fish kills, bird kills etc., kept by State agencies.

Rationale

Fish kills are highly visible events that can arouse great public concern. In general, fish kills occur as a result of changed water quality, due either to natural conditions (i.e. high temperatures and low dissolved oxygen) or water contamination (for example, from pesticides or acidic runoff). In some circumstances, other visible biota such as crustaceans, birds and other vertebrates can also be affected. It is essential that these events are carefully investigated to obtain a better understanding of the causes (Napier *et al.* 1997). Data from the fish kill records can help identify problem areas, especially those that require improved water management.

It is also possible to tabulate the proportion of reported fish kills:

- that lead to investigation;
- where causes are identified;
- where prosecutions ensue; and
- where remediation is attempted.

(These four steps form a continuum of increased levels of action — a potential indicator of response).

Analysis and interpretation

Record the number of events per catchment, size (as kilometres of stream or area) of kill, number of species and approximate number of individuals observed for each kill. Document putative causes and whether actions (such as prosecutions) arise as a result. Trends over time are important as well as current numbers. Links to putative causes are important for diagnostic interpretation (Napier *et al.* 1997).

Monitoring design and strategy

Event-based data collection should be maintained by the relevant agency. Most current registers rely on public reporting of observed kills of fish, birds and shellfish.

Reporting scale

The appropriate scale of reporting is Australia-wide. Aggregate State and Territory records into drainage divisions. Aggregate annual reporting to the SoE cycle (4–5 years).

Outputs

Information should be produced as a report, and data tabulated in an electronic database.

Data sources

This indicator is presently being monitored in some States (i.e. NSW Fisheries/EPA and Qld Department of the Environment hold well-maintained registers and publicly available databases now), and used in SoE reporting by Tasmania and Western Australia. Other States should be encouraged to formalise their registers and use them for SoE reporting.

Links to other indicators

Chemical residues (key indicator 3.4)
Pollution point sources (key indicator 3.6)
Licensing (key indicator 7.4)
Concentration of pollutants in fish

INDICATOR 6.4: WATERBIRDS

Description

The numbers of waterbirds of different species on wetlands and the breeding of colonially nesting species of waterbirds.

Rationale

Waterbirds are quite conspicuous and easily identified and counted. Their mobility allows them to track flooding and wetland conditions. The Royal Australian Ornithological Union (now Birds Australia) makes use of observations from the public (Anon 1996); therefore community-based input is possible. All species of waterbirds are relevant, but especially those that breed in our inland waters (as opposed to overseas or in some other habitat.

Analysis and interpretation

Breeding surveys need to identify total numbers of waterbirds. Changes in the indicator are difficult to determine, but orders-of-magnitude changes are probably detectable for long enough temporal scales (comparisons are now being made with the 1940–60s, see Kingsford and Thomas 1995).

Waterbird abundance in relation to the rainfall/El Niño–Southern Oscillation (ENSO) cycle can be expressed as observed versus expected numbers of birds or trends across regions. Calculating expected numbers of waterbirds would depend on previous population sizes and antecedent weather conditions (e.g. drought or flood). Summing the estimates of numbers over large areas would be useful to determine if the birds are just moving around ("following rain") or changing in cumulative abundance. Tagging data would also help with this. Such an indicator is only sensible if applied over large spatial scales, due to large-scale movements in relation to flooding.

Monitoring design and strategy

Essentially it is useful to know if, when water is around, the birds are as expected. The indicator need only be compiled once every 5–10 years.

Numbers of waterbirds: Protocols for estimating bird numbers and diversity tend to be expensive, involving aerial surveys, or timed observations on single bodies of water by several investigators. Surveys would need to be seasonal (by flooding events, not the calendar — especially for breeding) to coincide with waterbird behaviour and use of wetlands.

Breeding of waterbirds: Species list and turnover estimates are possible. Techniques for monitoring could include aerial surveys (most efficient), ground surveys, and (long-distance) photography for breeding bird surveys. Report breeding surveys by case studies of wetlands, catchments or rivers, or by population indices for different individual species.

Reporting scale

Reporting could be continental in extent through sampling of wetlands, but will more often be regional or wetland-based. The spatial scale of reporting is at the level of wetland, but could be aggregated to the catchment or regional level (e.g. drainage divisions). Annual counts may be of sufficient frequency for long-term analyses.

Outputs

Data should be reported for wetlands or regions within States and Territories and aggregated to drainage divisions and SoE cycles (4–5 years). Graphs of trends over time should also be presented.

Data sources

Waterbirds (both numbers and breeding) are presently being monitored over a geographic range that covers about 10% of the wetlands in eastern Australia (Mt Isa to Melbourne) which are surveyed each year for waterbirds by the National Parks and Wildlife Service (NPWS) or equivalent in each jurisdiction, with input from Environment Australia. The survey runs along ten 30 km-wide survey bands in October each year and began in 1983. The same wetlands are surveyed each year. Data are stored electronically, with custodianship given to the data collector. Good design should allow access to data through the Internet. NSW data are stored on a database held by NSW NPWS. Breeding data are also collected for Macquarie Marshes (i.e. numbers of each colonially breeding waterbird each year) and other wetlands of special interest.

Links to other indicators

Wetland extent (key indicator 6.7)
Flooding (key indicator 4.5)
Wetland distribution, numbers and area
Wetland degradation
Wetland condition
Southern Oscillation Index (SOI)
Rainfall
Droughts

Indicator 6.5: Habitat loss

Description

Natural river or wetland habitat lost or converted to other land use types.

Rationale

The rate of decline in available habitat areas influences other indicators, such as biodiversity and threatened species. Wetland numbers and areas are presently being monitored by Environment Australia, and State and Territory departments. Loss of river habitat is due to channelisation, riverine engineering, meander cut-offs, removal of snags for navigation, etc. Adjacent land uses (e.g. urban, agricultural, industrial or recreational) can impinge upon wetlands or rivers over time.

This indicator is related to more general indicators of pressure developed for the biodiversity theme (Saunders *et al*. 1998).

Analysis and interpretation

There is a need to define types of wetlands and rivers, and converted land, to cover the full range across the continent (this is being partially achieved by the Environment Australia/LWRRDC wetlands inventory). Aerial photography performed since the 1940s, or satellite imagery collected since 1975, could be useful for retrospective analyses at smaller scales as case studies. Changes of 10% would be considered significant. It would be useful to establish finer categories of wetland degradation than total area lost (see section on research and development needs and condition indices).

Monitoring design and strategy

Wetland areas should be mapped, as in the Environment Australia/LWRRDC inventory (combined with information from the ABS on land use statistics). Methods should involve techniques such as satellite imagery or aerial photography (Campbell and Wallace 1998) to identify types of land use. Related techniques are used for key indicator 6.7, where the extent of wetlands is measured with extensions to rivers as a linear feature (see comments in Campbell and Wallace 1998). Permits to drain wetlands (see key indicator 7.4) are also relevant.

Reporting scale

The spatial scale of reporting should be catchments or drainage divisions. The geographic extent of data collection should be Australia-wide.

Outputs

Outputs should be in the form of reports with maps showing locations and status of wetlands and rivers, and charts showing trends over time. The information could also be reported as case studies of wetlands, catchments or rivers.

Data sources

Data sources include the Environment Australia wetland inventory (ANCA 1996 or see WWW site http://www.anca.gov.au/environm/wetlands/wetdir.htm), NSW NPWS and NSW Department of Land and Water Conservation or equivalents in other States and Territories. University studies, and river engineering records from public works departments and local government authorities, are also possible data sources. Good design may allow access to data through the Internet.

Links to other indicators

Wetlands extent (key indicator 6.7)
Alienated floodplains (key indicator 4.6)
Stream sinuosity (key indicator 5.7)
Licensing (key indicator 7.4)
Wetland numbers and areas
Wetland degradation
Biodiversity indicator 2.1 Extent and rate of clearing, or major modification, of natural vegetation or marine habitat

Indicator 6.6: Exotic pest flora and fauna

Description

The status of exotic aquatic species (i.e. aquatic weeds, fish and cane toads) declared as pests or weeds per drainage division, where "status" corresponds to number and rate of spread.

Rationale

Many exotic flora and fauna are a direct pressure on native species. Their numbers are increasing due to escapes from the aquarium trade and deliberate releases. An understanding of the distribution of the exotic biota would assist in their management and control. To assess this impact, this indicator should go beyond a mere listing of which species are registered by various jurisdictions. States and Territories are responsible for weed assessment, but there is an opportunity for community involvement during the removal of weeds and pests.

Three sub-groups of exotics affecting aquatic ecosystems are obvious: aquatic weeds as the biggest problem, pest fish species (e.g. carp) as the next largest, and cane toads as a well-researched example.

This indicator is the aquatic equivalent of indicators developed for the land resources (Hamblin1998) and estuaries and the sea themes (Ward *et al.* 1998). Together, they form a significant pressure on biological diversity, and are discussed from this perspective in the report recommending indicators for biodiversity (Saunders *et al.* 1998).

Analysis and interpretation

Subgroup–Aquatic Weeds: Changes in the indicator are likely to be important in two ways. A sustained average yearly increase of 20% would be a significant negative trend, as would a shift from zero (absence) to presence. Conversely, a 50% decrease in two years, sustained through different years with contrasting seasons, would be a significant positive trend. Interpretation is clouded by the need to allow for year-to-year variability.

Sub-group–Fish: The variable is the proportion of fish catches that are introduced species (e.g. the dominance by carp was around 90% for the NSW Rivers Survey by NSW Fisheries).

Sub-group–Cane toad: The rate of spread across the continent (especially in relation to its predicted eventual limits) and dominance of this species within amphibian assemblages. Comparisons should be made against historical records.

A potentially useful approach is to assess the current distribution as a proportion of the potential range for each exotic species (e.g. estimating their potential as modelled by BIOCLIM or similar). This is not used as an indicator as far as we could determine, but addresses threats of future pressure.

Monitoring design and strategy

Subgroup–Aquatic Weeds: Infestations of noxious aquatic weeds should be measured as areal extent or percentage of a feature (presence–absence sampling is adequate). Any applicable technology could be employed — i.e. satellite, aerial photographs, observations, field-based measurements. The scale on which data could be collected is optional or equivocal. For example, data could be collected from the landscape level (floodplains) to local linear features such as drains. The indicator is relevant to floodplains, wetlands and agricultural landscapes where water is used or applied, and hence to both natural and "modified" features. The geographic extent of data collection is throughout the semi-arid and warm temperate zones of Australia, and possibly cold temperate zones. The frequency of monitoring depends on the nature of the suspected pressure. Annual monitoring is too frequent, but 5 yearly monitoring no longer gives any early warning. Somewhere in the 3–5 year range is probably appropriate in most contexts. This indicator is amenable to a key or reference sites approach (see section on research and development needs, p. 59). An alternative measure could be aquatic weeds as a proportion of biomass or their incidence in vegetation surveys.

Subgroup–Fish: Pest fish such as carp, gambusia, redfin, tilapia, loach etc should be monitored and their distribution tracked through records kept by fisheries departments, research institutions and fishing groups.

Subgroup–Cane toad: Although not so widespread, this species does pose a threat to native frog species on a national scale. The distribution of cane toads is mainly restricted to Queensland, but there have been reports from northern New South Wales and concern about the spread of this pest to the Northern Territory.

Reporting scale

Data should be aggregated by drainage division or State and Territory. Reporting only every 5 years is adequate, but some data will be available annually (from annual reports of fisheries and agriculture departments), and others at irregular intervals (e.g. major survey results).

Outputs

The data should be reported as presence–absence, relative changes and rates of change. Data could be stored as map images, as areas with spatially explicit references.

Data sources

The Bureau of Resource Sciences is taking the lead in assessing pests of importance to natural resources. State and Territory environment or agriculture departments, fisheries and local council weed control programs also hold data. There could be community involvement, for example through weed removal programs. Presently, this indicator is monitored patchily (for the worst perceived threats only). Commonwealth coordination and continued funding is changing this.

Links to other indicators

Frogwatch records (key indicator 6. 2) — for cane toads
Native versus introduced species
Aquatic weeds
Noxious species
Biomass exotic

Indicator 6.7: Wetland extent

Description

The extent of wetlands in each drainage division.

Rationale

The area or extent of wetlands and their distribution is basic information for inventory and other managerial purposes. Draining and other land uses have led to a loss of wetland area. Wetlands of international importance should be listed as a separate category, and different types (e.g. salinity classes, permanent versus temporary) should be treated separately in data collection and reporting.

The definition of "wetland" used here is any land thought to be naturally wet, either permanently or intermittently inundated (i.e. after above-average rains in the catchment), and includes much of the Australian inland. Note that this differs from the definition used in the *Ramsar Convention on Wetlands.*

Analysis and interpretation

Important changes in wetland areas and numbers are difficult to determine, but orders of magnitude changes are probably detectable for long temporal scales. Information should be reported as case studies of wetlands, catchments or rivers. The data analyses should ideally encompass 10–50 year time series, perhaps developing relationships with relevant hydrological data (e.g. flooding frequency and extent).

Satellite imagery collected since 1975 could be useful for retrospective analyses.

This indicator of condition is related to more general ones being developed by the biodiversity theme (Saunders *et al*. 1998)and has analogues in the estuaries and the sea theme (Ward *et al*. 1998). Here it is particularly concerned with inland wetlands.

Monitoring design and strategy

The measurement technique should be satellite imagery and aerial photography (Campbell and Wallace 1998). The geographic extent of data collection should be Australia-wide, although spatial scale could be at the level of wetland or catchment (with some size limitations imposed by remote sensing technology). The frequency of monitoring is dependent on the scale — possibly 5–10 years for many catchments, given climatic variability.

Reporting scale

Aggregate the areas in each drainage division as summations or frequency distributions.

Outputs

Outputs should be maps showing cumulative areas per drainage division and graphs showing frequency distributions. Good design should allow access to outputs through the Internet.

Data sources

Strong links to the Environment Australia wetland inventory, which may develop as a centralised national database, should be developed. Data storage (in NSW) is with the NSW National Parks and Wildlife Service and NSW Department of Land and Water Conservation, with the equivalent in other States. This indicator is presently being monitored in some areas (e.g. Macquarie Marshes, NSW).

Links to other indicators

Licences (key indicator 7.4)
Habitat loss (key indicator 6.5)
Wetland numbers and areas
Wetland distribution
Biodiversity indicator 11.1 Ecosytem diversity
Biodiversity indicator 11.2 Number and extent of ecological communities of high conservation potential

Indicator 6.8: Pest control

Description

Numbers of programs for, and money spent on, controlling exotic pest species.

Rationale

Pest control programs provide a response to, and measure of, the extent and severity of infestation by pest species. Examples of pest control programs include aquatic weeds (i.e. alligator weed, salvinia, water hyacinth etc.) control, and the poisoning and removal of carp by water authorities, agriculture departments and local councils.

This indicator is the aquatic analogue of indicators developed for the land (Hamblin 1998) and estuaries and the sea themes (Ward *et al.* 1998).

Analysis and interpretation

The effectiveness of exotic pest control programs could be assessed by the continued funding and geographic range of such programs. Arguably, declines indicate improvement while increases indicate a losing battle.

Monitoring design and strategy

For individual pests, the extent and severity of the infestation within a region will be monitored by the number of programs within a catchment and the amount of money spent on the control/eradication of the pest species.

Reporting scale

Reporting should be on a regional or catchment scale, Australia-wide, with aggregation to drainage divisions.

Outputs

Outputs should be maps of control programs and tables and charts of money spent.

Data sources

The Bureau of Resource Sciences is taking the lead in assessing pests of importance to natural resources for integrated control efforts. State and Territory environment departments, water authorities, National Parks and local government also hold relevant data. Annual reports on the various individual pest control programs are also a useful source of data on effort expended.

Links to other indicators

Biological control
Introduced species
Exotic pest flora and fauna (key indicator 6.6)

Issue or Element 7: Effective Management

Indicator 7.1: Consistency

Description

Tallies of management plans and policies that are in conflict with one another, per jurisdiction.

Rationale

Different departments or agencies within a government, or the different levels of government, can impinge simultaneously on most environmental issues. This is particularly so for inland waters. For example, bounties for clearing land would now be seen to be in conflict with attempts to limit water erosion. Therefore an indicator is needed to assess potential discrepancies amongst policies governing a single issue or waterbody. There are case studies available where the management of the land is inconsistent with the maintenance of water resources.

So, are the different elements of management policy in agreement regarding environmental protection of inland waters? This examination may require some careful consideration.

Analysis and interpretation

This is a completely novel indicator, and so will require considerable development. What is required is a technical assessment and judgement of the environmental impacts of public policy; such scientific scrutiny of policy decisions is presently quite patchy even in formal Environmental Impact Assessment (Fairweather 1989). The suggested approach is to score individual policies or incentives on the basis of whether they are benign, inimical or neutral to inland waters, and tally these scores to give a composite. Inconsistency arises when both inimical and benign policies apply to the same environmental feature. Hence the numbers of such mismatches would be important. The number of "negatives" per issue or waterbody could also be scored. The main interpretation would come from the trend over SoE reports. A significant change would be the reversal or repeal of cases that are in conflict (after they had been identified by this reporting).

Monitoring design and strategy

The variable is the number of management themes where a consistent approach is adopted by all relevant jurisdictions, possibly as a proportion of all such. Because this relies on determining inconsistencies among different pieces of legislation, regulation and policy, such data are difficult to capture without a dedicated examination. An exception might be during the infrequent reviews of legislation within a given portfolio, such as the current review of Commonwealth legislation. Another potential source of this may be the "watchdog" activities of academics, green politicians and community groups. Some national strategies may also have assessed such conflicts. The best start on this could be made by separating out just a few contentious issues or sectors for the next SoE cycle.

Reporting scale

Report separately for each jurisdiction (Commonwealth, State and Territory, local government) by the issue or element of the inland water environment under threat. A repeat cycle of 3–5 years would be appropriate.

Outputs

Outputs should be tables and lists.

Data sources

There are no current data sources — see the monitoring design and strategy section above.

Links to other indicators

Management effort (key indicator 7.2)

Indicator 7.2: Management effort

Description

A composite of management indicators (facilitators trained, research funding, monitoring schemes, policy development and implementation, government and community incentives and catchment management participation) per drainage division, per year.

Rationale

This completely novel indicator is a composite of a number of management variables into an inclusive and broad-based indicator. Growing attention to environmental issues relating to inland waters has seen management responses at a number of levels. It is difficult, however, to see how these different activities or regulations fit together. Therefore this indicator attempts to tally them as an overall sum of effort.

Analysis and interpretation

All of the indicators listed below measure, by various means, some management activity. Each separate indicator needs to be refined to make changes in management effort comparable across the varying scales of expression. When this is achieved, an aggregate of the activities can be developed into a final index of activity for reporting (with comparisons of trends over time). A tentative index scale for activity could consist of six categories: A — an increase to greater than 200% of the previous year's activity; B — an increase of less than 200%; C — 100% of the previous year's activity (i.e. no change); D — a decrease in activity of 50–100%; E — greater than 50% decrease; and F — no activity at all (so as to separate this situation from, say, C).

Monitoring design and strategy

A large number of potential attributes covering a variety of management activities could be measured. Each is currently used by some authority for its own purposes. Potential attributes include:

- Incentives: The number of incentives developed for integrated management (e.g. Landcare support);
- Catchment management: Development of programs such as Integrated Catchment Management (ICM), National Landcare Program (NLP) and Waterwatch, and the degree of participation;
- Government initiatives: Funds spent on Rivercare or similar government initiatives;
- Facilitators: Number of facilitators trained to help resource managers and community groups re Ecologically Sustainable Development (ESD) practices;
- Macrolevel policy: Development and implementation of management policy at national or regional scales — e.g. ESD, MDBC's Natural Resources Management Strategy (NRMS), COAG, WRA/Irrigation reform, water audit and capping, water quality guidelines;
- Monitoring schemes: Implementation and activity of monitoring schemes for specific problems re human health and inland waters — to be tallied and listed separately; and
- Research funding: The amount of funding committed for research and monitoring of water resources (e.g. funding for research on mosquito-borne viruses such as Ross River fever virus).

Reporting scale

The reporting scale should be nationally and by State and Territory. Only some of these components lend themselves to also being displayed on a drainage division or Local Government Area (LGA) basis.

Outputs

Trends in overall (cumulative) management effort over time are most important to display. This lends itself to charts showing trends over time, although the ability to disaggregate the components will be more useful for diagnostic purposes. Therefore electronic storage of the separate components is desirable, to allow inspection to determine the meaning of any observed trends.

Data sources

Government departments and agencies hold their own statutes, regulations and the like for public scrutiny. Also, research institutions, or water and land management groups, have some of this information. Because this indicator is not being compiled in the recommended form, effort needs to be put into an initial survey and that experience used to produce reporting forms for the future.

Links to other indicators

Consistency (key indicator 7.1)
Participation (key indicator 7.3)

Indicator 7.3: Participation

Description

The number of people or groups involved in community-based monitoring and action relating to inland waters.

Rationale

There are many community-based initiatives operating now (e.g. see Alexandra *et al.* 1996) to increase awareness of, and care for, inland waters. The most obvious of these is Waterwatch — including its State variants such as Streamwatch (NSW) and Ribbons of Blue (WA) — and similar schemes such as Salt Watch and Algalwatch are also relevant. More generally, involvement in Landcare or TCM committees that are relevant to water issues is also applicable to this indicator.

Analysis and interpretation

Sum membership of separate types of community groups. Each government-supported group keeps tallies of membership or other measures of participation. Some are audited infrequently. These must be collated. The main interest is, first, in the absolute proportion of involvement and, then, in any trends over time.

Monitoring design and strategy

Data will be collected from each relevant organisation or group. These will probably be State and Territory based (at least as branches and coordinators rather than grass-roots groups). Some groups, such as Landcare or Waterwatch, could possibly be traced back to catchment-level regionalisations; otherwise data would need to be aggregated by drainage division. Waterwatch data should be kept separate for use in key indicator 3.11.

Reporting scale

National, State and Territory, and drainage division scales are appropriate. Simple summations at each of these for the different types of groups are possible.

Outputs

Tabulations and listings would convey most of this information. Map overlays onto drainage divisions should also be employed.

Data sources

Data sources are: head offices of each organisation or group in national, State and Territory capitals, annual reports, and regular audit statements by portfolios. In general, these are currently kept separately, even in the same bureaucratic office.

Links to other indicators

Waterwatch participation (key indicator 3.11)
Management effort (key indicator 7.2)

Indicator 7.4: Licensing

Description

Licensing by governments for activities (see list below) relevant to inland waters.

Rationale

This is a novel indicator that seeks to assess how much potentially impacting activity the public wishes to impose upon inland waters. The bureaucratic systems of licences and consents for many activities by individuals and private and public sector entities can allow tracking of trends in different activities. Convictions against people failing to get consent or breaking licence conditions can also be instructive.

Analysis and interpretation

For each type of relevant activity, a range of attributes can be tallied:

- numbers of applications;
- number granted; and
- number of fines, convictions or court actions.

Trends over time are the most useful aspect for SoE reporting (a surrogate for activities and potential future pressures?).

Monitoring design and strategy

Essentially, tally the number of applications for new or continuing licences, and legal or licence breaches for each activity. The most relevant activities include:

- inland fisheries;
- pollution discharges;
- clearing riparian or floodplain vegetation;
- draining wetlands;
- irrigation works; and
- lakebed cropping or other land-use changes.

Data for each of these should be collected and tabulated separately.

Reporting scale

Reporting should be by jurisdiction (national to local government) initially, but information can also be usefully displayed by drainage division.

Outputs

Tables, and perhaps maps, for each type of activity convey the most information. Highlighting trends over time is probably most instructive.

Data sources

This indicator is not presently monitored for SoE purposes, although most of the data needed are collected by:

- fisheries departments in each State and Territory;
- EPAs or equivalents in each State and Territory;
- lands, conservation or forestry departments in each State and Territory, and local governments;
- lands or conservation departments in each State and Territory, and local governments;
- water authorities in each State and Territory; and
- agriculture departments and local governments.

Each of these units collects and reports data for their own uses. Only by combining data can the overall picture of these pressures on inland waters be assembled.

Links to other indicators

Irrigation?

Fish version of AUSRIVAS?

Research and development needs

In using indicators, we seek to integrate a lot of information about the environment. Therefore we must ensure, via research, that our process understanding of how each indicator works is solid. If not, the interpretive models will be lacking or inadequate. An important part of developing indicators for national SoE reporting is furthering their basis and validity by fostering research and development. This includes what needs to be done to "upgrade" some of the promising indicators not included in the key set.

Broadly, two sorts of developmental work are needed: first, to sort out the best approaches for effective SoE monitoring and reporting *per se;* and second, to work upon the scientific bases of the process understanding of, and hence interpretative models that are necessary to use with, each indicator. The following issues (in rough order of priority within each list) are important and so are recommended for further investigation by the SoE Unit:

SoE monitoring/reporting

- Monitoring and reporting strategies for the key set
- Issues of data sourcing and ownership
- Establishing a reference or key site network
- Incorporating remotely sensed and automated technologies into monitoring
- Quality of the data coming from community-based environmental monitoring
- Incorporating catchments on Environment Australia mapping databases
- Ecotoxicological and other approaches to pressure or condition versus risk *per se*
- Use of case studies in state of the environment reporting
- Methods of visual display of indicator information
- Transferring useful indicators across sectors

Scientific basis for interpretation

- Improving quality and coverage of data
- Developing rapidly assessed condition indices
- Ensuring historical records are available for comparisons
- How to initiate completely novel indicators
- Episodic updates of status of knowledge
- Ecosystem health as a conceptual framework

Research and development for SoE monitoring and reporting

Monitoring and reporting strategies for the key set

In deciding upon the design of an effective monitoring program, a greater focus is needed on what sort or level of change in the indicator should be detected. Once this is decided, meaningful considerations of statistical power and cost can be used to design a strategy. It may be that some key indicators cannot be sampled in a cost-effective manner because they are not powerful enough (probably because background variability is too great to permit a clear signal of change). Data for many indicators must be acquired locally via site-specific information rather than by a large-scale technology such as remote sensing.

Other indicators may not be routinely sampled at present in a way that gives even coverage. In such cases, the number of observations must be explicitly reported to document any patchy coverage. This will document the monitoring effort (important because of the reality of "seek and ye shall find") and allow "opportunistic" sampling (from reaction to scares or other events, scientific expeditions, etc.) to be exploited.

Reporting may also standardise across jurisdictions or bioregions by reporting deviations from local standards (where these vary by jurisdictions or bioregions). This is the approach being used for implementing water quality guidelines under the NWQMS and that we have taken with key indicators 2.1 and 3.1. Alternatively, aggregation using the percentages of cases (e.g. wetlands, rivers, groundwater wells, catchments) meeting or failing some agreed criterion is possible (see below for more discussion of this approach). This may be the most appropriate scaling and form of indicator expression for continental impacts or national significance.

Raw measurements of various attributes (e.g. the area of a wetland and the biomass of macrophytes within it) at specific sites are unlikely to produce an aggregate national picture by simple "summation" of point values. Instead, statements interpreting the condition of the wetland might be aggregated (e.g. the number of wetlands with "extensive" beds of "healthy" macrophytes) via a processing or scale change of units. This "processing" may include aggregation, standardisation, mathematical transformation, indexing, calculation or collation of records, data analysis or the application of spatial statistics, geostatistics, mathematical regionalisation from point measurements, spatially explicit modelling, fractal approaches and other rapidly emerging techniques for "scaling up" (see Schneider 1994 and Feddes 1996). For example, if the primary data were from a wetland vegetation survey, then the number, percentage and extent (i.e. relative observations) of exotic flora can be extracted for an indicator (i.e. we collate these to get an indicator of exotic flora). A series of such comparable surveys can be aggregated by considering what proportion of them have exotic floras present to *X* percentage occurrence (where *X* might be 0, 10 and 50%).

More generally, the shift from raw data to an indicator score or index constitutes the crucial pragmatic difference between pure or even applied science and SoE reporting. Attributes are the stuff that scientists want to measure, but an indicator *per se* is the stuff wanted by SoE managers. Many indicators are first developed at a local scale only. But for use in national SoE reporting, a more extensive view must be developed, either by focusing on a great many places across the nation — what Schneider (1994) called "panning", in an analogy with the use of a camera — or scaling up from local to national levels (via what Schneider (1994) called "zooming"). In the case of panning, data acquisition at a fine scale is repeated at a number of local sites, yielding essentially repetitive but site-specific information. There are then many possible means of constructing indices via differing forms of aggregation, because these are fundamentally comparable. The more the data acquisition varies across the continent from site to site, the more limited are ways of aggregating. These issues need to be considered very carefully. Use of broad-band remote sensing more closely corresponds to a zooming strategy, because the "window" observed can be varied within limits of resolution and size of scene (Campbell and Wallace 1998).

Possibly the best way to allow local regional variation in monitoring is for each jurisdiction to set its own criteria for "acceptable", "of concern" and "unacceptable" (or some other categorisation) as broadly comparable standards for states or trends. Then the number of places or cases falling into each of these categories can be tallied and displayed visually using a "traffic light" colour scheme (i.e. with green, orange and red, respectively; see DLWC 1996). It could be argued that a five-step scheme would allow more discrimination (e.g. excellent/good/fair/poor/bad) than the tripartite "traffic light". Either format should be readily understood by the wider population. This approach also fulfils the intention of the NWQMS; its guidelines are meant to be merely that — i.e. not fixed criteria, but guides for local or regional implementation taking into account different conditions.

For those indicators that do not lend themselves to such a region-diverse approach, the question remains of "how to aggregate the data?". Many aggregation issues can only be assessed properly by actually aggregating data. Therefore, a trial of acquiring raw data (i.e. monitoring), aggregating and reporting for a subset of key indicators, themes and areas is strongly recommended. This could, perhaps, be done through partnership with the Australian Local Government Association (ALGA), thereby focusing upon just a few regions (and also addressing some issues of quality control introduced below).

Issues of data sourcing and ownership

It has not been possible to completely evaluate all the key indicators during this limited consultancy. Issues of data sources, ownership and cooperation certainly need more exploration because we found that these were the hardest to uncover. The information we found either: made up very repetitive lists of government departments in each State and Territory (and these have been summarised in the indicator lists); lacked any detailed summary; or was extremely hard to find at all. This experience was shared by a number of the Indicator Liaison Officers. This amounts to an unfortunate level of distrust and/or lack of organisation amongst many environmental agencies. The SoE Unit will have to work hard to overcome this, to "liberate" the large amounts of data that are out there but not currently "available". Most of these databases are not being used for SoE purposes, but a number of the States and Territories now have accumulated more experience in obtaining and using them. The SoE Unit is not the owner of most of the data needed for the next SoE report.

The quality of any data to be used also needs thorough assessment. It is not sufficient to say that data exist and can potentially be sourced from some agency for SoE purposes. The task of examining data records for quality (including historical bases, gaps, ease of collation and evaluation, and statistical analysis) is not a trivial one. It was far beyond the scope of this consultancy. The SoE Unit needs to conduct a quality control and assurance audit of any data source it intends to use. A consultancy on this issue could also address the issues of finding historical records and the quality of community monitoring data (see below).

The effort to rectify this situation should be cooperative rather than coercive, although in these times anyone with funding can effectively call the tune. Presumably the resources for SoE are limited and so we cannot seek to rectify the data acquisition problem by commercial means alone. Where possible, the SoE Unit should build partnerships with efforts already under way that are being resourced and do show great promise (e.g. the FNARH just under way using the AUSRIVAS technology, or the LWRRDC/ANCA wetlands research and development program, both of which are co-managed by other units within Environment Australia).

Establishing a reference or key site network

Although some of the data underlying these indicators are routinely collected for all of Australia now, most of the novel indicators herein will require new measurements made for SoE purposes. This is especially true of those indicators that cannot be remotely sensed and so require ground measurements across the country. A number of jurisdictions have adopted a system of repeated measurements for water quality analyses. For example, in NSW DLWC has a system of 89 key sites for their State of the Rivers and Estuaries monitoring, and Victoria has just reviewed its several networks of State-wide water quality monitoring (EWQMC 1996). Olsen *et al.* (1997) make the point that types of monitoring sites differ in their intents and sampling intensities; in particular, they contrast intensive or sentinel sites with research site networks, and these both with less regular synoptic surveys. SoE reporting implies a regularity of sampling that needs to be built into any site network.

The SoE Unit should consider facilitating the establishment of a key sites network across the nation to support the various themes in the next and subsequent reports. The sites would probably be run by the States and Territories and perhaps other interested groups (perhaps in the community but more likely in the universities and other research institutions). Apart from ensuring that some data are collected expressly for the purpose of SoE at all levels (and so the core set of indicators would be measured therein), a crucial issue could also be addressed by such a network. This is the issue of the power to detect real changes in SoE indicators. As part of ongoing consultancies concerning this issue, the sorts of measurements made across a reference site network could be explicitly modelled as to their power and optimal choices therefore made about the frequency, spatial arrangement and type of measurements. There are arguments for and against limiting such a network to relatively "pristine" sites (assuming these could be found) so as to give an understanding of background levels of change in the absence of human activities. While it may be possible to find these for one or a few specific impacts, generally untouched places around the continent are less obvious. The converse of this strategy is to set up a series of test sites wherein the environmental insults are reasonably well known and so different indicators can be trialed and compared to reveal exactly how much information can be retrieved. Such comparative trials have been used by the UN to evaluate competing techniques for assessing oil pollution (see Bayne *et al.* 1988). Several techniques were shown in such trials to be less than convincing under novel field circumstances, leading to them lapsing. The best performed were further supported and eventually used as standard methods. Such an approach in Australia would be useful for further developing condition indices and other novel indicators.

Incorporating remotely sensed and automated technologies into monitoring

In a country as large as a continent, we must make the best use of broad-range technologies to return data of use in these SoE indicators. Quite a few of them can be remotely sensed now (Campbell and Wallace 1998), and this should be encouraged by adopting those indicators and contracting for the data required. More importantly, in the next five to ten years there will be many more platforms available to capture such data, both in terms of new satellites with different and more affordable scanners and also regarding the cost and availability of airborne scanners. Automated systems for measuring aspects of water quality and quantity and downloading such data via remote communications (telephones, satellites) are with us now, but not employed routinely. SoE reporting has a role in encouraging the spread of such new technology, especially where it can be very cost effective (e.g. returning data from important but remote waterbodies).

Quality of the data coming from community-based environmental monitoring

During discussions with experts around Australia, we were struck by the misgivings that various people have about the use of data coming from community programs such as Waterwatch. An example of this scepticism is the advice on nutrient sampling commissioned from Baldwin (1997). At issue is the quality of the data resulting and therefore the standard of quality control and assurance involved in these programs. Any rush to using community-generated data would fly in the face of national standardisation procedures such as National Association of Testing Authorities (NATA) accreditation, low level nutrient trials, inter-laboratory benchmarking comparisons and the like. The experience from the USA and elsewhere is that, while not entirely useless, these programs should not substitute for scientific monitoring. Given that community monitoring would likely extend the network of sites beyond any resources currently available to governments and research institutions, Environment Australia needs to carefully consider the role the community could play in SoE in the future. An appropriate way to tackle this is to set up comparative trials where Waterwatch results are ground-truthed by certified experts (and perhaps vice versa!). At the least such an exercise could identify which water quality measurements can be reliably used from Waterwatch exercises; it may be that a subset is more reliable that the whole gamut of measurements. Such results would also feed into developing workable quality control and assurance protocols.

Incorporating catchments on the Environment Australia mapping databases

It should be possible to store, map and display data on the geographical basis of the 245 or so catchments across Australia. Environment Australia advises that currently it is possible to use the twelve AWRC drainage division basins, but no finer resolution. This should be a high priority for routine use of GIS technology for preparing the next SoE report.

Ecotoxicological and other approaches to pressure or condition versus risk *per se*

For SoE purposes, it makes sense to focus upon environmental effects *per se*, not just statements of present circumstance. Thus when concentrations or even loads of pollutants are measured in Australian rivers or wetlands we often lack the contextual understanding to know what a certain value means. In the past, many guideline or criterion values have been promulgated so that attention has focused on these as some "threshold", below which everything is fine. This is an unrealistic view of risk from exposure to different and multiple chemicals (Colborn *et al*. 1996). The philosophy behind the National Water Quality Management Strategy (see e.g. ANZECC 1992) does not take this view, but implementing such a philosophy has proven a difficult task. It is likely that the new Australian Water Quality Guidelines will focus much more on biological expressions of water quality effects than on chemical concentrations.

An adjunct to this is the wider use of ecotoxicological measurements to measure effects *per se* (see Chapman 1997). The SoE Unit should encourage the development of cost-effective ecotoxicological measures of impact that are relatively easy to use and applicable across the country.

Use of case studies in state of the environment reporting

Much of *Australia: State of the Environment 1996* (State of the Environment Advisory Council 1996) used case studies of particular environmental problems where indicators were lacking. Although this might have been a function of the relatively undeveloped nature of national indicators, it is probably a desirable reporting technique for locally focused attributes. Such cannot be done systematically for the whole country. A number of rejected proto-indicators might benefit our understanding of environmental impacts if sampled for inclusion as a case study rather than for a nation-wide indicator. These include:

- point source contamination (as focal case studies of Condition-Pressure-Response (C-P-R)) — i.e. where a toxicant is suspected, it should be monitored;
- local presence and abundance of reptiles such as turtles, water dragons and red-bellied black snakes — e.g. using observations in wetlands and rivers made seasonally, to coincide with increased activity;

- impacts of introduced biota (e.g. mimosa, cane toad, carp, gambusia, newer species) on native biota and ecosystems;
- changes to ecosystem structure and function or community composition;
- the few mammals restricted to freshwater habitats (e.g. platypus, two native water rats, plus others associated with wetlands or floodplains) — can be surveyed relatively accurately and cost-effectively using baited hair tubes, where hairs can be identified using standard references (Brunner and Coman 1974), trapping, mark and recapture techniques, and scat and track analysis; and
- quantitative fish sampling techniques being developed by the Cooperative Research Centre for Freshwater Ecology/NSW Fisheries Rivers Survey (Harris 1995) and ERISS (Bishop *et al*. 1995).

Methods of visual display of indicator information

Traditionally, SoE information has used very traditional means of display, including colour-coded maps, histograms, tables and lists. Perhaps it is time to think creatively about novel and better ways to convey this information, especially in electronic form. Much of the information recommended in this and other theme reports is repetitive in its type, and so choosing the most impressive output early in the next SoE cycle may assist the overall process. For example, many of the indicators take the form of continuous data, but the utility of reporting such numbers (especially to very high and probably spurious precision) to managers and the wider public is questionable. Many potential users may be satisfied with classes of information output. For example, DLWC (1996) used a "traffic light" format (red = poor, orange = fair, green = good) to convey rating information about several water quality variables in a comparable manner (as well as the actual values). These visual keys were overlain on maps to show point assessments within each NSW catchment. Other situations could demand a five-point scale to also convey trend information, viz.:

Rating	A	improving generally
	B	improvement patchy or slight
	C	no net change
	D	declines in some places or not drastically
	E	widespread or large declines

The implicit advantage of such display models is that they can subsume a lot of the interpretive model(s) underlying the information and its analysis. As long as the model and rating schemes for each display are explained somewhere, the report can concentrate on the message and its meaning. It may also be possible to build in some implication modelling, for example extrapolations of the current situation to detail the consequences of ignoring the message. The scenario development of decision support systems (DSS) routinely allows such simple predictions.

Transferring useful indicators across sectors

Some indicators that are immediately useful within one sector or theme may also show promise in another. Therefore, translating them across themes becomes a valid research and development activity. For example, the biological activity of soils is assessed at the paddock scale using a cotton-strip assay (King and Pankhurst 1996). Such a relatively simple indicator captures information about decomposition, a crucial process in nutrient cycling largely performed by microbes and other inaccessible organisms. As such, the formal test using standard strips of cotton cloth is a surrogate for a variety of biota and their actions that cannot be observed or assessed more directly. Such an indicator also shows promise for assessing the biological activity, and hence condition, of inland waters such as wetlands (and especially their sediments), but we need to develop an equivalent test for use in waters. A review should be made of all these thematic reports to see how many recommended indicators could be further examined for transference.

Research and development for a scientific basis to interpret indicators

Improving quality and coverage of data

Many of the indicators recommended in this report have either uncertain data sources or patchy coverage of the continent. For example, the national system of river gauging stations is not nationally coordinated, being run by each State or Territory, and the coverage is incomplete. This is exacerbated when the aim is to express current condition in relation to some prior (perhaps "pristine") state. Research effort should be put into methods of estimating historical conditions for rivers that have little or no gauging records. This is partly environmental history and partly mathematical.

Developing rapidly assessed condition indices

The crux of the ecosystem change issue concerns habitat, but most assessment is too local. There are many possible measures of habitat condition. Indicators are required to assess river or wetland habitat beyond its mere extent and/or distribution, i.e. the character or quality of the habitat. Ideally, this should be done relatively simply and rapidly to allow assessment on the ground potentially in remote locations and by non-expert users such as community groups. There are several such possibilities being developed; four examples are:

(a) locally derived schemes that use knowledge from residents and landowners as well as scientists to derive simple schemes refined for that location. A good example is the slim manual for wetland assessment in the Hawkesbury–Nepean system (Hawkesbury–Nepean Catchment Management Trust 1996). These may be too local to attempt to apply everywhere.

(b) general schemes imported from overseas and modified for local use. A good example is the RCE (Riparian–Channel–Environmental) inventory devised for use with Northern Hemisphere rivers by Petersen (1992) and recently applied with modification in an Australian river by Chessman *et al.* (1997). Because these schemes tend to be general at the start, they can often be readily modified to apply in a particular local version of a general class of habitat (e.g. small streams in agricultural landscapes in the case of the RCE).

(c) physical measurements currently employed by water agencies in Queensland and Victoria using a methodology developed by John Anderson, Southern Cross University. Victorian authorities have developed this further into an index of stream condition (ISC), which expands this with considerable biological information so that the ISC comprises five components: hydrology; water quality; aquatic life; physical form; and riparian zones (Waterway and Floodplain Unit 1997 a,b,c). We found the split of their documentation into background justification (Waterway and Floodplain Unit 1997 a), evaluation via field trials (Waterway and Floodplain Unit 1997b) and a user's manual (Waterway and Floodplain Unit 1997c) useful.

(d) locally developed rapid assessment schemes that directly address Australian conditions and management issues. A good example is the rapid appraisal index of wetland condition (Spencer 1996) being developed for landowners to assess their own properties in southern NSW and northern Victoria. Field trials against both local knowledge and expert views have been built into this development. This is an ongoing research activity under the direction of Professor Alistar Robertson of Charles Sturt University at Wagga Wagga, NSW.

A fruitful avenue of research and development for the SoE Unit to promote would be extending such schemes to wider areas of the country. Skilleter (1996) provides an estuarine example of the sort of research needed. Ideally this would be done by funding the researchers involved to spend, say, a year developing their indices in new places. Then these techniques should be comparatively trialed by taking them to comparable but new places (to provide an independent test) and comparing their performance in terms of information retrieved, the ease of use and the time needed to train people to use them. Only by such direct comparisons can competing methods be usefully evaluated.

Ensuring historical records are available for comparisons

Many of the indicators outlined earlier require some comparison to be made with antecedent conditions; i.e. any apparent alteration is interpreted as a change from the historical record. This requires that such records be available. We see three important aspects of this as worthy of SoE Unit support for the chosen indicators. First, the curatorial effort must be made to archive whatever historical records exist. The stored records should be lodged with a suitable authority as part of a contractual arrangement to supply SoE data. Second, any gaps in such records should be filled with appropriate modelling. This may also be necessary for extending the historical record using mathematical techniques of interpolation or regionalisation. Third, the statistical properties of the historical record must be analysed and examined for later comparison with SoE data. MDBC has been successful in analysing its historical records of water quality, phytoplankton and, most recently, salinity (see Williamson *et al*. 1997) in the River Murray. For ease of comparison when compiling later SoE reports, all three steps should be taken now.

Novel ways of exploring and summarising historical data sets should also be encouraged.

How to initiate completely novel indicators

As a prime user of indicators, the SoE Unit should also try to tempt the research community to become more involved in indicator development. We were surprised at the level of scepticism or even cynicism amongst the limnological community about indicator development *per se*. Those scientists who were interested often felt that, unless they had leapt onto the one or two well-funded bandwagons, then the support for their particular ideas was almost non-existent. This is not to demean the development that is under way but to highlight that various environmental administrations seem to be putting their eggs into very few baskets. Novel ideas that do not fit into the "methodology of the month" are left without even modest amounts to support testing or refining. We strongly urge that some funds be made available for tentative development of novel indicators; this could take the form of a "general call" for expressions of interest open to all researchers and their ideas. LWRRDC has usefully employed such a call as an adjunct to its more focused research programs. Another useful strategy would be to further develop some of the ALGA regions (plus some inland sites) as test sites for further indicator development; again this is similar to AWRC and LWRRDC's focal catchments. These tend to converge and attract different research activities that can be more effective because of the synergies that emerge from shared study sites.

Episodic updates of status of knowledge

Our knowledge of the Australian environment is constantly changing, but it is not always easy to assess the status of our biota and ecosystems. An alternative approach for biota would be to use museum records and distribution maps to assess range expansions and contractions at, say, 5–10 year intervals. Such reviews of status and biogeography (e.g. in relation to BIOCLIM predictions or as for frog disappearances) ought to be done by museum and university specialists. Then this could be extended over time to all major groups of organisms. Such decadal mapping inventory may be the only way to assess changes in distribution and abundance of native flora and fauna.

Ecosystem health as a conceptual framework

Ecosystem health potentially provides a paradigm for interpreting many of the changes occurring in inland waters and other parts of the Australian environment. The advantages of this are generally seen (e.g. see Fairweather submitted) as: being inclusive of different viewpoints and imperatives (including non-human ones); using a wide range of data sources and types; and allowing society at large to set desired goals. These are all consistent with SoE reporting.

Many of the sixteen issues addressed above concern what data to acquire for SoE purposes and how. However, the effort put into deriving new and potentially useful indicators at the national scale, especially of responses, means that their novelty itself could deem some of the key indicator Set to be stillborn. We recommend that the research and development program involved in the next phase of indicator development work on trialing some of these more novel indicators.

In conclusion, this report has attempted to examine in both a creative and a rigorous manner the many potential indicators across a wide range of perspectives relevant to our inland waters. More generally, environmental indicator development within Australia to suit our unique conditions is at a rather early stage. Of course, it is now up to the SoE Unit to decide upon the best approach to further this work.

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http://www.erin.gov.au/environment/epcg/soe.html

Appendix 1 Indicators considered for the key set but not included

There were at east four reasons why a suggested proto-indicator was not eventually selected for the recommended key list.

Not of national significance

The issues considered are generally of import, but this may not extend from the local to the national. The latter was the purview of this report. Therefore, some locally or regionally crucial issues (such as fire in wetlands in south-western WA) could not enter the key set because their national significance was not indisputable. It is also possible that what was so discounted for inland waters might be more widely important for some other theme (see below also).

Overlapping with selected Key Indicators

During discussions with experts and examining indicators in use, quite often a number of proto-indicators for national use were suggested that addressed one or a group of similar concerns. In such cases, we chose the ones most closely approaching the selection criteria given in the introductory part of this report. This should maximise the information content of these indicators for use in national SoE reporting.

Technical difficulties with interpretation or measurement

Without more research and development, many of the proto-indicators are doomed to fall into the category of "an interesting idea" rather than an indicator that can be implemented for management purposes (Fairweather submitted). The data measurements required can be difficult or expensive, especially when extended to the national scale. Many interpretive models are also possible with the use of slightly different sets of data, so for some suggestions it was not clear what they would be indicating.

More appropriate for another theme

The interconnected nature of the environment means that a number of issues could be usefully considered in more than one of the seven SoE themes. During this consultancy, the consultants tried to ensure that the most appropriate theme took over such shared issues. For example, what was a potential indicator of pressure for inland waters could also be an indicator of condition for the land (see Hamblin 1998), and so was dealt with by that report.

Below are listed the 163 proto-indicators that were rejected. They are listed by the prime issue or element that they were considered against and with letter(s) indicating the reason for discounting them (A = not of national significance; B = overlaps with a selected key indicator; C = technical difficulties; and D = traded to another indicator report theme — the theme is listed in parentheses):

Groundwater

- Rate of groundwater extraction — B
- Chemical indicators of groundwater quality and pollution — C
- Annual availability and use of groundwater — C
- Area of continent with groundwater discharging — B, C
- Groundwater recharge — B
- Area with groundwater recharging — C
- Number of groundwater systems under stress — C
- Schemes for induced groundwater recharge — C, A
- Piezometric levels in vicinity of capped bores — C

Human Health

- Water-based recreational activities (to human settlements and the land) — A, C, D
- Aesthetic indicators (colour, taste, odour, etc.) — B
- Indicators of human health risk, e.g. faecal coliforms, viruses etc. in recreational or drinking waters (to human settlements) — B, D
- Microbiological indicators — B, C
- Appearance of the riparian zone along streams — A
- Supply amenity — B
- Monitoring schemes re human health — B
- Surveys of mosquito-borne infections — A

- Incidence of sickness from giardia, cryptosporidia etc A, C

Water Quality

- Instream pH B
- Instream turbidity B
- Toxic material concentrations B
- N:P ratios (concentrations in waters) C, B
- Extent of erosion-added sediment in rivers C
- Excess nutrients from eroded soils, fertilisers, septic tanks, sewage discharge and animal wastes C
- Fertiliser use rates (to the land) C, D
- Mining, urbanisation, industrial activity, aquaculture and waste disposal C
- Nutrient (P and N) generation rates for different land use (to the land) C, D
- Pollution regulation C
- Proportionate contributions of different sources to phosphorus loads C
- Source density C
- Bioassays for sensitivity to toxicity of resident aquatic populations C
- Specific chemical indicators C, B
- Concentration of pollutants in fish or shellfish B
- Occurrence of deformity biomarkers C, B
- Occurrence of developmental asymmetry biomarkers C, A
- BOD (re eutrophication) C
- Heavy metals B, C
- Temperature change B
- Total chlorophyll C, B
- Total phosphorus B
- Estimated phosphorus transport resulting from sheet and rill erosion C
- Percentage of key sites meeting water quality objectives B
- Detention of polluted waters in artificial wetlands C
- Total use of fertilisers through sales A, C
- Percentage population on sewage or grey water treatment (to human settlements) C, A, D
- Number of schools participating in Streamwatch, Waterwatch, Ribbons of Blue or other community water monitoring B
- Number of closed catchments A, C
- Water quality guidelines or criteria C
- Usage (e.g. application rates) of pesticides (to the land) D
- Areas of pesticide application C, A
- Extent of organic or heavy metal contamination C
- Effluent disposal B, C
- Lake number to predict eutrophication C, B
- Bushfires as a pressure A, C
- Nuisance macrophytes and other plants A, B, C

Water Quantity

- Amount of water developed/abstracted per year (e.g. direct pumping, diversion, etc.) B
- River regulation B, C
- Irrigation sector expansion B
- Number of dams on and off watercourses (to the land) B, D
- River regulation B, C
- Irrigation sector expansion B
- Number of dams on and off watercourses (to the land) B, D

- Number of farm dams (to the land) B, D
- Growth in capacity of major storage reservoirs B
- Shares of irrigation, domestic/urban and industrial water consumption C
- Percentage of environmental flow needs diverted (by sector) B, C
- Growth in water storage capacity B
- Rainfall patterns — departure from historic records (to the atmosphere) D
- Water usage by sources (irrigation, industrial, urban etc.) B
- Average annual water application by crop type A
- Residential water use in cities (to human settlements) D
- Growth in area of key irrigated crops A
- "Excess" in on-farm water balance A
- Inter-basin water transfers B
- State of the irrigation industry A
- Average annual water application by crop type A
- Area of irrigated agriculture by commodity groups B
- Average household water consumption in cities (to human settlements) D
- Alterations to stream power C
- Percentage of river length impounded B
- Hydroelectric generating capacity and water "usage" A
- Artificial wetlands, farm dams, irrigation supply canals and drainage channels created C
- Applications to drain/reclaim wetlands or divert rivers B
- Median stream depth or depth for some exceedance percentile as percentage of past records C
- Water rights/demands management C
- Growth in area of key irrigated crops A
- Relative profitability of commodities using irrigation versus not A
- Use of rainwater tanks C
- Water use for fighting bushfires B, A
- Pesticide usage (to the land) D

Physical Change

- Changes in catchment and habitats C
- Recreational activities A
- Sediment mining, de-snagging and "improving" rivers B
- Streambank appearance A, C
- Level of unstable runoff C
- Codes of forestry practice (buffer strips etc.) (to the land) C, D
- Bank erosion C
- Sediment delivery ratio C
- Sediment mining A, B
- Replacement of deep-rooted natives with shallow-rooted pasture and annual crops (to the land) C, D
- Clearing rate of land (to biodiversity) D
- Grazing B
- Land uses affecting soil structure (to the land) D
- Percentage of trees cleared in a catchment B
- Area of salinised land (to the land) D
- Gully control works (to the land) A, D
- In-river engineering works (e.g. realignment, straightening, de-snagging) B

- Valley form C
- Erosion rates from different sources A
- Condition of riparian zone (to the land) C, D
- Rate of riverbank erosion in relation to catchment area C
- Rates of pool/channel infilling with sediments C
- Land uses affecting soil structure (to the land) D
- Sediment particle size sorting C
- Proportion of river channels changed via engineering and other "improvements" C
- Waterlogged soils A, C
- Rate of infilling of reservoirs and wetlands C

Biotic Habitat Quality

- Populations of microbes in surface waters (to biodiversity) C, D
- Numbers and dominance of introduced plants and animal species as listed by jurisdictions (to biodiversity) B, D
- Benthic algae and aquatic macrophytes B, C
- Fire in wetlands A
- Populations of reptiles in surface waters (to biodiversity) D
- Impact on biota and ecosystems of management actions C
- Removal of native vegetation (to biodiversity) D
- Impacts of introduced and displaced biota on native biota and ecosystems (to biodiversity) D
- Vegetation on bank, edge and instream as percentage of stream that is vegetated C
- Wetland degradation as percentage of dead wetland/floodplain perennial vegetation C
- Wetland area nationally B
- Amphibian populations (to biodiversity) B, D
- Aquatic weeds B
- Bioactivity, especially of microbes C
- Biodiversity of irrigated or other riverine lands (to biodiversity) C, A, D
- Percentage of biomass/dominance of exotic species B
- Decomposition using cotton-strip-assay (CSA) C
- Changes to ecosystem structure, function and community composition C
- Populations of fishes in surface waters (to biodiversity) D
- Changes in distribution and abundance of native flora and fauna (to biodiversity) D
- Population of mammals in surface waters (to biodiversity) D
- Proportion of native versus introduced plant species in wetlands and rivers B, C
- Number of organisms declared noxious pests or weeds by each jurisdiction C
- Phytoplankton populations B
- Macroinvertebrate community structure B
- Macroinvertebrate community function C
- Benthic diatom indicator assemblages B, C
- Biological control of aquatic pests measured as effort or funds spent B
- Number of endangered aquatic species (to biodiversity) D
- Wetland habitat condition C
- Relative weighting of different taxonomic groups C
- Subsurface fauna in the hyporheos C

- Inland commercial and recreational fishing A, C

Effective Management

- Wetland management C
- Inland fisheries C, A
- Research funding B
- Macro-level policy initiatives B
- Number of resource managers or facilitators B
- Adoption of user pays principle C
- Incentives for integrated catchment management (e.g. Landcare) B
- Percentage protected area of catchment C
- Catchment management, e.g. National Landcare Program B
- Number of Landcare groups or catchment committees per catchment/region B
- Government initiatives B
- Monitoring schemes B
- Incentives for environmental works B
- Efficiency bounties for chemical usage (e.g. fertiliser, pesticide, etc.) (to the land) D
- Management of dams etc. as cultural heritage items (to natural and cultural heritage) D
- Wild rivers management (to natural and cultural heritage) D
- Covenants over wetlands or water quality A, C
- Freshwater aquaculture A, C

Appendix 2 Approaches to expanding the expertise base of this consultancy

Unlike some of the later sector consultancies, a workshop (DEST 1996) on inland waters prior to this consultancy did not provide much raw material for assessing potential indicators. Thus, we undertook to poll the community of environmental researchers and managers involved in assessing inland waters as to which indicators were worth pursuing and what features of each were crucial to consider. Answers to 12 questions about any proto-indicator were sought (as for the other consultancies) as well as comments on the list of suggested indicators at that time. This was done by electronic mail (and a minimum of postage), contacting 123 experts from across Australia. Replies from 37 people were obtained after some follow-up. Of these, 13 people made substantive contributions, useful suggestions came from another six, and the remaining 15 expressed interest in the outcome of this consultancy. We also took the opportunity of conferences and meetings to publicise this work and seek input from experts.

Pro forma for SoE Reporting indicators

1. Issue or element name
2. Pressure, state or response
3. Indicator description
4. What technique/method should be used to monitor this indicator?
5. On what spatial scale should data be collected?
6. What should the geographic extent of data collection be?
7. How frequently should this indicator be measured?
8. What sort or level of change in the indicator is likely to be important?
9. How should the information be reported?
10. How should the data be stored?
11. Is this indicator presently being monitored?
12. If so, over what geographic range, on what spatial scale, how frequently and where are the data stored?

List of contributors to the expert poll used in this consultancy

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List of acronyms

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
ALGA	Australian Local Government Association
AGSO	Australian Geological Survey Organisation
ANCA	Australian Nature Conservation Agency
ANZECC	Australia and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture, Resources, and Minerals Council of Australia and New Zealand
AUSRIVAS	Australian River Assessment Scheme
AWRC	Australian Water Resources Commission
AWWA	Australian Water and Wastewater Association
COAG	Council of Australian Governments
CONCOM	Council of Nature Conservation Ministers
COSSA	CSIRO Office of Space Science and Applications
C-P-R	Condition - Pressure - Response
CRC	Cooperative Research Centre
CRES	Centre for Resource and Environment Studies
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEM	Digital elevation model
DL	Detection limits
DLWC	Department of Land and Water Conservation
DPIE	Department of Primary Industries and Energy
EC	Electrical Conductivity
ENSO	El Niño–Southern Oscillation
EPA	Environment Protection Authority
EWQMC	Environmental Water Quality Monitoring Committee
ERISS	Environmental Research Institute of the Supervising Scientist
ESD	Ecologically sustainable development
FNARH	First National Assessment of River Health
GIS	Geographic information system
IBRA	Interim Biogeographic Regionalisation for Australia
ICM	Integrated Catchment Management
IMCRA	Interim Marine and Coastal Regionalisation for Australia
LGA	Local Government Area
LOR	Limits of reporting
LWRRDC	Land and Water Resources Research and Development Corporation
MDBC	Murray–Darling Basin Commission
MRL	Maximum residue limit
MRHI	Monitoring River Health Initiative
NATA	National Association of Testing Authorities

NHMRC	National Health and Medical Research Council
NHRP	National River Health Program
NLP	National Landcare Program
NLWA	National Land and Water Resources Audit
NPWS	National Parks and Wildlife Service
NRMS	Natural Resources Management Strategy
NRS	National Residue Survey
NTU	Nephelometric Turbidity Unit
NWRA	National Water Resources Assessment
NWQMS	National Water Quality Monitoring Strategy
OECD	Organisation for Economic Co-operation and Development
PMSEC	Prime Minister's Science and Engineering Council
SACC	State Algal Coordinating Committee
SoE	State of the Environment
SoER	State of the Environment Reporting
SOI	Southern Oscillation Index
TCM	Total Catchment Management
UN	United Nations
WRA	Water Resources Assessment