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AUSTRALIAN CATCHMENT, RIVER AND ESTUARY ASSESSMENT 2002

National Land & Water Resources Audit

A program of the Natural Heritage Trust

VOLUME 1

NATIONAL LAND AND WATER RESOURCES AUDIT

Providing Australia-wide assessments

The National Land and Water Resources Audit (Audit) is facilitating improved natural resource management decision making by:

Providing a clear understanding of the status of, and changes in, the nation's land, vegetation and water resources and implications for their sustainable use.

Providing an interpretation of the costs and benefits (economic, environmental and social) of land and water resource change and any remedial actions.

Developing a national information system of compatible and readily accessible land and water data.

Producing national land and water (surface and groundwater) **assessments** as integrated components of the Audit.

Ensuring integration with, and **collaboration between**, other relevant initiatives.

Providing a framework for monitoring Australia's land and water resources in an ongoing and structured way.

In partnership with Commonwealth, and State and Territory agencies, and through its theme activities—Water Availability; Dryland Salinity; Native Vegetation; Rangeland Monitoring; Agricultural Productivity and Sustainability; Australians and Natural Resource Management; Catchments, Rivers and Estuaries Condition; and Information Management—the Audit has prepared:

Assessments of the status of and, where possible, recent changes in the condition of Australia's land, vegetation and water resources to assist decision makers achieve ecological sustainability. These assessments set a baseline or benchmark for monitoring change.

Integrated reports on the economic, environmental and social dimensions of land and water resource management, including recommendations for management activities.

Australian Natural Resources Atlas to provide internet-based access to integrated national, State and regional data and information on key natural resource issues.

Guidelines and protocols for assessing and monitoring the condition and management of Australia's land, vegetation and water resources.

Australian Catchment, River and Estuary Assessment 2002 presents the key findings for the Audit's Ecosystem Health theme by:

- reporting on the condition of catchments, rivers and estuaries within Australia's more intensively used river basins
- presenting assessment methods based on an understanding of the key biophysical processes affecting catchment, river and estuary condition
- serving as an input towards improved assessment and management.

Australian Catchment, River and Estuary Assessment 2002 was prepared in partnership with State, Territory and Commonwealth agencies; the Fisheries Research and Development Corporation; the Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management; the Cooperative Research Centre for Freshwater Ecology; Geoscience Australia; CSIRO Land and Water; and CSIRO Marine.

AUSTRALIAN CATCHMENT, RIVER AND ESTUARY ASSESSMENT 2002

Assessing the aggregate impact of resource use on key natural ecosystems

Volume 1

National Land & Water Resources Audit

A program of the Natural Heritage Trust

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March 2002

Minister for Agriculture Fisheries and Forestry
Parliament House
Canberra, ACT 2600

Minister for Environment and Heritage
Parliament House
Canberra, ACT 2600

Dear Ministers,

I have pleasure in presenting to you *Australian Catchment, River and Estuary Assessment 2002*—a report of the National Land and Water Resources Audit (Audit).

The report recognises and reinforces the role of integrated catchment management, tracing the impacts of land use activity within our catchments on important common property resources, rivers and estuaries. This assessment has been made in the context of a decision support tool that integrates biophysical data sets at the catchment scale and allows for comparisons between catchments.

As Australia's first comprehensive assessment of our catchments, rivers and estuaries, this report clearly identifies the need to:

- manage impact at the source;
- focus on improved practice in all land uses; and
- base targets for improvement in natural resource condition on practice.

The focus on practice provides frameworks for community action to translate a widespread environmental commitment of land users into actions that will deliver significant environmental benefits. Monitoring systems that track natural resource condition in response to changes in practice can then inform us of progress towards meeting these targets and provide a sound basis for program improvement.

By assessing the comparative condition of our catchments, rivers and estuaries, the report raises issues of how best to invest in management to deliver a quality Australian environment. A key role for natural resource programs is investment in protective management from regional to national scales. Catchment-based protective management that seeks to maintain natural resource condition is broadly acknowledged as much more cost-effective than remedial works. Catchments, rivers and estuaries in comparatively good condition are identified in the report. The challenge now lies with policy makers to determine the most appropriate mix of strategies to deliver protective management.

Many of Australia's rivers and estuaries require remedial works. The Audit's emphasis on key causes of decline in condition gives an insight into where best to invest to improve their condition. Activities such as reducing nutrient and sediment loads, rehabilitating riparian vegetation, re-establishing fish passage and tidal flows, and re-creating wetlands and in-stream habitats are all important.

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The Audit's work in catchments, rivers and estuaries results from high levels of commitment and partnerships to improve natural resource management across Australia. The estuary initiative exemplifies this cooperation:

- Estuaries provide Australia's highest value biophysical resources in ecosystem services. The Audit's estuary initiative involved all States and the Northern Territory, Environment Australia, the Fisheries Research and Development Corporation, and the Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management and its partners. It builds on a high level of community interest in improved estuary management.

The estuary initiative has already spawned further investment by the Fisheries Research and Development Corporation, and through the Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management with the formation of an Australia-wide group of estuary managers.

I am pleased to present this report to the Natural Heritage Ministerial Board. It will inform the setting of priorities and targets and the development of strategies as the National Action Plan for Salinity and Water Quality and the National Heritage Trust Extension are implemented.

Yours sincerely,

Roy Green

Chair
National Land and Water Resources Audit Advisory Council
March 2002

SUMMARY

Australian Catchment, River and Estuary Assessment 2002

Assessing the status of Australia's natural resources and the health of its ecosystems is of paramount importance for their wise use, development and management. The National Land and Water Resources Audit (Audit) Australian Catchment, River and Estuary Assessment 2002 is Australia's first comprehensive assessment of catchments, rivers and estuaries. The assessment uses a systemic approach based on surface water catchments to determine the aggregate impact of patterns of resource use on rivers and estuaries (key common property resources).

Benchmarks for the assessments were based on natural conditions and provide a good basis for assessing aggregate impact and change in condition. Nevertheless for many extensively modified catchments, rivers and estuaries, management targets need to be defined in the context of trade-offs between natural condition and the other values provided by uses.

Australia's catchments

The assessment of catchment condition provides a way to compare the biophysical condition of catchments. Using indicators based on nationally available data to assess condition of land, water and biota of river basins and subcatchments, it produced a composite assessment of relative catchment condition. The assessment provides insight into the magnitude of environmental issues being faced in Australia's more intensively used catchments.

The majority of catchments in the poorest condition classes have also been identified as priorities under the National Action Plan for Salinity and Water Quality (Commonwealth of Australia 2000). Important areas for remedial works outside the National Action Plan include the Hunter and Hawkesbury River basins in central New South Wales, smaller coastal river basins in northern New South Wales, southern and central Queensland, and coastal Victoria.

The biophysical condition of a significant proportion of catchments (between 15 and 25%) is likely to continue to decline because of the long-term nature of environmental processes and degree of change in the catchment. These catchments are in the cleared, agronomically marginal rainfall areas, and have soils of relatively poor fertility and structure. They are prone to soil structure decline, soil erosion and salinisation and have low flexibility in terms of profitable land uses.

The assessment demonstrated that spatial pattern and variation in catchment condition can be described by a few indicators—change in vegetation cover, native vegetation fragmentation, sediment and nutrient inputs into rivers, changes to catchment hydrology (particularly the effects of impoundments) and land use intensity. These indicators enable the relative importance of different catchment condition drivers to be identified allowing for more targeted management planning.

The assessment and reporting methods developed can also be used at State and regional scales to examine management scenarios.

Australia's rivers

Rivers provide water for agriculture, industry and domestic use. They sustain ecosystems that provide economic, recreational, aesthetic, social and cultural benefits. The assessment of Australian rivers found that they have been significantly altered by land use and that without informed and strategic management, the condition of Australia's rivers will continue to deteriorate.

The river assessment collated and interpreted data for about 14 000 reaches across the more intensively used catchments. The assessment uses a range of attributes reflecting key ecological processes at the river reach and basin scales and builds on other river assessment initiatives such as AUSRIVAS. Two indices were used:

- an *aquatic biota index* using macro-invertebrates; and
- an *environment index* with four subindices—catchment disturbance, hydrological disturbance, habitat, and nutrient and suspended sediment load.

Key findings include:

- one third of the assessed river length has *impaired* aquatic biota;
- over 85% of the assessed river reaches are classified as *significantly modified* in terms of environmental features;
- over 80% of the reaches are affected by catchment disturbance;
- with limited data on change of hydrology from natural flows, hydrologic change could be assessed in only 25% of reaches;
- over half of the river reaches have *modified* habitat, mainly linked to changes in sediment loads that can also alter channel shape; and
- nutrients (mainly phosphorus) and suspended sediment loads are higher than natural loads in over 90% of reaches, with 33% classified as *substantially modified.*

Management challenges

Protective management. River reaches that were classified *largely unmodified* in all aspects (habitat, catchment disturbance and nutrient and suspended sediment loads) are scattered throughout the assessed area, especially in far north Queensland, eastern Victoria and Tasmania. They require investment in protective management to ensure their condition is maintained.

Rehabilitation and strategic management. Rivers with the most degraded reaches are located in the Murray–Darling Basin, the Western Australian wheatbelt, western Victoria, and South Australian agricultural basins. These river reaches generally:

- have highly modified catchments;
- are subject to high nutrient and suspended sediment loads;
- have lost much of their riparian vegetation; and
- have dams and levees that disrupt the movement of biota and material into and from the river.

Control of nutrient and suspended sediment loads. Some river reaches have *largely unmodified* habitat (bed condition, riparian vegetation, connectivity) but very high nutrient and suspended sediment loads. These include the majority of river reaches in Queensland, northern coastal New South Wales, western Victoria and south-west Western Australia. Erosion from hill slopes and stream banks is high and control of nutrient and suspended sediment loads is essential for rehabilitation of these streams.

Murchison River, Western Australia

Environmental flows and longitudinal connectivity. A small group of river reaches in central Tasmania, central Victoria and New South Wales have *severely modified* habitat following construction of dams. They are otherwise in good condition. These reaches need restoration of environmental flows and longitudinal connectivity (e.g. fish ladders).

Improving management. A key management challenge that follows from this assessment is to implement clearer delineation of institutional and lead agency responsibilities for river management at regional, State and Commonwealth levels.

Building better river assessments

Several areas for improvement were identified, including:

- collection of finer-scale management-relevant data on riparian vegetation—a key component of river condition and rehabilitation works;
- collecting and then using more representative and responsive biotic information, especially fish populations;
- gaining Australia-wide agreement on river reaches, assessment methods and reporting so that changes in condition can be tracked and management activities evaluated; and
- information on changes in river hydrology, especially comparing natural and current flow regimes.

Australia's estuaries

Australia has 36 700 km of coastline and over 1000 estuaries. Estuaries provide highly productive and diverse habitats for fauna and flora. They support fisheries, aquaculture, ports and recreational activities, and are dynamic systems that link catchments, rivers and inshore marine waters. Eighty-three percent of Australia's 19.4 million people live in coastal Australia. The assessment of estuaries has identified that land use impacts are compromising the ecological, economic and social values of Australian estuaries.

The assessment compiled readily available data and used qualitative and quantitative methods within a 'pressure, state, response' assessment framework. The assessment provides detail on the condition of Australian estuaries including:

- amount of modification from the pristine state;
- drivers of change;
- susceptibility to further change; and
- key management needs.

Estuarine geomorphic data were mapped and compiled to classify estuaries in terms of the dominant processes governing their form and function. Detailed site-specific data were collected from a selection of estuaries around Australia and used to develop the Simple Estuarine Response Model. This internet-based decision support tool models the behaviour of estuaries identifying likely consequences of particular management activities.

Of the 979 estuaries and coastal waterways assessed:

- 50% are in *near-pristine* condition;
- 22% are in *largely unmodified* condition;
- 19% are in *modified* condition; and
- 9% are in *extensively modified* condition.

Most of Australia's near-pristine estuaries are located away from population centres. Some are found around the developed areas of Australia, often within or adjacent to managed public lands such as national parks. The majority of estuaries in near-pristine condition have relatively small catchments (< 15 km^2). Protective management of the fisheries and nature conservation values of the near-pristine estuary resource is essential.

Estuaries that have experienced significant change in their condition are those with extensive floodplains that support agriculture, of sufficient size to support industrial ports or with recreational assets surrounded by urban development.

Some of the common challenges facing Australia's modified estuaries are:

- excess nutrients and sedimentation;
- habitat loss;
- changes to natural flows and tidal flushing;
- pathogens and toxicants;
- introduced pests; and
- change to ocean entrances.

Understanding the dominant natural processes in estuaries will assist in developing cost-effective management strategies. Australia's estuaries were classified into six subclasses according to relative influence of the wave, tide and river energies that shape them:

- 17% of estuaries were classified as wave-dominated 'true' estuaries;
- 11% were classified as tide-dominated 'true' estuaries;
- 10% were classified as wave-dominated deltas;
- 9% were classified as tide-dominated deltas;
- 5% were classified as strand plains, coastal lakes and lagoons; and
- 35% were classified as tidal creeks and flats.

Tide-dominated systems are mainly located in northern tropical Australia. Wave-dominated systems are mainly located in southern temperate regions. Their management needs and ecological processes vary.

Sharing information and management approaches

The estuary assessment engaged agencies and groups from around Australia with an interest in estuarine management and has catalysed a number of estuarine specific initiatives including the establishment of a national estuary management network. The groundwork is set for partnerships across Australia to ensure efficiencies in applying research findings, a common level of understanding of management imperatives, publicly accessible information on estuaries and provide for effective involvement of community groups in estuarine monitoring.

Lower Hastings River estuary, New South Wales: extensively modified by urban development

Management challenges

The key challenges facing estuarine managers include:

- establishing and maintaining protective management for near-pristine estuaries;
- working to achieve estuarine management targets within catchment management planning processes;
- implementing a clearer delineation of institutional and lead agency responsibilities for estuarine management at a State and national level;
- developing an Australia-wide, estuarine-specific policy and management initiative that builds on the strong industry and community commitment for improved estuarine management; and
- continuing to provide information, training and support to assist local government planning and estuarine management staff.

Natural resource condition in Australia's drainage divisions

Natural resource management strategies need to identify interactions between different resource management issues and deal with development opportunities and degradation issues systemically. Use of an integrated catchment management framework for tackling natural resource issues has been promoted for many years, most recently by the Commonwealth as part of its National Action Plan for Salinity and Water Quality.

Natural resource assessments compiled by the Audit provide an unprecedented opportunity to examine the regional patterns of geographic and resource use drivers of ecosystem condition. Audit findings within Australia's drainage divisions:

- identify climatic, geographic and resource use drivers of catchment, river and estuary condition;
- define the relative importance of these drivers;
- examine relationships between patterns of resource use and the condition of catchments, rivers and estuaries; and
- suggest regionally specific, integrated natural resource management challenges.

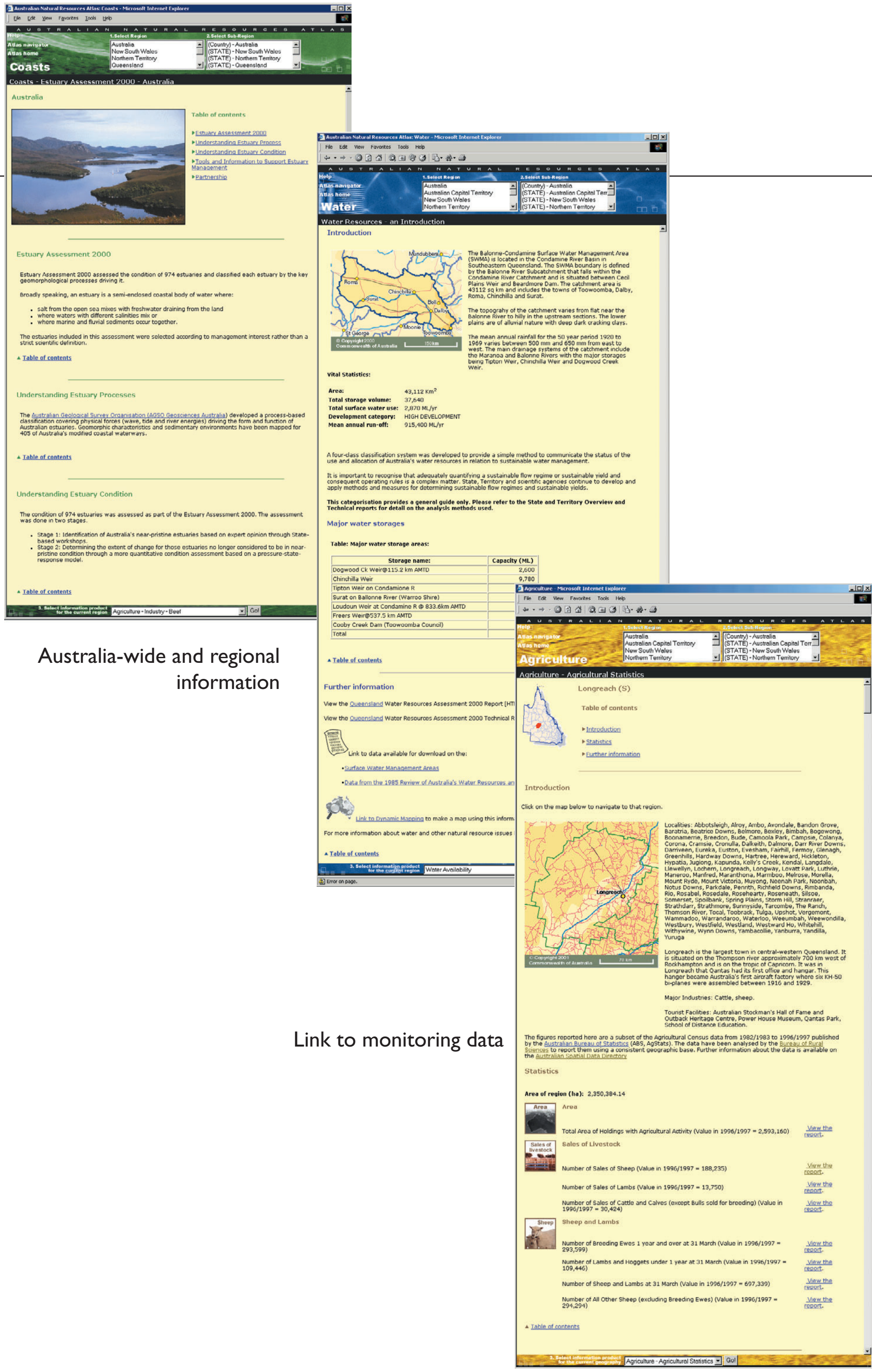
Ways forward

The Audit assessment of Australia's catchments, rivers and estuaries reveals that much remains to be done to; understand impacts; improve management practice and fully assess benefits, costs, opportunities and trade-offs.

Key challenges

- **Land use**. We need to continually re-assess and improve land use patterns and practices, with attention to issues of soil erosion, landscape, nutrient balance, dryland salinity, vegetation and pasture management, water resource sustainability, and water use efficiency.
- **Institutional and policy needs**. We need to seek a balance between public and private benefits and costs, especially for key public resources—rivers and estuaries—and develop integrated approaches to natural resource management.
- **Information provision**. We need to ensure monitoring and assessment are cost-effective and provide information to support management decisions and track progress from regional to Australia-wide scales.

Australia has many programs in place and there is widespread community and government commitment to improved natural resource management. Audit findings and information sets are available in the Australian Natural Resources Atlas (Atlas) <www.environment.gov.au/atlas>. The Atlas provides insight into key issues and the differences in resource condition across Australia's regions, as well as an information base to assist in setting management priorities. With continued commitment to sustainability, Australia's productive and ecologically diverse landscapes will continue to provide the goods and services the community demands.



Australia-wide and regional information

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Australian Catchment, River and Estuary Assessment 2002 is Australia's first comprehensive assessment of catchments, rivers and estuaries. The assessment:

- uses a systemic approach based on catchments to determine the aggregate impact of land use on catchments, rivers and estuaries;
- provides a method for the relative comparison of catchment condition across Australia's more intensively used river basins;
- presents an assessment of river condition using a reach framework that provides a basis for future Australia-wide river assessment;
- classifies Australia's estuaries in terms of their condition and dominant biophysical processes that govern their form, function and management needs;
- raises issues of how best to invest in catchment, river and estuary management including choices between protective management and remedial works; and
- identifies knowledge gaps and data deficiencies that need to be addressed to improve Australian catchment, river and estuary management.

Australian Catchment, River and Estuary Assessment 2002 was prepared in partnership with State, Territory and Commonwealth natural resource management agencies and organisations.

Australian Capital Territory
  Environment ACT

New South Wales
  Department of Land and Water Conservation
  Environment Protection Authority

Northern Territory
  Department of Lands, Planning & Environment

Queensland
  Department of Natural Resources and Mines
  Environment Protection Agency
  Department of Primary Industries

South Australia
  Department of Primary Industries South Australia
  Environment Protection Agency
  Australian Water Quality Centre

Tasmania
  Department of Primary Industries, Water & Environment

Victoria
  Department of Natural Resources & Environment
  Environment Protection Authority

Western Australia
  Water and Rivers Commission
  Environmental Protection Authority

Commonwealth
  Environment Australia
  Agriculture, Fisheries and Forestry – Australia
  Geoscience Australia
  Bureau of Rural Sciences
  CSIRO Land and Water
  CSIRO Marine Research

Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management

Cooperative Research Centre for Freshwater Ecology

Fisheries Research and Development Corporation

University of Queensland

CATCHMENTS, RIVERS AND ESTUARIES IN CONTEXT

Integrated assessment—based on an understanding of ecological processes

The assessment of catchments, rivers and estuaries is one of a series of natural resource assessment and reporting initiatives fostered under the National Land and Water Resources Audit (Audit). It provides the basis for an improved understanding of the aggregate impact of natural resource use on Australia's ecosystems. Other relevant issues addressed by the Audit include water quantity and quality, dryland salinity, native vegetation, rangelands, sustainable agriculture and production, and social and economic wellbeing.

Management of water is critical to the management of ecosystems.

- The status of Australia's surface and groundwater resources, including their extent, use, quality and sustainability, is detailed in the Audit's report *Australian Water Resources Assessment 2000*.

Dryland salinity is a land degradation issue that has impact on many agricultural regions of Australia and is a major cause of impacts to downslope land and water resources.

- Assessment of the likely hazard of dryland salinity based on salt stores and an understanding of the water balance is provided in the Audit report *Australian Dryland Salinity Assessment 2000*.

The Audit's activities in developing a readily accessible and standardised database of native vegetation are essential to the management of Australia's ecosystems.

- The Audit's National Vegetation Information System provides a hierarchy of vegetation information from structure to communities and species. This information is available in the Audit report *Australian Native Vegetation Assessment 2001*.

Rangelands occupy three quarters of Australia.

- An Australia-wide monitoring framework to assess the condition and biodiversity of Australia's rangelands is proposed in the Audit's *Tracking Changes—Australian Collaborative Rangelands Information System* report.

Application of best management practice systems are gaining impetus as Australian agriculture develops its export and domestic product position based on a combined ethos of food quality, efficient production and sustainable resource use.

- Information on nutrient and sediment loads generated by land use and mobilised through rivers and estuaries, together with best practice activities in key agricultural industries are detailed in the Audit's *Australian Agriculture Assessment 2001* report.

Biodiversity is a key measure of the condition status of ecosystems. Where species information is not available to measure biological diversity, surrogate measures including vegetation and landscape diversity and condition are used.

- An assessment of landscape health for Australia's bioregions and component subregions is provided by the Audit report *Landscape Health in Australia 2001*.
- Analysis of the status of terrestrial biodiversity in Australia, dominant threatening processes and conservation strategy options will be presented in the Audit report *Assessment of Terrestrial Biodiversity* (in preparation).

Natural resource management is multidisciplinary and takes account of not only biophysical conditions but also social and economic constraints and opportunities. Australia has an opportunity to improve the condition of its catchments, rivers and estuaries and at the same time enhance economic and social benefits generated by better management of these key natural systems.

- The Audit has collated resource accounting information on rural land use, the benefits of agriculture production to the Australian economy, costs resulting from land degradation and the opportunities that arise from improved management. This analysis is presented in the Audit report *Australians and Natural Resource Management* (in preparation).

Australia needs to adopt comparable approaches to data collection and management, assessment and information provision, and to link results of monitoring with land use practices, progressively upgrading and making accessible management-orientated natural resource information.

- Overall natural resource data management maintenance and information provision is reported as part of the *Australian Natural Resources Information 2002* report.

Integration through the Atlas

Access to information on natural resources provides opportunities for increased awareness and informed debate. This has been improved through internet and database technology. The interactive web-based Australian Natural Resources Atlas (Atlas) presents Audit products at scales from local to regional to Australia-wide.

The Atlas provides information to aid decision making across all aspects of natural resource management under the broad categories of water, land, agriculture, biodiversity and vegetation, people, and ecosystems. The Atlas is organised by geographic region (national, State, ecological) and by information topic. A data library supports the Atlas with links to Commonwealth, State and Territory data management systems and atlases.

Project reports for the component projects of *Catchment, River and Estuary Assessment 2002* are also available on the Atlas. These include:

Heap A., Bryce S., Ryan D., Radke L., Smith C., Smith R., Harris P. & Heggie D. 2001, *Australian Estuaries and Coastal Waterways – A geoscience perspective for improved and integrated resource management*, Geoscience Australia.

Morgan G. 2001, *Landscape Health in Australia: A rapid assessment of the relative condition of Australia's bioregions and subregions*, Environment Australia and National Land and Water Resources Audit.

Norris H., Prosser I., Young B., Liston P., Bauer N., Davies N., Dyer F., Linke S. & Thoms, M. 2001, *Assessment of River Condition: An audit of the ecological condition of Australian rivers*, report to National Land and Water Resources Audit, Cooperative Research Centre for Freshwater Ecology and CSIRO Land and Water.

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Walker J., Veitch S., Braaten R., Dowling T., Guppy L. and Herron N. 2001, *Assessment of the catchment condition in Australia's intensive land use zone: a biophysical assessment at the national scale*, report to the National Land and Water Resources Audit, December, CSIRO Land and Water, and Bureau of Rural Sciences.

INTRODUCTION

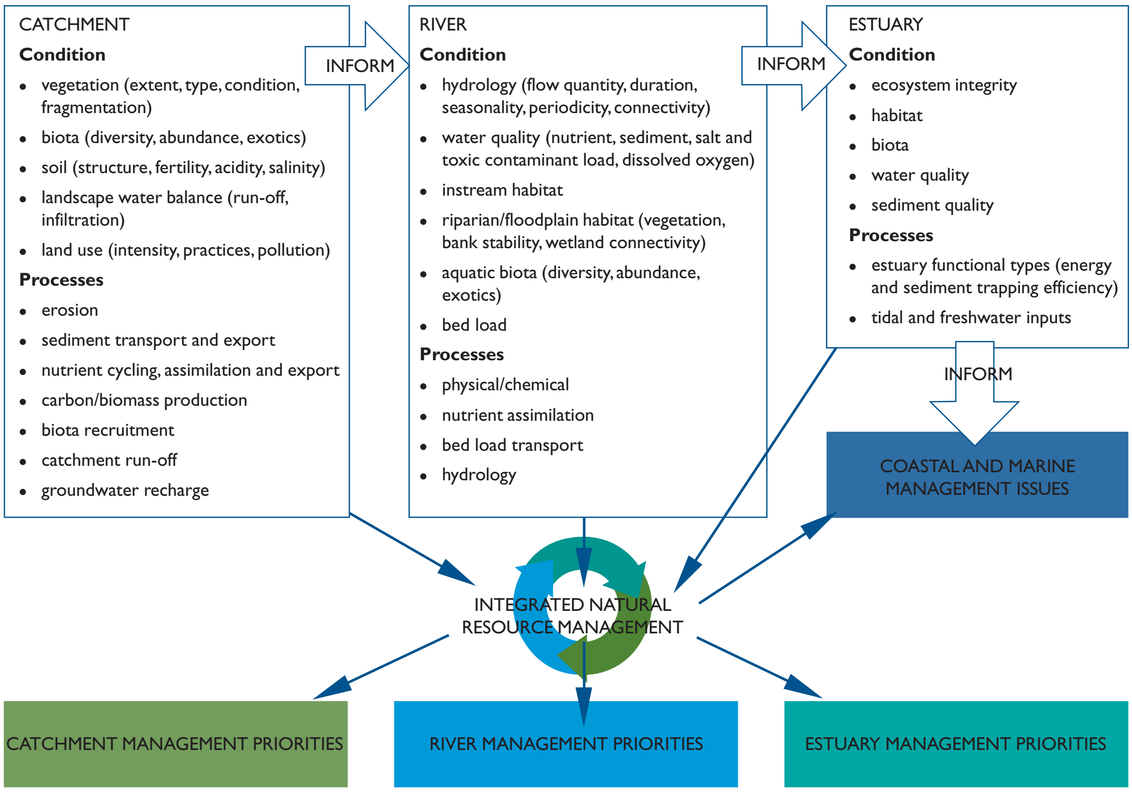
Assessing the aggregate impact of resource use on key natural ecosystems

Ecological sustainability is the cornerstone of Australian natural resource legislation and management. Natural resources are the natural capital underpinning a strong economy and a healthy society. Assessing the status of Australia's natural resources and the health of its ecosystems is therefore important. Understanding how use of natural resources has changed ecosystem function and health could prevent further resource degradation and reduction of options for future generations.

Impacts on ecosystems occur from a range of causes that operate through links between physical and ecological systems. The natural dynamics of ecosystems, including seasonal and catastrophic events, can mask changes associated with impacts of resource use. To understand the process links and impact drivers operating on natural systems, an integrated natural resource assessment approach is required (Figure 1). *Australian Catchment, River and Estuary Assessment 2002* applies a systems approach to undertake its integrated assessment of these key natural resources.

Australian Catchment, River and Estuary Assessment 2002 assesses aggregate impacts of natural resource use on catchment, river and estuary condition and identifies priority management challenges for the maintenance of these natural assets.

Figure 1. Catchment-based integrated natural resource assessment.



Catchments, rivers and estuaries

Catchment. An area that drains all precipitation that falls on it to a single point. A **river basin** includes all the catchment area that drains to a major river mouth and is named after the river. The Australian Water Resources Council defined 246 river basins that are the subbasins of **drainage divisions**.

River. The main drainage channel of a large catchment area. Most Australian rivers have seasonal flow patterns and some are intermittent. *Australian Catchment, River and Estuary Assessment 2002* defines 246 river basins by name and by the 1:250 000 scale mapping of Australian drainage patterns.

Estuary. A semi-enclosed coastal body of water where salt water from the open sea mixes with freshwater draining from the land. This management-based definition was formed to ensure that all types of estuaries and embayments identified by the Australian community were included in the assessment.

Australia's diverse landscapes

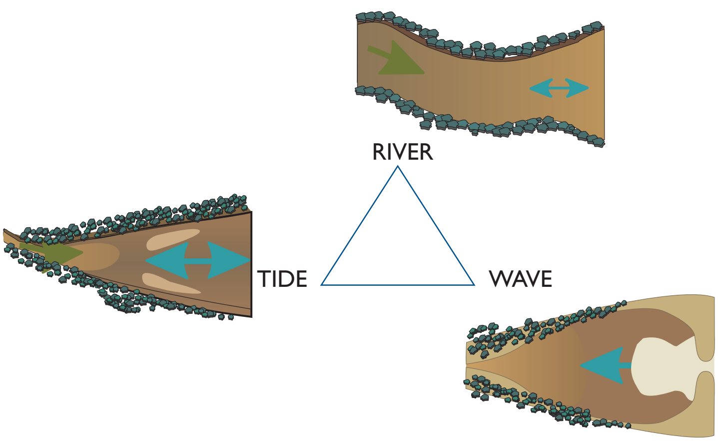
Australia is a diverse continent and this is reflected in its vegetation, biota, landscapes, riverine habitats and estuaries.

Differences in catchment and river function across Australia reflect regional climatic, geological and land use patterns (e.g. water quality and flow characteristics of a tropical river fed by monsoonal rain and draining savanna rangelands are very different to those of a temperate river draining wet rainforests).

Australian estuary form and function is also diverse being governed by a combination of river, tide and wave energies. Around Australia the relative dominance of these energies varies, forming a range of estuary functional types (Figure 2).

Although we do not yet fully understand the causal links and relationships in ecosystems, we do understand key drivers of ecosystem function and dysfunction (e.g. processes such as water flow, sediment movement, nutrient cycling and fire regime). We can use information on these drivers within the biophysical frameworks provided by catchments, to assess ecosystem condition and examine the importance of process-based links between component ecosystems.

Figure 2. Process drivers of the form and function of Australian estuaries.



Assessment concepts

Assessment of Australia's catchments, rivers and estuaries is based on two key related concepts: ecosystem health and condition. These concepts are difficult to define in absolute terms.

Definitions of health consider the status of the whole system rather than individual components and are usually made by reference to attributes that assess ecosystem vigour, organisation and resilience (Rapport 1998). The ecosystem health paradigm can be applied to natural ecosystems and to ecosystems dominated by human production. It recognises that agricultural lands and even cities are ultimately 'ecosystems' that can occur in a range of states of health. Difficulties in applying this paradigm lie in:

- identifying attributes that may be appropriately used to define the vigour, organisation and resilience of a particular ecosystem;
- collecting appropriate data to assess resilience; and
- defining ecosystem health—ultimately a goal-directed enterprise (Rapport 1998) that may span a range of value-driven goals from production sustainability to biodiversity conservation.

Assessing the condition of a natural system usually involves measuring the distance of that system from some ideal state or benchmark. Benchmarks differ for different systems and value judgements by sectors of society. A desirable condition is governed by the pattern of resource use and acceptable trade-offs between economic development, biodiversity, aesthetics, and cultural, spiritual and recreational values.

An objective benchmark for rivers and estuaries—concerned with the maintenance of natural values—is the pristine or pre-European settlement state. In the case of extensively modified systems (e.g. river impoundments or shipping ports) a pristine state only represents a useful reference point rather than a realistic or desirable management goal.

While it may be desirable to manage rivers and estuaries to maintain natural values and characteristics, catchments that are highly modified by human settlement and industry cannot be realisitically managed to a natural state target.

Benchmarks for good catchment condition need to reflect an ideal balance between a natural and modified productive state that is capable of maintaining or mimicking near-natural biophysical processes, supplies goods and services required by the community and minimises impact on downstream riverine and estuarine ecosystems. Such benchmarks have not yet been defined for Australian catchments. The approach adopted in this assessment has been to produce a relative condition assessment across catchments.

Biophysical assessment and reporting frameworks

Catchments

The water cycle and hydrology are major drivers of many ecosystems. Catchments provide examples of natural systems where links between system components can be readily identified (e.g. soil erosion on the land surface in the upper catchment may ultimately affect the quality of water that flows to the lower catchment and in turn the ecology of biological communities living within the estuary at the bottom of the catchment).

Catchments are therefore an appropriate biophysical framework to assess the status of natural resources (land, water and vegetation) that affect the condition of river and estuary ecosystems.

River basins (see Appendix 1)

River basins represent the total catchment of a river system and are the primary basis for reporting in *Australian Catchment, River and Estuary Assessment 2002*. For finer scale reporting of river condition, rivers have been divided into 'reaches' representing sections of river with relatively uniform physical characteristics. Each designated reach is about 5 km in length.

River basins are aggregated to form 12 drainage divisions and have been used to provide overview summaries for Australia-wide integrated findings.

Estuaries

Estuary condition reporting is by reference to individual estuaries and to a classification system of physical processes that classes the estuary in relation to the dominant geomorphic processes governing its form and function. Recognising the importance of contributory catchments in determining the status of estuaries, each estuary has also been identified in relation to the river basin within which it occurs.

Landscape units within catchments

Catchments and river basins contain a range of landscape units (e.g. alluvial floodplains, colluvial slopes, upland tablelands), usually having distinct characteristics in terms of biophysical elements (e.g. soil, vegetation, biota) and processes (e.g. soil formation, water balance, erosion) and consequently resource use suitability and land use.

Landscape units provide an appropriate framework for assessing the status of terrestrial biota and drivers of ecosystem condition. They are also a more appropriate framework than catchments for the large arid proportion of Australia (~ 40%) that lacks surface drainage to well-defined catchments.

Landscape units called subregions (Appendix 2) were used in the Audit assessment of landscape health (NLWRA 2001a), and are used to provide additional ecosystem condition context in the integrated findings section of this report.

Port Melbourne: developed for urban and industrial uses

Ecosystem condition – what drives it?

Ecosystem condition drivers include biophysical elements and processes, and socioeconomic factors (e.g. market prices; profitability; and aesthetic, recreational and cultural values). Socioeconomic factors are recognised to be drivers of ecosystem condition since they affect the behaviour of individuals and communities, but their role as condition drivers was not considered in this assessment.

Biophysical elements and processes that determine the patterns of and change in biota, material and energy within ecosystems are considered *condition drivers* in that changes to these biophysical processes or elements 'drive' the ecosystem to a different condition state. We can distinguish *condition drivers* associated with the geographic context of an ecosystem (climate, rainfall, topography, soil type) and those associated with resource use and degradation patterns (vegetation cover, water quality, soil degradation). Intensive land and water use has the greatest impact on ecosystem condition. However, not all ecosystems are equally susceptible. Geographic context (including climate, topography, and soil type) is important in determining ecosystem resilience and also affects the extent to which drivers associated with resource use and degradation patterns impact on ecosystem condition.

In modified ecosystems, particularly those in stressed landscapes, the influence of an individual driver (e.g. soil erosion) may dominate. This can result in irreversible changes that undermine the resource capital (e.g. soil fertility, structure, carbon content) of the system and lead to an ecosystem condition with reduced structural complexity, biological diversity and primary productivity.

This contrasts with unstressed natural ecosystems where condition drivers operating at varying scales or rates (e.g. climate seasonality and decadal climate variability) maintain a dynamic, often cyclical, ecosystem condition equilibrium.

The condition of a natural ecosystem can be considered a function of:

- resilience;
- use intensity; and
- the number of active condition degradation drivers over time (see Figure 3).

While condition drivers can be described individually, they usually operate collectively to generate change. Rainfall intensity, for example, is a primary driver of soil erosion mediated by vegetation cover, soil type and topography. Soil erosion drives surface water quality (turbidity and nutrient loading), and this drives instream primary productivity, which in turn drives aquatic biotic community composition. These drivers of condition are all interlinked and may in turn impact on each other.

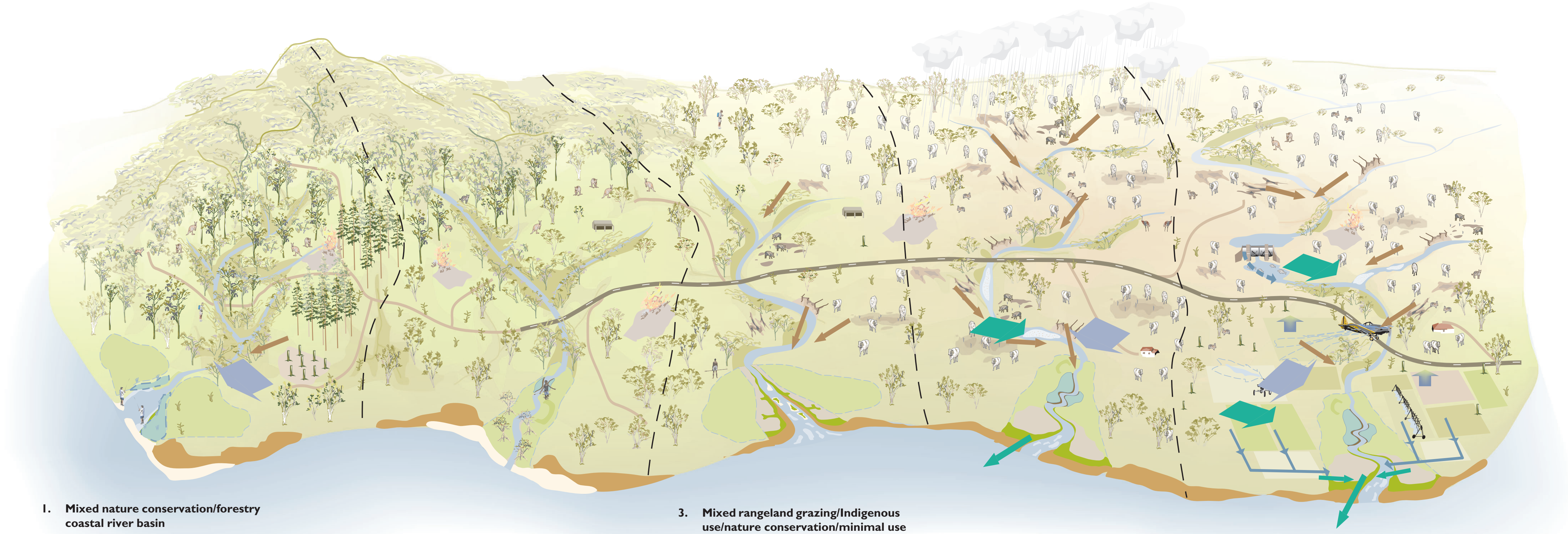
This presents challenges when seeking to discover the primary causes (and therefore key management priorities) for maintaining ecosystem health.

The suite of ecosystem condition drivers operating in any particular basin is dependant on the pattern and intensity of land use and its geographic characteristics. Australia's river basins have a broad spectrum of geographic and land use settings. Figures 4 to 6 illustrate some of the land use patterns in river basins and associated key drivers of ecosystem condition.

Figure 3. Conceptual relationship of natural ecosystem condition determinants.

$$\text{Natural ecosystem condition} = \frac{\text{ecosystem resilience (related to landscape or biophysical setting)}}{\text{natural resource use intensity} \times \text{number of entrained degradation drivers} \times \text{time}}$$

Figure 4. Land use patterns within Australian river basins and associated drivers of ecosystem condition—coastal basins with lower intensity use.



1. **Mixed nature conservation/forestry coastal river basin**

- A low intensity land use pattern—generally maintains good ecosystem condition.
- Ecosystem condition drivers include clearing, changed run-off patterns, increased sediment loads, weeds, feral animals and altered fire regime.
- Examples include Shannon River Western Australia, Gordon River Basin Tasmania.

2. **Mixed nature conservation/ Indigenous use coastal river basin**

- A low intensity land use patterns—generally maintains good ecosystem condition.
- Ecosystem condition drivers include weeds, feral animals and fire regime change.
- Most examples in northern Australia (e.g. Jardine River, Queensland; East Alligator River, Northern Territory).

3. **Mixed rangeland grazing/Indigenous use/nature conservation/minimal use (crown land) coastal river basin**

- Relatively low intensity land use—maintains good ecosystem condition.
- Ecosystem condition drivers include total grazing pressure, increased sediment loads, weeds, feral animals and fire regime change.
- Most examples in northern Australia (e.g. Drysdale River, Western Australia; Nicholson River, Northern Territory and Queensland).

4. **Extensive rangeland grazing coastal river basin**

- Extensive land use—ecosystem condition dependent upon total grazing pressure, pasture management and climate extremes.
- Ecosystem condition drivers include total grazing pressure, soil erosion, increased sediment and nutrient loads, river bed sedimentation, altered run-off patterns, weeds, feral animals, and fire regime change.
- In the monsoonal tropics, intense summer rainfall can exacerbate soil erosion and generate large sediment (and associated nutrient) loads.
- Where river basins drain to a tide-dominated estuary with low sediment trapping efficiency, an increased nutrient load may be exported to the marine environment associated with fine sediment.
- Most examples in tropical and subtropical Australia (e.g. Gascoyne River, Western Australia; Flinders River, Queensland).

5. **Extensive rangeland grazing coastal river basin with irrigated agriculture floodplain**

- Extensive grazing area—ecosystem condition dependent on total grazing pressure, pasture management and climate extremes.
- Ecosystem condition drivers include total grazing pressure, soil erosion, increased sediment and nutrient loads, river bed sedimentation, changed run-off, floodplain/ groundwater hydrology, altered flow regimes, clearing, weeds, feral animals, fire regime change, chemical use and fish passage barriers.
- In the monsoonal tropics, intense summer rainfall can exacerbate soil erosion and generate large sediment (and associated nutrient) loads.
- Where river basins drain to a tide-dominated estuary with low sediment trapping efficiency, an increased nutrient load may be exported to the marine environment associated with fine sediment.
- Most examples in tropical Australia (e.g. Ord River, Western Australia; Burdekin River, Queensland).

Ecosystem condition drivers

Land use

- nature conservation
- forestry
- recreation
- Indigenous use
- livestock grazing
- ports/canal estates
- urban/industry
- agriculture
- irrigation

Clearing

Erosion and sedimentation processes

- hillslope soil erosion
- gully erosion
- riverbank erosion
- sediment source
- river sedimentation
- bare ground

Chemical use

Fire regime change

Hydrological change

- changed run-off
- dryland salinity
- changed flow regime
- water storages and flow control structures
- constructed drains and channel network
- fish barriers
- groundwater rise
- tidal barrage

Nutrient sources and loads

- diffuse nutrient sources
- increased basin nutrient load
- point nutrient sources
- sewage treatment plant

Feral animals and weeds

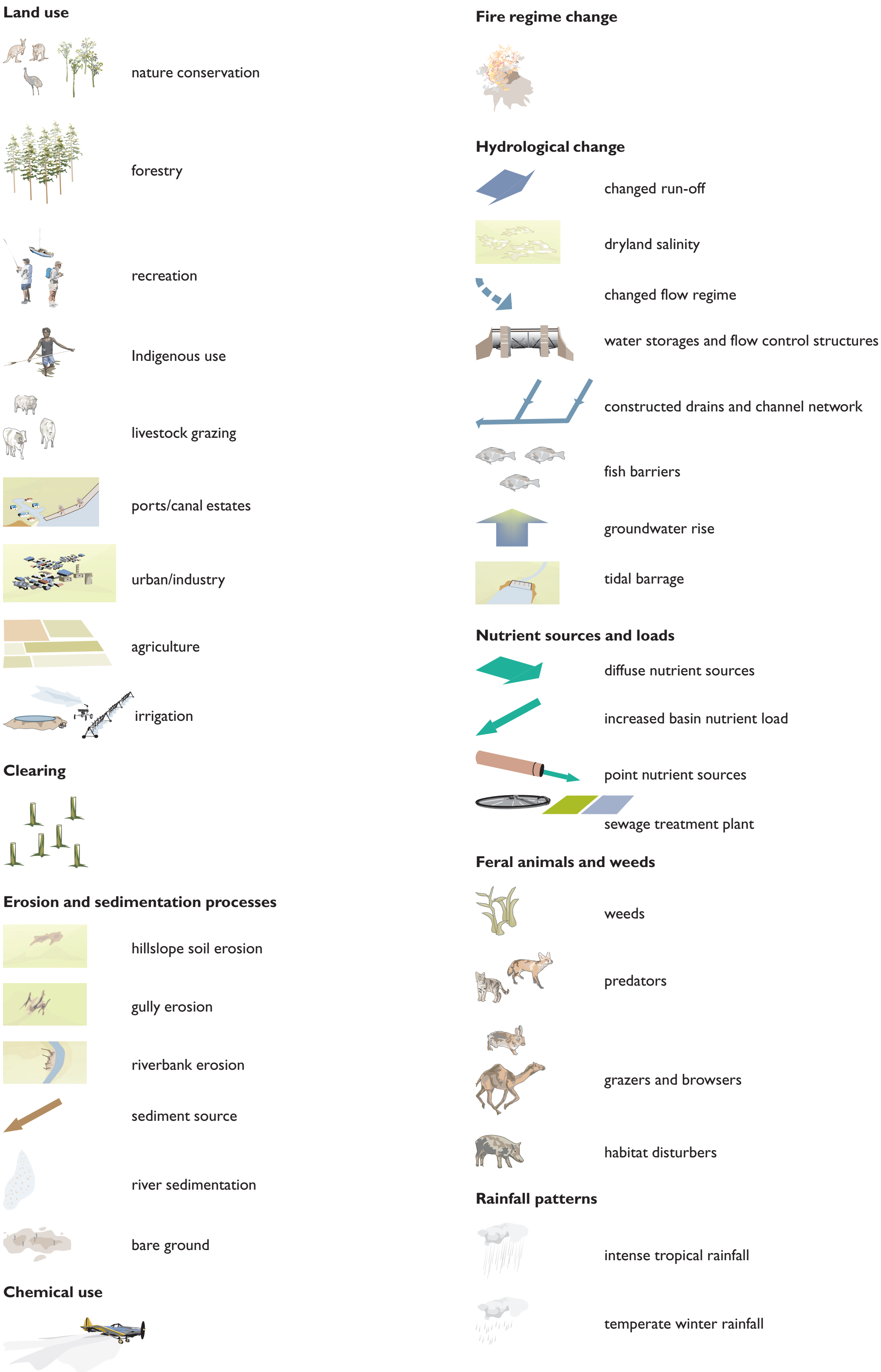
- weeds
- predators
- grazers and browsers
- habitat disturbers

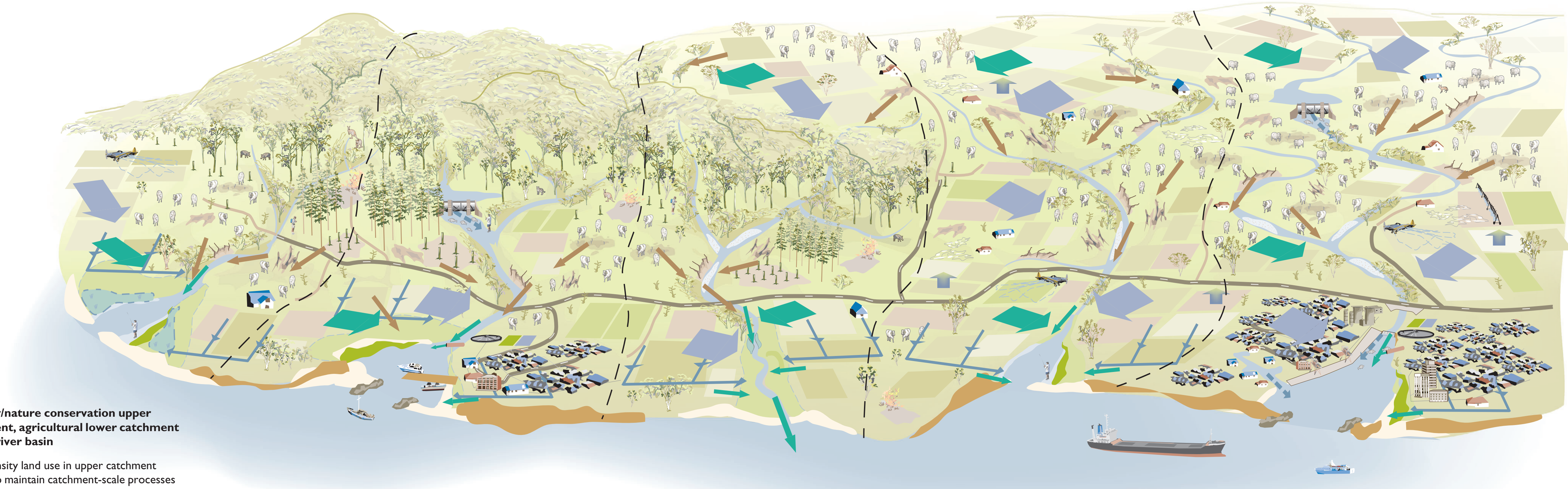
Rainfall patterns

- intense tropical rainfall
- temperate winter rainfall

Figure 5. Land use pattern within Australian river basins and associated drivers of ecosystem condition—coastal basins with higher intensity use.

Ecosystem condition drivers





6. **Forestry/nature conservation upper catchment, agricultural lower catchment coastal river basin**

- Low intensity land use in upper catchment areas help maintain catchment-scale processes and good ecosystem condition.
- Ecosystem condition drivers, mainly associated with more intensive land use of lower catchment area, include clearing, total grazing pressure, increased sediment and diffuse nutrient loads, changed run-off and floodplain hydrology, chemical use, weeds, feral animals, and fire regime change.
- Examples in southern and eastern Australia (e.g. Bega River, New South Wales; Huon River, Tasmania).

7. **Forestry/nature conservation upper catchment, agricultural mid and built environment lower catchment coastal river basin**

- Low intensity land use in upper catchment areas help maintain catchment-scale processes and good ecosystem condition.
- Ecosystem condition drivers—mainly associated with more intensive land uses of middle and lower catchment area—include clearing, total grazing pressure, changed run-off and floodplain hydrology, altered flow regimes, increased sediment and diffuse nutrient loads, point source nutrient and pollutant loads, fish passage barriers, chemical use, intensive recreational use, weeds, feral animals, and fire regime change.
- Where these river basins drain to wave-dominated estuaries with high sediment trapping efficiency and poor tidal exchange, there is significant potential for impacts on estuary condition.
- Many examples in southern Australia (e.g. Yarra River, Victoria; Hawkesbury River, New South Wales).

8. **Agriculture/grazing tablelands forestry/nature conservation mid catchment and agriculture/built environment lower catchment river basin**

- Low intensity land use areas in mid catchment—potentially affected by ecosystem condition drivers operating in upper catchment.
- Ecosystem condition drivers—mainly associated with more intensive land uses of upper and lower catchment area—include clearing, total grazing pressure, changed run-off and floodplain hydrology, increased sediment and diffuse nutrient loads, chemical use, weeds, feral animals, fire regime change.
- Many examples in southern and eastern Australia (e.g. Macleay River, New South Wales; Johnstone River, Queensland).

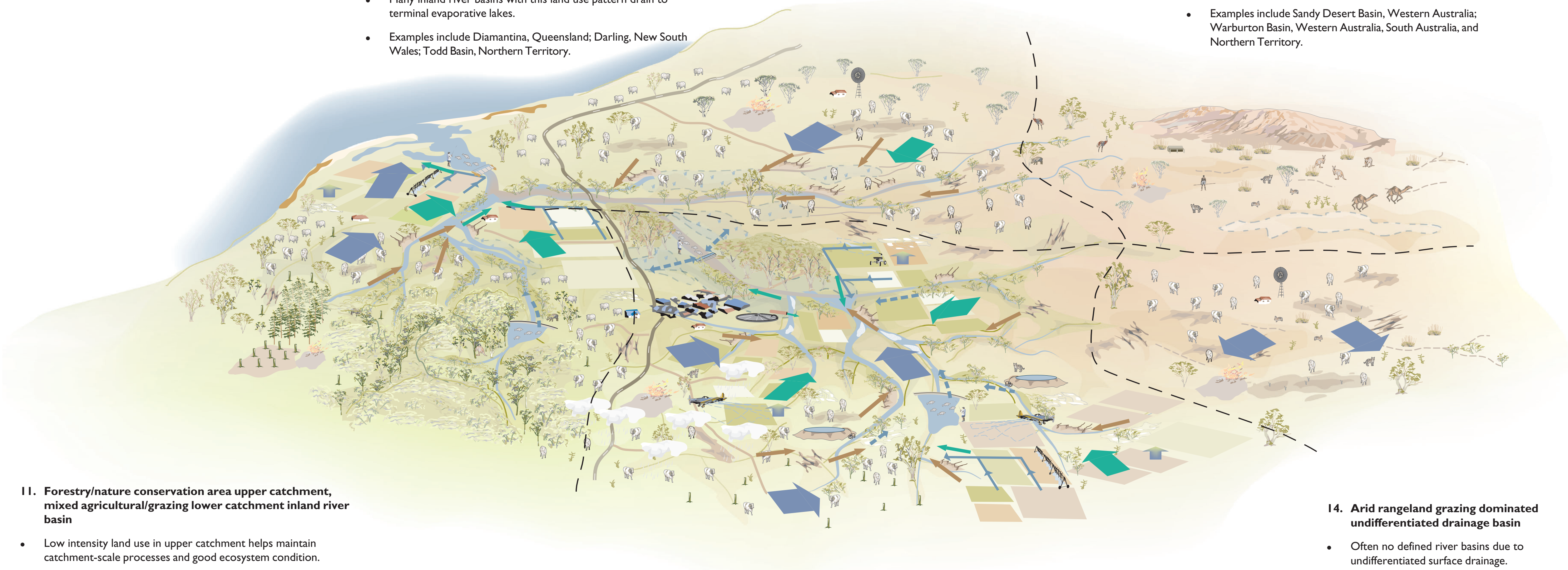
9. **Mixed dryland agriculture/grazing coastal river basin**

- Relatively intensive land use pattern throughout basin.
- Ecosystem condition drivers include clearing, total grazing pressure, changed run-off and floodplain/groundwater hydrology, dryland salinity, increased sediment and diffuse nutrient loads, chemical use, weeds, feral animals, and fire regime change.
- Where these river basins drain to wave-dominated estuaries with high sediment trapping efficiency and poor tidal exchange, there is significant potential for impacts on estuary condition.
- Many examples in southern Australia (e.g. Avon River, Western Australia; Gawler River, South Australia; Hopkins River, Victoria).

10. **Mixed agriculture/grazing upper catchment and built environment lower catchment coastal river basin**

- Relatively intensive land use pattern throughout basin with built environment in lower catchment.
- Ecosystem condition drivers include clearing, total grazing pressure, increased sediment and diffuse nutrient loads, changed run-off and floodplain/groundwater hydrology, dryland salinity, altered river and tidal flow regime, fish passage barriers, chemical use, weeds, feral animals, fire regime change, point source nutrient and pollutant loading, and intensive estuary use.
- Where these river basins drain to wave-dominated estuaries with high sediment trapping efficiency and low tidal exchange, there is significant potential for impacts on estuary condition.
- Many examples in southern Australia (e.g. Swan Coast Basin, Western Australia; Torrens River, South Australia; Maribyrnong River, Victoria).

Figure 6. Land use patterns within Australian river basins and associated drivers of ecosystem condition—inland basins.



13. Mixed rangeland grazing, nature conservation, Indigenous use inland drainage river basin

- Extensive land use—ecosystem condition dependent on total grazing pressure, pasture management and climate extremes.
- Ecosystem condition drivers include total grazing pressure, soil erosion, increased sediment and diffuse nutrient loads, changed run-off patterns, weeds, feral animals and fire regime change.
- Many inland river basins with this land use pattern drain to terminal evaporative lakes.
- Examples include Diamantina, Queensland; Darling, New South Wales; Todd Basin, Northern Territory.

15. Mixed Indigenous/minimal use (crown land)/nature conservation undifferentiated drainage basin

- Often no defined river basins due to undifferentiated surface drainage.
- One of the lowest intensity land uses.
- Ecosystem condition drivers include altered fire regime, feral animals, total grazing pressure and weeds.
- Examples include Sandy Desert Basin, Western Australia; Warburton Basin, Western Australia, South Australia, and Northern Territory.

11. Forestry/nature conservation area upper catchment, mixed agricultural/grazing lower catchment inland river basin

- Low intensity land use in upper catchment helps maintain catchment-scale processes and good ecosystem condition.
- Ecosystem condition drivers—mainly associated with more intensive land use of lower catchment area—include clearing, total grazing pressure, increased sediment and diffuse nutrient loads, changed run-off and floodplain/groundwater hydrology, dryland salinity, altered flow regime, fish passage barriers, chemical use, weeds, feral animals, and fire regime change.
- Basin drains to confluence with other basins and to single estuary.
- Examples include Goulburn River, Victoria; Upper Murray, Victoria/New South Wales; Murrumbidgee, New South Wales.

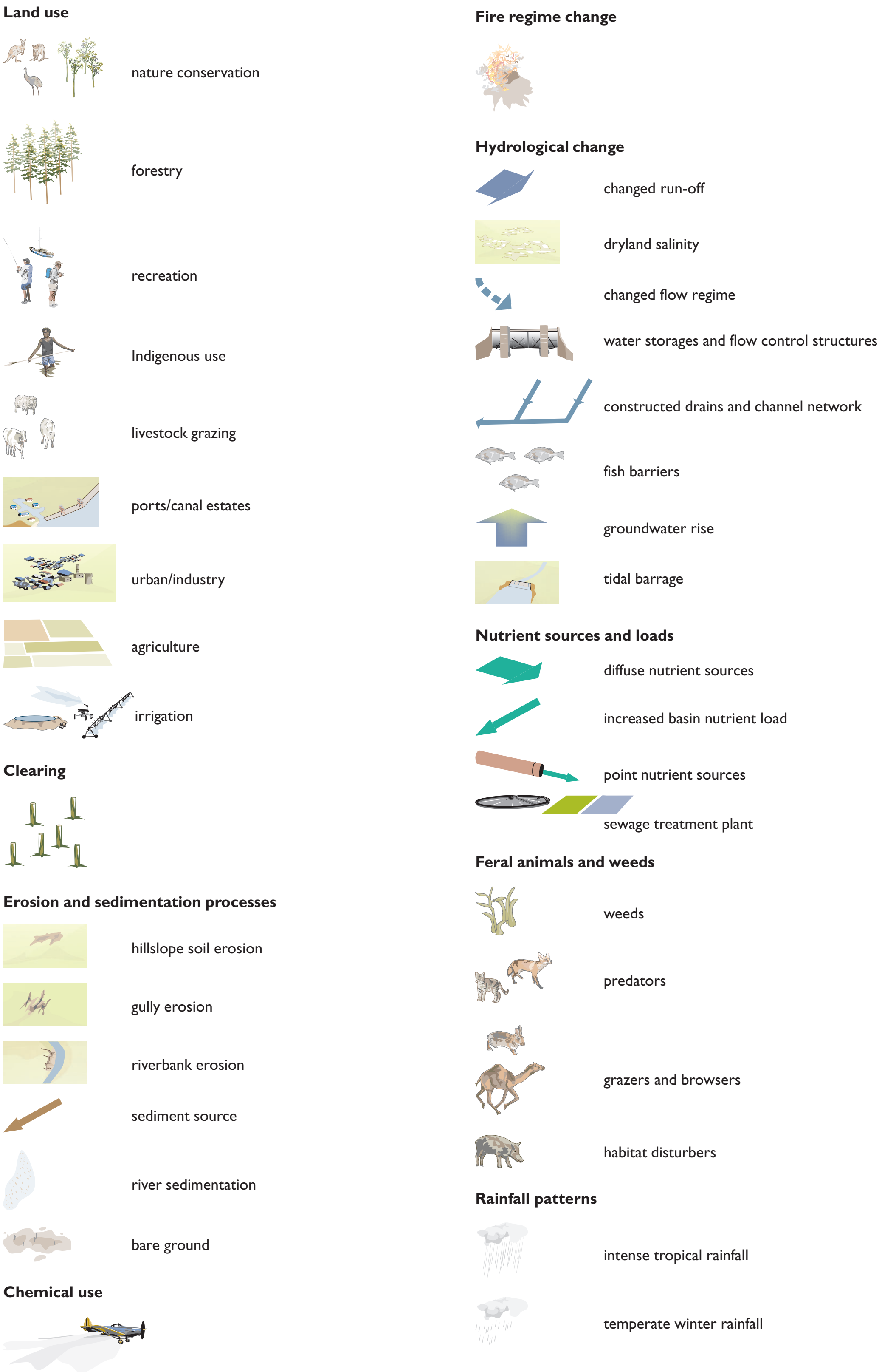
12. Mixed agriculture/grazing with forestry inland river basin

- Relatively intensive mixed land use pattern throughout basin. Some basins contain major regional centres of built environment.
- Ecosystem condition drivers include clearing, total grazing pressure, increased sediment and nutrient loads, changed run-off and floodplain/groundwater hydrology, dryland salinity, altered flow regime, fish passage barriers, river sedimentation, chemical use, weeds, feral animals, and fire regime change.
- Temperate climate–winter rainfall areas are susceptible to dryland salinity due to rainfall infiltration being greater than evapotranspiration.
- Basin drains to confluence with other basins and to single estuary.
- Examples include Namoi River, New South Wales; Condamine – Culgoa River Basin, Queensland; Loddon River, Victoria.

14. Arid rangeland grazing dominated undifferentiated drainage basin

- Often no defined river basins due to undifferentiated surface drainage. Drainage often ends in terminal evaporative basins.
- Low intensity extensive land use pattern—ecosystem condition dependent upon total grazing pressure, pasture management, climate extremes and significance of other ecosystem condition drivers including soil erosion, altered fire regime, feral animals and weeds.
- Examples include Salt Lake Basin, Western Australia; Burt Basin, Northern Territory.

Ecosystem condition drivers



Geographic drivers

Ecosystem characteristics—climate, topography, soil properties and vegetation type—are important determinants of resilience to impacts of resource use (Table 1). They affect the extent to which condition drivers such as erosion and landscape water balance can act under different land use patterns.

Table 1. Geographic drivers of ecosystem condition.

Climate and rainfall

- Climate affects primary productivity, nutrient cycling rate, soil moisture and evaporative potential, soil formation, types of erosion, and water oxygen concentration.
- Rainfall affects water balance, vegetation cover, erosion rates (and types), surface water flow, fire regime.
- Ecosystems that have moderate climates in terms of evenly distributed medium rainfall and limited extremes in temperature, rainfall intensity or aridity are considered more resilient to resource use impacts because they are more likely to maintain ground vegetation cover and have higher rates of nutrient cycling and soil formation producing better-structured and more fertile soils.
- Key input to modelling of soil erosion, nutrient loading and landscape water balance (NLWRA 2001b).

Topography

- Affects erosion potential, stream flow gradients, water balance, size of catchments, and potential land use intensity.
- Generalisations concerning influence are difficult as topography interacts with climate and soil types. Steeper landscapes generally have a greater potential for soil erosion and higher gradient streams have greater flow velocities and sediment transport capacities. Larger catchments associated with less dissected landscapes usually have lower stream flow rates and lower sediment transport capacity.
- Topography is often one of the primary determinants of land use intensity.
- Key input to Audit modelling (NLWRA 2001b).
- Geomorphic landscape units form assessment framework for the Audit landscape health project.

Soil properties

- Affect landscape water balance, nutrient leaching, catchment hydrology, vegetation type, primary productivity, wind and water erosion potential and downstream water quality.
- Deep well structured fertile soils are the most resilient in terms of resource use impacts.
- Properties that make major Australian soil types susceptible to impacts include:
  - low reserves of organic matter (e.g. Tenosols, Rudosols)
  - dispersiveness (e.g. Sodosols)
  - proneness to compaction (e.g. Vertosols, Organosols)
  - proneness to waterlogging (e.g. Podosols)
  - proneness to slaking (e.g. Dermosols)
  - proneness to hardsetting and crusting (e.g. Chromosols, Kandosols, Sodosols)
  - proneness to acidification (e.g. Kurosols, Ferrosols, Hydrosols)
  - low fertility (e.g. Tenosols, Rudosols, Podosols, Sodosols, Calcarosols)
  - low water retention capacity (e.g. Calcarosols, Tenosols, Rudosols, Sodosols)
  - proneness to water erosion (e.g. Sodosols, Organosols, Ferrosols, Kandosols)
  - proneness to wind erosion (e.g. Calcarosols, Podosols, Tenosols, Rudosols)
- Distribution of soil types and properties (NLWRA 2001b).
- Key input to modelling and soil condition assessments (NLWRA 2001b).

Vegetation type

- Affects water balance, erosion rates, soil structure and fertility, nutrient cycling, primary productivity, and fire regime.
- Susceptibility to use impact is dependent on interactions with climate and soil type. Characteristics that favour resilience include high percentage ground cover, low palatability to livestock, fire resistance, and capacity to grow in nutrient poor soils.
- Native vegetation types and extent compiled and mapped (NLWRA 2001c).
- Key input to assessment of agricultural productivity and sustainability (NLWRA 2001b) and assessments of landscape water and nutrient balance and erosion rate.

Floodplains support high value industries

Land use-associated drivers

Intensity of land and water use determines the potential for impacts on ecosystem condition. Intensity ranges from maintenance of essentially natural ecosystems to the complete alteration of land surfaces and ecosystem biophysical processes. Land use has been summarised into nine classes (Table 2). The proportion of each land use within river basins is presented in Appendix 3.

Table 2. Land use-associated drivers of ecosystem condition.

Nature conservation

- Usually contains ecosystems in pre-settlement condition.
- Condition drivers (e.g. exotic biota, altered fire regime, altered water balance and modified stream flow) may still be operating in areas used for nature conservation.
- Extent of nature conservation area used as an indicator in catchment condition and landscape health assessments (NLWRA 2001a and this report).
- Incorporated into catchment disturbance index of the river condition assessment (this report).

Other protected areas and indigenous use

- Areas with indigenous land uses usually contain ecosystems in good condition. Indigenous use includes traditional hunting, and in some instances livestock grazing, forestry and other primary production uses.
- Ecosystem condition drivers include exotic biota, altered fire regime, grazing pressure and erosion.
- Incorporated into landscape health assessment of extent of conservative land tenure (NLWRA 2001a).

Minimal use

- Includes a range of crown lands where use of resources does not greatly affect ecosystem condition. Exceptions are in localised areas used for more intensive purposes (e.g. military use and transport corridors).
- Ecosystem condition drivers include exotic biota, altered fire regime, grazing pressure and erosion and in some cases complete loss of the ecosystem as occurs with road and rail construction.
- Incorporated into landscape health assessment of extent of conservative land tenure (NLWRA 2001a).

Forestry

- Includes both native production forests and plantation forestry.
- Where native forests are only selectively logged, many ecosystem process drivers maintain their function. Some processes operating at the species and community level may be affected.
- Plantation forestry is a more intense land use as it includes clear felling of natural vegetation and produces significant changes to biophysical processes and ecosystem conditions. While plantation forests are growing, they contribute to the stability of many catchment scale ecosystem condition drivers.
- Key condition drivers affected by forestry land uses include exotic biota, altered fire regime, grazing pressure, erosion, altered water balance, changed catchment hydrology, and water quality degradation.
- Incorporated into landscape health assessment of extent of conservative land tenure (NLWRA 2001a).
- Incorporated into catchment disturbance index of the river condition assessment (this report).

Irrigated agriculture requires high quality water

Table 2. Land use-associated drivers of ecosystem condition (continued).

Livestock grazing

- This land use class is the most extensive in Australia.
- Impacts on ecosystem condition depend upon landscape resilience, grazing pressure and the level of pasture improvement such as tree clearing and exotic pasture sowing. Livestock grazing on native pastures is less intensive than agriculture or built environments. Ecosystem condition impacts can be intensive within susceptible landscapes.
- Most of this class represents uncleared native pastures or rangelands.
- Cultivated improved pastures are included within the dryland agriculture land use class.
- Key condition drivers include grazing pressure, vegetation cover and condition, fire regime, soil erosion and compaction, exotic biota, altered water balance, changed catchment hydrology, nutrient loading and water quality degradation.
- Extent of total grazing pressure is used in the Audit's *Landscape Health in Australia* assessment (NLWRA 2001a).
- Also incorporated into catchment disturbance index of the river condition assessment (this report).
- Key attribute for rangeland monitoring and assessment (NLWRA 2001d).

Dryland agriculture

- Dependent on rainfall for crop growth. Includes land that has been cleared and where surface form and soil properties have been modified by land levelling, cultivation and addition of ameliorants and fertilisers.
- Includes improved pastures and cereal and grain crops.
- Ecosystem condition is dependent on suitability of the landscape and soil type for agriculture and management practices in place.
- Key ecosystem condition drivers include loss of vegetation cover, soil erosion, compaction, and acidification, altered water balance, dryland salinity, changed catchment hydrology, nutrient loading, water quality degradation, exotic biota, and fire regime.
- Key input to the Audit assessment of agricultural productivity and sustainability (NLWRA 2001b) and assessments of landscape water and nutrient balance and erosion rate.
- Input to assessment of catchment condition (this report)

Irrigated agriculture

- Has the capacity to affect all the condition drivers also affected by dryland agriculture.
- Increases potential for a range of degradation issues associated with soil and landscape water balance.
- Generates ecosystem impacts through drivers associated with river regulation, construction of dams and tail water discharge (i.e. aquatic habitat connectivity, flow regime change and associated water quality changes).
- One of the more intensive forms of land use.
- Key input to the Audit assessment of agricultural productivity and sustainability (NLWRA 2001b).
- Input to assessment of catchment condition (this report).

Built environment

- Includes urban and industrial development and is the most intensive land use in terms of resource use impacts. Only larger cities and industrial complexes are mapped.
- Key ecosystem condition drivers operating in built environment areas include vegetation cover loss, soil erosion, altered water balance, dryland salinity, changed catchment hydrology (especially hard panning), nutrient loading, toxicant pollution, water quality degradation, exotic biota, and fire regime change.
- Incorporated into catchment disturbance index of the river condition assessment (this report).
- Input to assessment of catchment condition (this report).

Water bodies

- In eastern Australia, many water bodies mapped in the national land use coverage are constructed impoundments and reflect river regulation and water resource use associated with irrigated agriculture or urban development.
- Majority of mapped water bodies are inland drainage terminal evaporative basins and saline lakes. Other types include coastal mangrove and saltpan wetland complexes (northern tropical Australia), floodplain wetlands (Murray–Darling basin), coastal (south-eastern Australia) and inland lakes (e.g. Lake George in New South Wales).

Resource use drivers

Patterns of resource use and degradation are important drivers of ecosystem condition.

Table 3. Resource use and degradation drivers of ecosystem condition.

Native vegetation extent and condition

- Extent of native vegetation cover is determined by the intensity of current or past land uses.
- An important determinant of landscape water balance, nutrient cycling, soil structure, erosion rates, catchment hydrology, fire regime, and habitat availability.
- Riparian vegetation is particularly important for the stability of catchments and their ecosystems. It provides habitat, stabilises stream banks intercepts nutrients and sediment, and moderates instream temperature by shading.
- Where vegetation has not been cleared, its condition can influence the operation of key ecosystem condition drivers.
- In developed catchments, exotic vegetation cover including crops and plantation forests can perform some of the biophysical roles important for maintaining catchment condition stability.
- Incorporated into riparian vegetation index of the river condition assessment (this report).
- Extent of native vegetation used in the Audit landscape health (NLWRA 2001a) and the catchment condition assessment (this report).
- Recommended attribute for rangeland monitoring and assessment (NLWRA 2001d).

Fire regime

- Fire has played an important role in the evolution of Australian ecosystems and many Australian landscape mosaics are mediated by fire.
- Key driver of vegetation cover and structure, soil fertility (and structure), erosion potential, biota and habitat availability.
- In areas of more intensive land use, fire is seldom used as a management tool, except for specific production or risk reduction goals.
- Current fire regimes are often far removed from pre-settlement conditions. In areas of extensive land use, fire regimes are often determined by production goals (i.e. pasture management).
- Assessment of changes to fire regime is limited by availability of Australia-wide data. Qualitative information compiled for the Audit assessment of landscape health (NLWRA 2001a).
- Recommended attribute for rangeland monitoring and assessment (NLWRA 2001d).

Soil erosion

- Australia's climate and soils make landscapes particularly prone to soil erosion.
- Associated with a range of land uses and drivers.
- Significant driver of ecosystem condition causing soil structure and fertility decline, altered catchment hydrology, change in vegetation community, surface water turbidity, benthic habitat smothering, stream channel bed aggradation, and nutrient loading and changes in aquatic biota community composition.
- Water-borne soil can be transported beyond the mouth of a river basin affecting water quality in near-coastal marine environments (e.g. fringing coral reefs of the Great Barrier Reef Marine Park).
- Wind erosion is a significant degradation driver particularly for ecosystems containing infertile and poorly structured sandy soils.
- Ratio of current soil erosion to natural rates has been assessed by the Audit assessment of agricultural productivity and sustainability (NLWRA 2001b).
- Hill slope erosion used as input to the catchment condition assessment (this report).
- Suspended sediment and bed load data incorporated into water quality and physical habitat indices of the river condition assessment (this report).

Soil degradation (see Table 1 for degradation issues)

- Key affected processes include landscape water balance, catchment hydrology, soil erosion, primary productivity, and downstream water quality.
- Soil acidification is usually associated with structural and fertility decline which can provide prerequisite conditions for changes in rainfall infiltration rates and changes in landscape water balance.
- Soil degradation hazard used as input to the catchment condition assessment (this report) .
- Acid soil lime requirements and soil management input into the Audit assessment of agricultural productivity and sustainability (NLWRA 2001b).

Dryland salinity is caused by rising groundwater mobilising salt in the soil

Table 3. Resource use and degradation drivers of ecosystem condition (continued).

Landscape water balance/catchment hydrology

- Rainfall infiltration rate is a key determinant and is governed by topography, type and extent of vegetation, and soil type and condition.
- Modified by water use patterns including irrigation and groundwater use.
- Primary driver of ecosystem processes including groundwater discharge to stream surface flows and wetlands.
- Governs catchment hydrology and the distribution of vegetation and groundwater dependent ecosystems.
- An unstable landscape water balance is the basis for dryland salinity.
- Catchment hydrology is affected by water resource use patterns and patterns of land development including land levelling, wetland draining and levee and dam construction.
- Hydrology changes incorporated in the Audit assessment of landscape health (NLWRA 2001a).
- Impoundment density used as input to the catchment condition assessment (this report).
- Hydrology changes incorporated into the river condition assessment (this report).

Dryland salinity

- Driven by landscape and catchment water balance.
- Salinised soils lead to the death of native vegetation, soil and riverbank erosion and habitat loss.
- Input into the Audit assessment of dryland salinity (NLWRA 2001e).
- Input to assessment of catchment condition assessment (this report) and landscape health (NLWRA 2001a).
- Basin salinity exceedances incorporated into the river condition assessment (this report).
- Surface water quality salinity exceedances input into the Audit assessment of water quality (NLWRA 2001f).

Water quality

- Processes such as loss of vegetation cover and soil erosion are often related to land use intensity and may be primary drivers of water quality deterioration.
- Water quality issues include turbidity, salinity, nutrient and organic loading, low dissolved oxygen, acidity, heavy metals and pollutants.
- Impacts caused by these include change in instream metabolism (temperature and primary productivity), algal blooms, smothering of benthic habitats, and loss of aquatic biota.
- Surface water quality exceedances for turbidity, total nitrogen, total phosphorus, pH and salinity input to the Audit water resources assessment (NLWRA 2001f).
- Suspended sediment, nitrogen, phosphorus and salinity incorporated into the river condition assessment (this report).
- Pesticide, industrial point source and nutrient point source hazard and suspended sediment load incorporated into the catchment condition assessment (this report).

Surface water and groundwater use

- Ecosystem condition is related to volumes available to maintain environmental flows or groundwater dependent ecosystems and the design, construction and operation of water supply infrastructure such as impoundments and weirs.
- Surface water and groundwater use can affect seasonality of flows, water temperature, water quality, habitat connectivity, distribution and reproduction of aquatic biota, stream channel and estuarine geomorphology, and catchment hydrogeology.
- Input to the Audit water resources assessment (NLWRA 2001f).
- Impoundment density used in the catchment condition assessment (this report).
- Hydrology change and habitat connectivity incorporated into the river condition assessment (this report).
- Recommended attribute for rangeland monitoring and assessment (NLWRA 2001d).

Table 3. Resource use and degradation drivers of ecosystem condition (continued).

Nutrient loading	Exotic biota
• Many Australian ecosystems have evolved in nutrient limited conditions because of the naturally low nutrient status of soils. • Surplus nutrient sources include agricultural fertilisers and discharges from point sources such as sewage treatment plants. • Nutrient loads derived from diffuse sources such as water-borne soil erosion are the most significant sources in terms of total quantities contributed. • Landscape features that help reduce nutrient and sediment loads exported from catchments include wetland detention basins and riparian vegetation. These features are often degraded or lost with intensive land use. This loss can act as a secondary driver for nutrient loading problems. • Ecosystem impacts associated with nutrient loading include water quality deterioration (e.g. algal blooms and dissolved oxygen decline), and changes to the composition of aquatic biota communities in wetlands, rivers, estuaries and coastal environments. • Landscape balance for nitrogen and phosphorous input to the Audit assessment of agricultural productivity and sustainability (NLWRA 2001b). • Phosphorus and nitrogen load incorporated into the river condition assessment (this report). • Nutrient point source hazard incorporated into the catchment condition assessment (this report). • Water quality measures, point source discharges and ecological integrity measures associated with nutrient loading used in estuary condition assessment (this report).	• Include wild stock, feral vertebrate pests (e.g. foxes, rabbits and cats), exotic plant species and invertebrates. • Many have been accidental or incidental introductions and may be more appropriately considered ecosystem degradation rather than resource use. • The ecosystem pressures associated with domestic stock and exotic species introduced to the wild for recreational purposes (e.g. trout) are patterns of resource use. • Can affect biophysical process drivers such as catchment hydrology and soil erosion through physical impacts on native vegetation and landscapes (e.g. trampling, increased grazing pressure, soil disturbance and the exclusion of ground cover). Exotic biota can compete with native biota for habitat and food resources, and can be predators. • Exotic vertebrates and weeds of national significance used as input to the catchment condition assessment (this report) and the Audit assessment of landscape Health (NLWRA 2001a). • Recommended attribute for rangeland monitoring and assessment (NLWRA 2001d).

Australia-wide assessments: context for regional action

Natural resource management decision makers need to be able to place specific issues within an informed, broader context, to be able to strategically target investment. This requires operating over a range of scales and setting strategic directions at larger scales while defining specific on-ground activities at regional scales.

The Audit's Australia-wide resource assessments use consistent, integrative approaches based on an understanding of key biophysical process drivers to compare natural resource systems and management issues. This comparability provides an appropriate broad scale context for setting natural resource management program and policy priorities.

Those involved in onground activities and regional planning processes can use the Audit's information as an input for setting regional priorities. To complete the analysis at regional scales, information on social and economic benefits and costs is essential. This ensures explicit trade-offs are made to deliver the most cost-effective and regionally appropriate set of works and activities.

ASSESSMENT EXTENT AND LIMITATIONS

Availability of data is the primary limitation on the coverage in this assessment.

The area of assessment for catchments and rivers includes all river basins with intensive land use (Figure 7) and selected river basins (in the Northern Territory and the western division of the Murray–Darling Basin) that do not contain intensive land use, but for which resource data were available. Whole river basins were used so that processes such as hydrology, and sediment and nutrient movement could be modelled and balanced over entire river basins.

The estuary assessment has an Australia-wide coverage. In more remote areas the limited availability of data has resulted in a greater dependence on qualitative assessment methods using expert opinion and remotely sensed data. Estuary condition also provides an indicative, integrated measure of catchment and river condition.

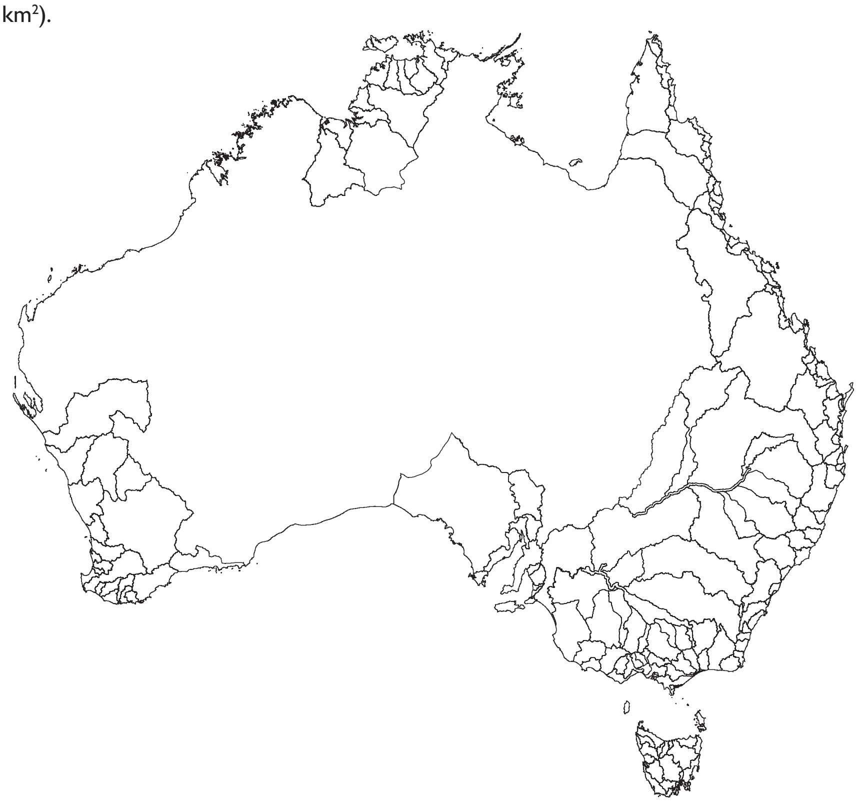
The Audit landscape health report (NLWRA 2001a) includes Australia-wide assessments of the condition of bioregions and component subregions including more remote areas. These findings have been used to provide context for the *integrated findings* section of this report.

Uniform assessment frameworks that use comparable data are needed to produce Australia-wide assessments. State and Territory data has been compiled using consistent standards and unit protocols. Where not available, assessments have used national data sets.

Data limitations include:

- water quality (no chemical, heavy metals or thermal pollution data);
- vegetation (no specific riparian vegetation community or condition data);
- biota (limited national data beyond freshwater macro-invertebrates in the case of river condition assessments) and;
- habitat (no freshwater wetland data to support the catchment condition assessment).

Figure 7. River basins that contain areas of intensive land use. The area represents 40% of the continent (3 million km^2).



CATCHMENTS SUMMARY

Land use linked by water

- The Australian catchment condition assessment presents a way to make comparative assessments of catchment biophysical condition. Australia-wide reports and maps presented allow detailed and location-specific condition comparisons to be made. Comparisons at river basin and subcatchment scales are available as part of the Australian Natural Resources Atlas.
- The assessment provides insight into the biophysical condition of Australia's more intensively used catchments. Most catchments in the lower condition classes have been identified as priorities under the National Action Plan for Salinity and Water Quality (Commonwealth of Australia 2000). Notable areas for remedial works outside the National Action Plan for Salinity and Water Quality include the Hunter and Hawkesbury River basins in central New South Wales and smaller coastal river basins in northern New South Wales, southern and central Queensland and coastal Victoria (Figure 13).
- Using the composite catchment condition index:
  - 5% of catchments are in the lowest condition class (< 20 percentile);
  - 15% are in the lower condition class (20–40 percentile);
  - 50% are in the mid-range condition class (40–60 percentile); and
  - 30% are in the highest condition classes (> 60 percentile).
- The biophysical condition of a significant proportion of catchments (15–25%) is likely to continue to decline because of the long-term nature of environmental processes and degree of change in the catchment. These catchments are in the cleared, agronomically marginal rainfall areas, and have soils of relatively poor fertility and structural properties. They are prone to soil structure decline, soil erosion and salinisation and have low flexibility in terms of profitable land use options.
- Catchments in the lower condition classes are in the areas of most intensive land use. Improving land use practices is the key to improved condition for these catchments.
- At the other end of the scale, the 30% of catchment in the highest condition classes provide an indication of priorities for protective management—strategic investment will be cost-effective and ensure the maintenance of good condition of these catchments.
- This assessment has demonstrated that spatial pattern and variation in catchment condition can be described by using relatively few attributes—change in vegetative cover, native vegetation fragmentation, inputs into rivers and streams, and changes to catchment hydrology, particularly impoundments. These attributes all relate to land use intensity.

INTRODUCTION

Catchment management is a key community process in place across much of Australia. The House of Representatives Standing Committee on Environment and Heritage Inquiry into Catchment Management (December 2000) noted that a catchment management approach combines three ingredients necessary to address environmental problems facing the nation. There are:

- use of natural geographic divisions that are readily understood;
- a basis for linking communities of similar and shared interests into regions of interest, to build a stronger and coordinated response to environmental degradation; and
- widespread community acceptance of the approach and existing infrastructure.

For these reasons the Standing Committee concluded that:

> *… an approach based on the management of catchment systems must underpin the identification of the problems, the administrative arrangements and ultimately the delivery of appropriate remedial action.*
>
> House of Representatives Standing Committee of Environment and Heritage 2001

The Standing Committee noted that not only is this approach based upon natural facts about the landscape, but that it already enjoys considerable and widespread support.

Recognising both the widespread community support for catchment management approaches and the importance of linked biological and physical processes in determining the condition of catchments, the catchment assessment was designed to assess the relative biophysical condition of Australia's catchments. It is restricted to the key catchments of intensive land use across Australia (Figure 7) and includes data sets from many of the other Audit assessments.

The assessment of catchment condition was conducted as a partnership between the Audit, the Bureau of Rural Sciences and CSIRO Land and Water with support and involvement of State and Territory natural resource management agencies.

Project objectives

- To develop a classification system that uses biophysical data to define catchment condition and provides an integration and synthesis of Audit data at the catchment scale
- To apply the classification system to provide an integrated Australian-wide report on the relative condition and main pressures operating on catchment condition
- To develop and provide a readily applied and extendable database and presentation framework for compiling, analysing and integrating catchment condition data with consideration to the capacity to integrate data across a range of scales
- To provide catchment specific information that allows decision makers to identify implications for catchment management needs, including information gaps and priorities for more intensive investigation and further research

Catchment condition is a value judgement that depends on biophysical attributes interacting with social values and economic factors. A systems model of catchment function was developed to capture the main elements needed to define catchment condition (Figure 8).

This comparative assessment was limited to a biophysical definition of catchment condition with catchment function defined in terms of land, water and biota components (Figure 9). These components can be viewed through:

- individual indicators;
- combined indicators for each component (subindices); or
- combined across the three components into an overall catchment condition index.

Figure 8. A systems model of catchment function.

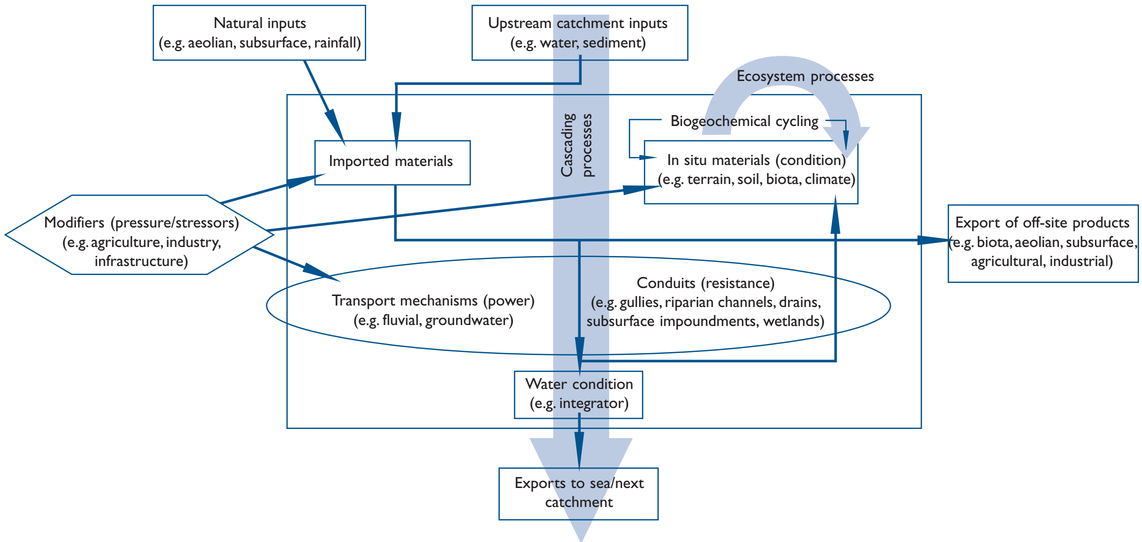
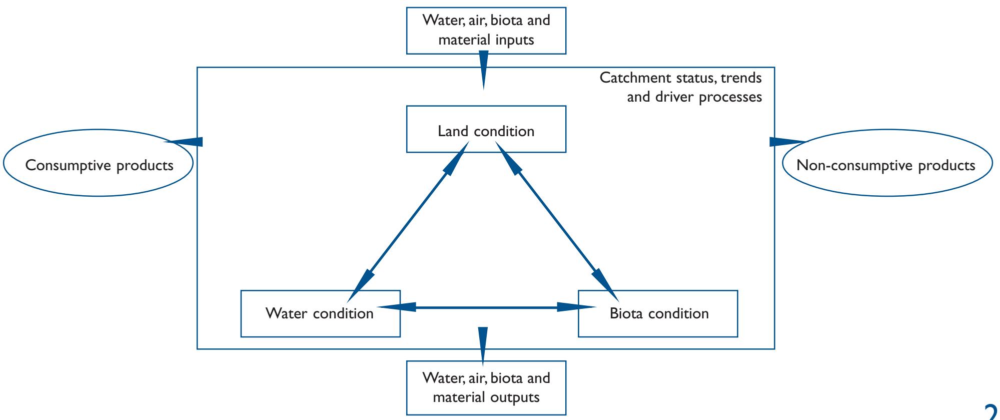


Figure 9. Model of catchment condition used to develop the assessment framework.



The city of Hobart at the bottom of the Derwent River catchment

Selection criteria (Table 4) were developed and applied to 110 biophysical attributes to screen for suitable indicators. Criteria incorporated:

- data quality;
- ease of interpretation;
- compilation scale;
- relevance to catchment function; and
- relevance to management.

Fourteen indicators were selected (Table 5) and used to calculate the composite catchment condition index and subindices. Calculations were done using a data compilation system (CatCon) based on the ASSESS decision support system (Veitch 1997). This system allows spatially referenced indicators to be viewed, weighted, reclassified and combined to form composite indices within a geographic information system.

Table 4. Catchment condition indicator selection criteria.

Rationale	
1.	Relevant to landscape function at the scale of intended use (e.g. large catchment) based on current knowledge/expert opinion
2.	Relevant to action planning, management, policies, and regulations
3.	Sensitive to system change
Data availability	
4.	Are the data available at the scale of intended use? (compilation scale)
5.	Cost limitations in acquiring and processing the data
Data quality	
6.	Are the methods of data collection and sources of error well documented?
7.	Is the variability in the data large enough to affect the interpretation of the attribute at the scale of intended use?
Meaning	
8.	Has the attribute been validated to have meaning relative to the assessment question being asked and the scale of intended use?
9.	Does the attribute indicate a response in condition relative to management action?
10.	Understood widely by users

A five-point condition scale from better to poorer was used to rank and map relative catchment condition. The result is colour-coded maps for:

- individual indicators;
- composite subindices for water, land and biota condition; and
- an overall composite catchment condition index.

The CatCon system allows patterns for classes of relative catchment condition to be defined. These patterns provide the basis for decision support on priorities and opportunities for protective catchment management or remedial action.

Comparisons of catchment condition were made across Australia. The method also has application to a smaller number of catchments to determine relative ranking within a State/Territory or a drainage division (e.g. catchments draining to the Great Barrier Reef or the Murray–Darling Basin).

Regional differences in catchment function: building a framework to set targets

Catchment management issues and biophysical responses to similar land uses vary regionally due to differences in climate, land forms, soil types and land use patterns. Social and economic aspirations will also affect regional priorities for catchment management.

Weightings for indicators can be assigned from zero upwards to facilitate this type of comparative assessment within a region. As more data sets become available, additional indicators can be included, enhancing the query functionality of the system and its regional applicability as a tool for catchment management target setting.

Table 5. Indicators used to define the water, land and biota subindices and the catchment condition index.

Indicators	Related catchment management issue
Water	
Suspended sediment load	Modelled post-settlement change in suspended sediment loads
Pesticide hazard	Pesticide use is a surrogate for pesticide pollution risk
Industrial point source hazard	Industrial pollution contamination risk
Nutrient point source hazard	Nutrient point source loading of waterways
Impoundment density	Ecosystem changes associated with altered flows
Land	
2050 high dryland salinity risk/hazard	Modelled risk assessment of salinity impacts
Soil degradation hazard	Soil and land use assessment of soil degradation risk
Hill slope erosion ratio	Modelled assessment of changes in hill slope erosion potential from natural conditions
Biota	
Native vegetation fragmentation	Deterioration in native habitat
Native vegetation extent	Habitat quantity and distribution
Protected areas	How much habitat is protected
Road density	Human population and land use intensity pressures
Feral animal density	Extent feral animals have impacted on native biota
Weed density	Extent of disturbance to native vegetation

The indicator approach (Figure 10, Table 6) for assessing catchment condition selects indicators either as specific or aggregated measures.

The approach recognises that broad-scale data sets are often more readily available and better depict regional pattern than fine-scale data. Broad-scale coverages are usually generalised from detailed data and so tend to highlight the predominant biophysical processes and characteristics that determine catchment condition. The major benefit of broad-scale data in decision-support systems is a clearer identification of key and dominant patterns than can be provided through aggregating a collection of discontinuous and inconsistent fine-scale data sets.

Indicator values were ranked into five classes reflecting values from poorer to better condition. Indicators or composite indices can either be ranked on equal intervals or equal areas under a frequency distribution curve (Figure 11). Indicators had extremely skewed distributions and an equal area ranking was found to be the most appropriate. Composite indices had distributions that approached a normal distribution and equal interval rankings were used.

Maps based on rankings are useful for comparing relative conditions, but do not convey actual values. The probability that an interpretation in relative terms will be meaningful increases at a national scale. Histograms showing the number of catchments versus indicator value are a useful tool for estimating the range of values associated with a particular group of catchments (Figure 12).

Figure 10. Process for selecting catchment condition assessment indicators.

Identify societal values

↓

Identify issues relative to each societal value

↓

Develop a set of assessment questions (endpoints) for all the issues

↓

Select a list of attributes that are thought to describe or measure the assessment question

↓

Evaluate the utility of each attribute by passing it through a set of technical criteria

↓

Select indicators for the assessment

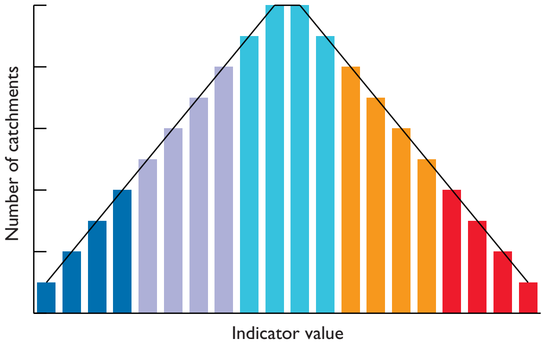
↓

Apply, interpret, communicate and initiate action

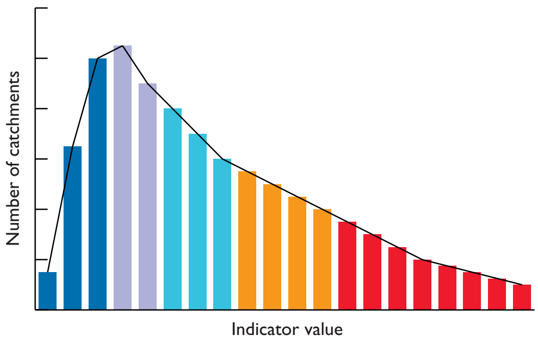
Table 6. Example of an application of the indicator selection process.

Societal value	Good land condition/sustainable landscapes
Issue	Loss of crop production due to salinisation
Assessment	What areas are at risk to future salinisation
Attribute	• Changes to watertable depth
	• Salt stores (hazard)
	• Mobilisation risk
	• Area of cleared land in salt affected areas
Criteria	Technical selection criteria (Table 4) test to reduce or remove poor measures
Indicator	Area of cleared land in salt affected areas

Figure 11. Classification approaches used for catchment condition indicator and index values.

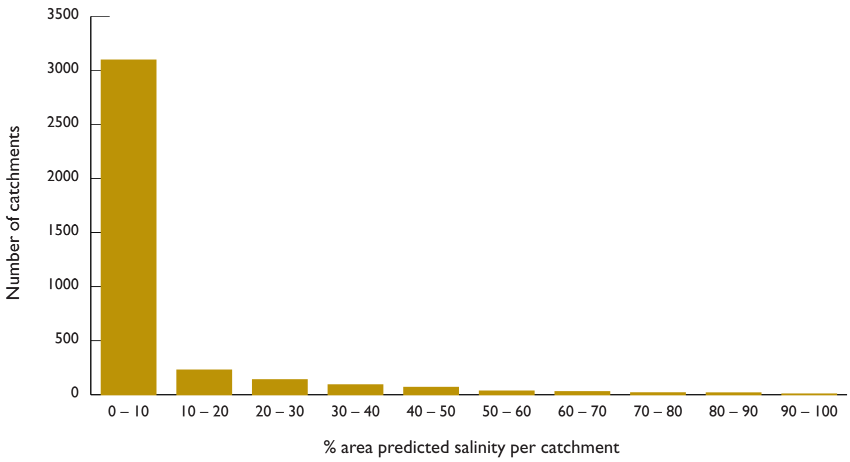


Equal interval classification used for normally distributed index values



Equal area classification used for indicator values with skewed distribution

Figure 12. Number of subcatchments with predicted extent high salinity risk/hazard.



VISUALISING CATCHMENTS

Catchments can be presented at a range of scales from subcatchment to total river basin. This assessment found that a catchment size of 500 km^2 provided sufficient detail to be useful at both the national scale and the catchment management scale. Other visualisations that were trialled included:

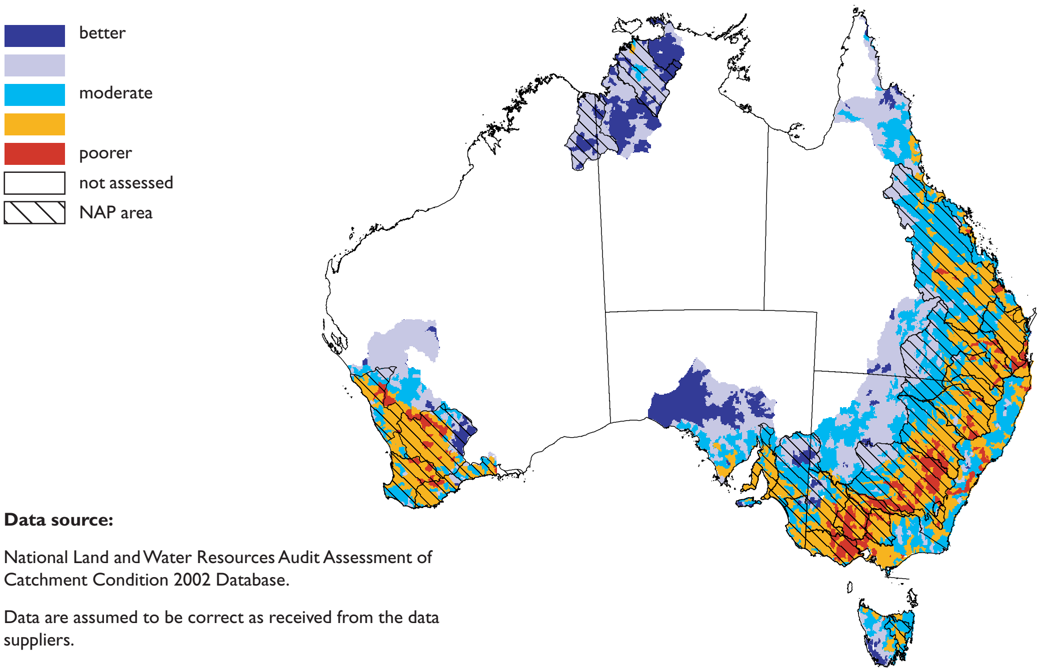
- a 5 x 5 km grid;
- State government-defined catchment management areas;
- Australian Water Resources Council river basins;
- bioregions (Interim Biological Regionalisation of Australia); and
- a combination of river basins and bioregions.

These gave different visualisations and were useful, depending on the purpose of the analysis.

For assessment reporting in this report each indicator and aggregate index output is presented at three scales:

- 5 x 5 km grid, taking data sets and creating values for each 5 x 5 km cell (115 226 in total);
- 500 km^2 catchments based on the Centre for Resource and Environmental Studies, Australian National University, 1:250 000 digital elevation model and creating values from the data for each 500 km^2 catchment (3718 in total); and
- Australian Water Resources Council river basins (197 in the assessment area).

Figure 13. Catchment condition and National Action Plan (NAP) for Salinity and Water Quality priority catchments.



Data source:

National Land and Water Resources Audit Assessment of Catchment Condition 2002 Database.

Data are assumed to be correct as received from the data suppliers.

ASSESSMENT LIMITATIONS

Integration across biophysical condition data only

- Productivity (e.g. agriculture, forestry, fish production), ecosystem services (e.g. quality of life, conservation, recreation) and social and economic factors were not included in the biophysical definition of catchment condition used for this assessment.

Circularity through linked data sets

- Some key data sets such as land use, soil distribution and vegetation used to derive catchment scale indicators are linked (e.g. most land uses require the clearing of native vegetation and occur on the better quality soils). False precision and bias due to the inter-correlation of variables used in deriving an index can occur.

Quality of available spatial data

- Only biophysical data that are readily available were used. These included satellite imagery, topographic and digital elevation model data, computed or derived indicators (e.g. erosion, soil wetness, salinity risk), data from the Audit, data from State and Territory governments, and existing geographic information system data in the national archive (e.g. vegetation, soils, geology). Data sets have differing levels of data quality. Care has been taken in the selection of data sets to avoid compounding of errors.

Time constraints

- Restricted Audit timelines meant that some Audit data sets were not available in time for incorporation (e.g. Australian Soil Resources Information System, soil acidity, river condition and estuary condition).

Thresholds of condition

- For all biophysical aspects of a catchment there will be a threshold of condition (e.g. induced soil acidity should not be allowed to go below pH of 4.8 as major changes to soil structure, condition and ability to support production occur at these low pH levels [NLWRA 2001b]). Likewise, if our goal is to maintain biodiversity, loss of species accelerates greatly when less than 30% of native vegetation remains (James & Saunders CSIRO 2001). Review of the five-class rating from *better* to *poorer* to incorporate thresholds is essential if we are to base our natural resource management on a target-based approach.

The poorest relative condition class catchments are in areas with intensive land use. They occur in cleared, agronomically marginal rainfall areas appearing as a crescent shape through inland Australia at the margins of the main cropping areas. These areas have soils of relatively poor fertility and structural properties. They are prone to soil structure decline, soil erosion and salinisation. They also have low flexibility in terms of land use options.

Other catchments in the relatively poor condition class have more reliable rainfall and greater land use flexibility. They have the potential for recovery given appropriate management.

Native vegetation changes and intensity of land use cause changes to the water cycle, soil chemistry and soil structure. They are the main drivers of catchment condition. Several indicators are highly representative of overall catchment biophysical condition and provide a minimum set for monitoring activities.

Values for key condition indicators, subindices and composites indices for river basins within the assessment areas are presented in Appendix 3.

Composite catchment condition assessment (14 indicators)

5 km x 5 km grid cell scale

When viewed at the 5 x 5 km grid cell resolution (Figure 14), the relative biophysical condition of catchments within the assessment area shows a clear pattern of clusters of the grid cells into larger patches.

The most coherent and solid patches with relatively poorer condition occur in:

- the wheat–sheep belt and coastal agricultural areas of Western Australia;
- cropping areas of South Australia;
- western and central Victoria;
- the western slopes and plains of New South Wales; and
- the north-east Murray–Darling Basin in southern Queensland.

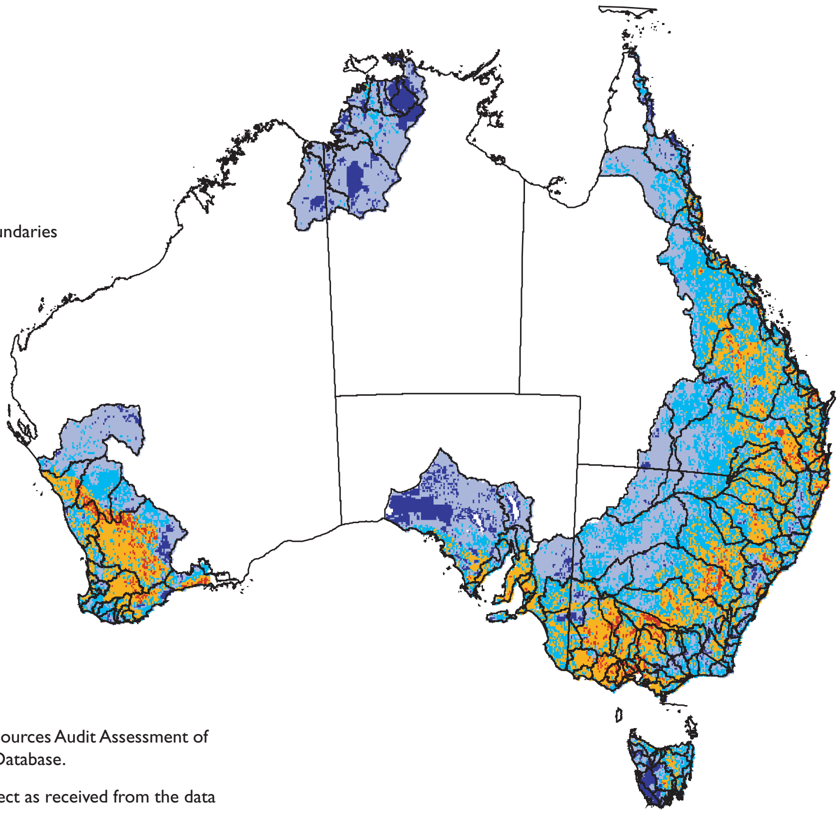
Disjunct areas of poorer catchment condition also occur in the larger inland-extending basins in central and south-eastern Queensland; and coastal floodplain areas of north, central and south-eastern Queensland and northern New South Wales. The more intensively developed central coastal basins of New South Wales also show poorer condition. In Tasmania the main patches of relatively poor condition match with the more intense cropping and grazing areas of the Tasmanian midlands.

The areas with relatively better condition correspond to conserved lands such as national parks, particularly in the non-tropical, higher rainfall areas. Other clusters of better condition are in the Northern Territory, Cape York and arid parts of western South Australia, corresponding with areas of lower land use intensity.

Figure 14. Catchment condition for 5 km x 5 km cells.

Relative condition

- better
- moderate
- poorer
- not assessed
- Basin and State boundaries



Data source:

National Land and Water Resources Audit Assessment of Catchment Condition 2002 Database.

Data are assumed to be correct as received from the data suppliers.

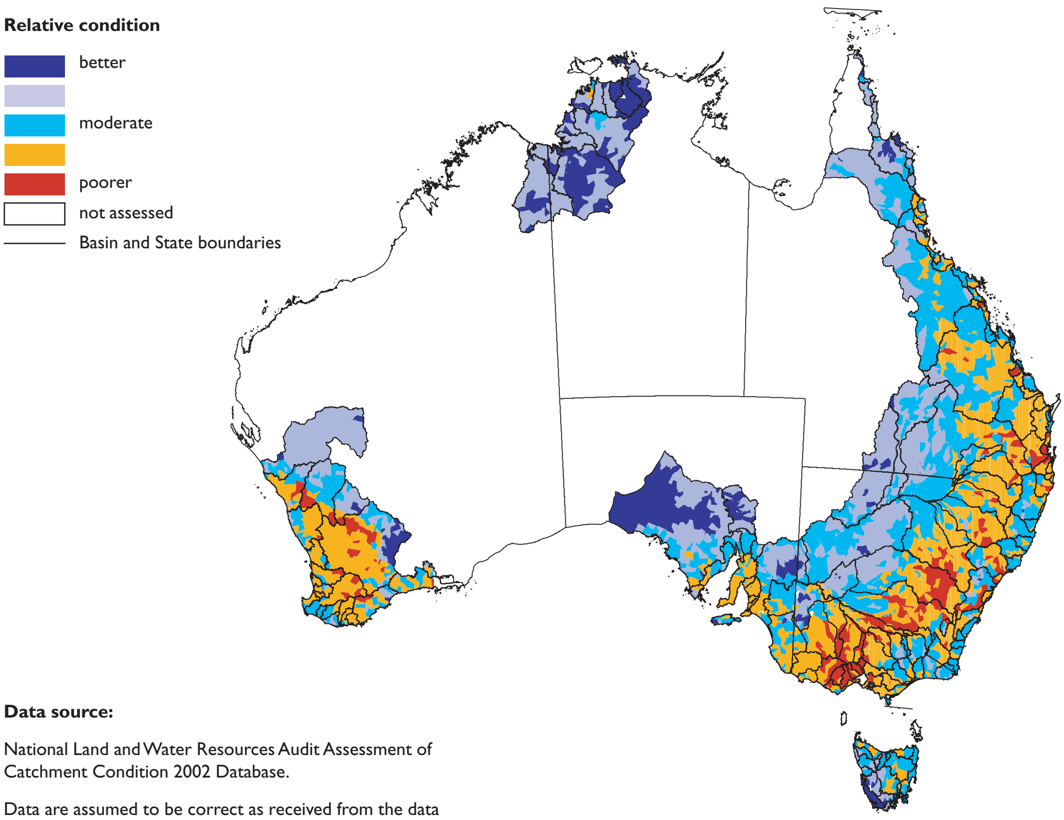
500 km² subcatchment scale

Aggregation to 500 km² subcatchment resolution shows a similar overall pattern (Figure 15) to the 5 x 5 km resolution but is limited in data variation spatially. There are large, coherent areas with relatively poorer conditions in the wheat and sheep zones of Western Australia, through western and central Victoria and west Gippsland, and onto the western slopes and plains of New South Wales.

In South Australia, Tasmania and Queensland the catchments in poorer condition appear confined and disjunct. In Queensland, these catchments in poorer condition include the upper reaches of the Condamine River in the Murray–Darling Basin, and the more intensively developed, larger river basins in central to south-east Queensland (Fitzroy, Burnett, Mary, Brisbane,) and smaller, coastal basins with developed, coastal floodplains.

Similar to the 5 x 5 km resolution, catchments in relatively good condition lie within the less intensively used parts of the assessment area. In the non-tropical higher rainfall zone, conserved lands have less influence and good condition areas are much more restricted. South-west Tasmania, north-eastern Victoria, the Blue Mountains National Park, parts of the upper Clarence River basin in New South Wales and the south-west of Western Australia are of relatively better catchment condition.

Figure 15. Catchment condition for 500 km² subcatchments.



Data source:

National Land and Water Resources Audit Assessment of Catchment Condition 2002 Database.

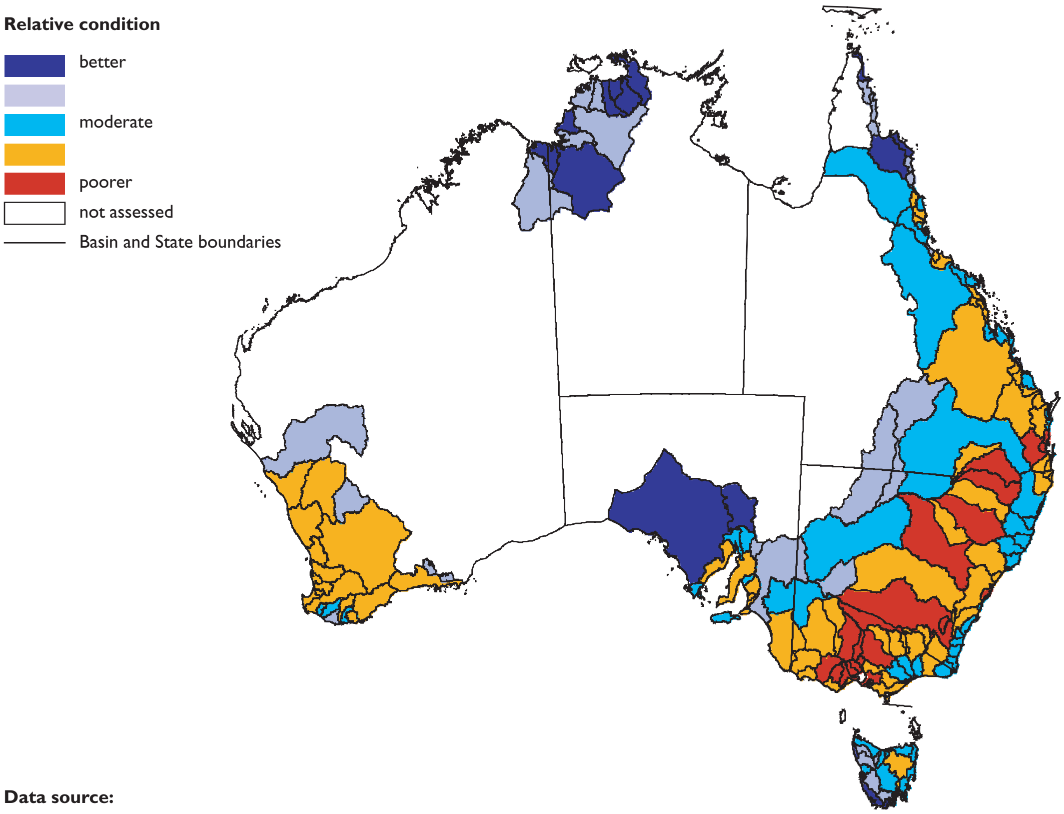
Data are assumed to be correct as received from the data suppliers.

River basin scale

At the coarse level of aggregation to river basin scale (Figure 16), the poorest condition catchments occur in the Murray–Darling drainage division in south-eastern Queensland, western New South Wales and central northern Victoria. They include the Border Rivers, Namoi, Macquarie–Bogan Murrumbidgee, Murray–Riverina, Goulburn, Campaspe and Loddon River basins. River basins in the more intensively developed south-east of Queensland (Brisbane, Pine, Maroochy), central New South Wales coast (Sydney Coast – Georges River, Wollongong Coast) and central to western Victoria (Bunyip, Maribyrnong, Werribee, Moorabool, Barwon, Lake Corangamite and Hopkins) also fall into the poorest catchment condition class.

River basins in better condition are confined to the less intensively developed parts of the assessment area including, Cape York, the Northern Territory, arid rangelands in South Australia, southern Western Australia and the south-west of Tasmania.

Figure 16. Catchment condition for river basins.



Data source:

National Land and Water Resources Audit Assessment of Catchment Condition 2002 Database.

Data are assumed to be correct as received from the data suppliers.

High intensity grazing of a tropical Queensland coastal floodplain

DEMONSTRATING APPLICATIONS OF THE TOOL

Catchment land condition assessment (3 indicators)

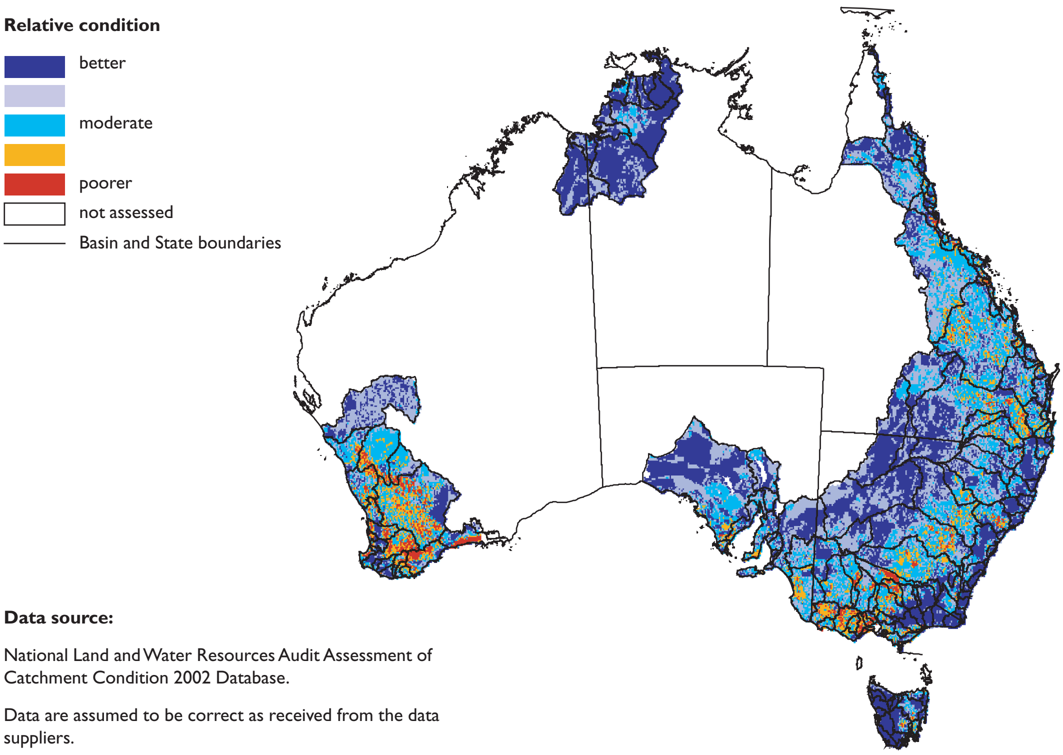
5 km x 5 km grid cell scale

At the 5 x 5 km grid cell resolution, the land index of relative biophysical condition within the assessment area indicates similar areas of poorer condition (Figure 17) to the 14 indicator representation, with areas of poorer condition more concentrated. Far less of the South Australian Gulf Drainage Division has the poorer condition categories, and larger parts of northern South Australia and the Darling River system in New South Wales indicate relatively better land condition.

Poorer condition areas are distributed between tropical and temperate Australia and highlight areas of higher land use intensity. These include:

- the sheep–wheat belt of south-west Western Australia;
- eastern South Australia;
- western and central Victoria;
- the Riverina;
- mid to upper areas of eastern basins within the Murray–Darling Basin;
- the Hunter River basin in central coastal New South Wales; and
- grazing and cropping basins with coastal floodplains in tropical Queensland.

Figure 17. Land condition subindex for 5 km x 5 km cells



Data source:

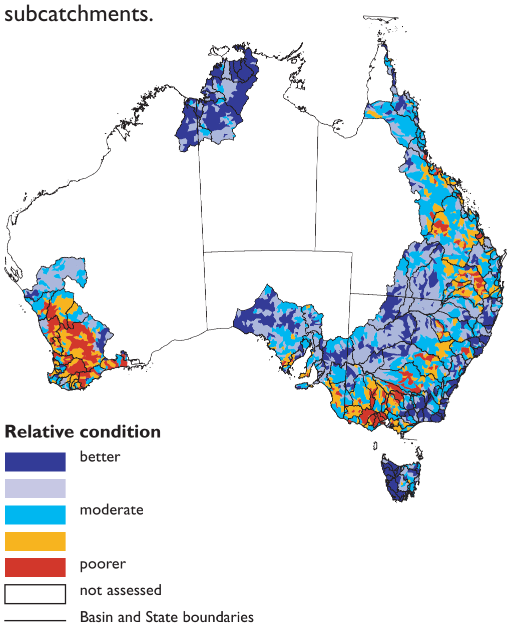
National Land and Water Resources Audit Assessment of Catchment Condition 2002 Database.

Data are assumed to be correct as received from the data suppliers.

500 km^2 subcatchment scale

The general pattern of land condition is amplified at the 500 km^2 catchment level (Figure 18). Large parts of western New South Wales and northern South Australia are shown with relatively better land condition.

Figure 18. Land condition subindex for 500 km^2 subcatchments.



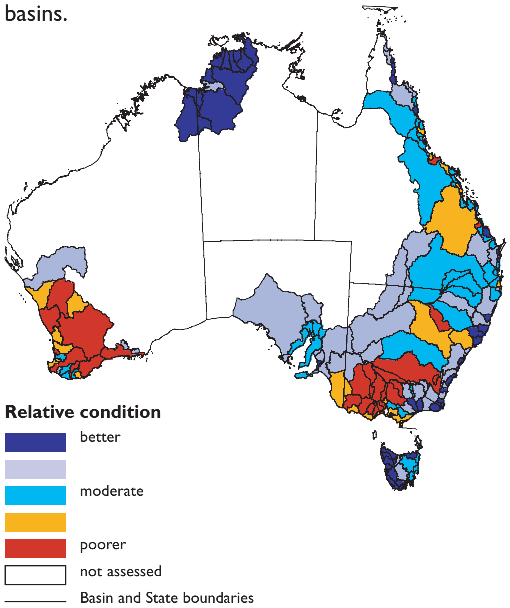
River basin scale

At the basin level of aggregation, the land condition index shows most of Western Australia, south-east Murray-Darling Drainage Division and western Victorian river basins with the relatively poorer condition class (Figure 19). Outside these clusters the Castlereagh River in the eastern Murray-Darling Drainage Division and tropical Queensland coastal river basins (Calliope and Haughton) are also rated in the poorer condition class by the land index.

River basins with better land condition include those with significant areas used for nature conservation or forestry:

- south-west Tasmania;
- north-eastern Victoria;
- coastal New South Wales; and
- areas with relatively limited development such as the Northern Territory.

Figure 19. Land condition subindex for river basins.



Increased turbidity is a major water quality issue for most of eastern Australia

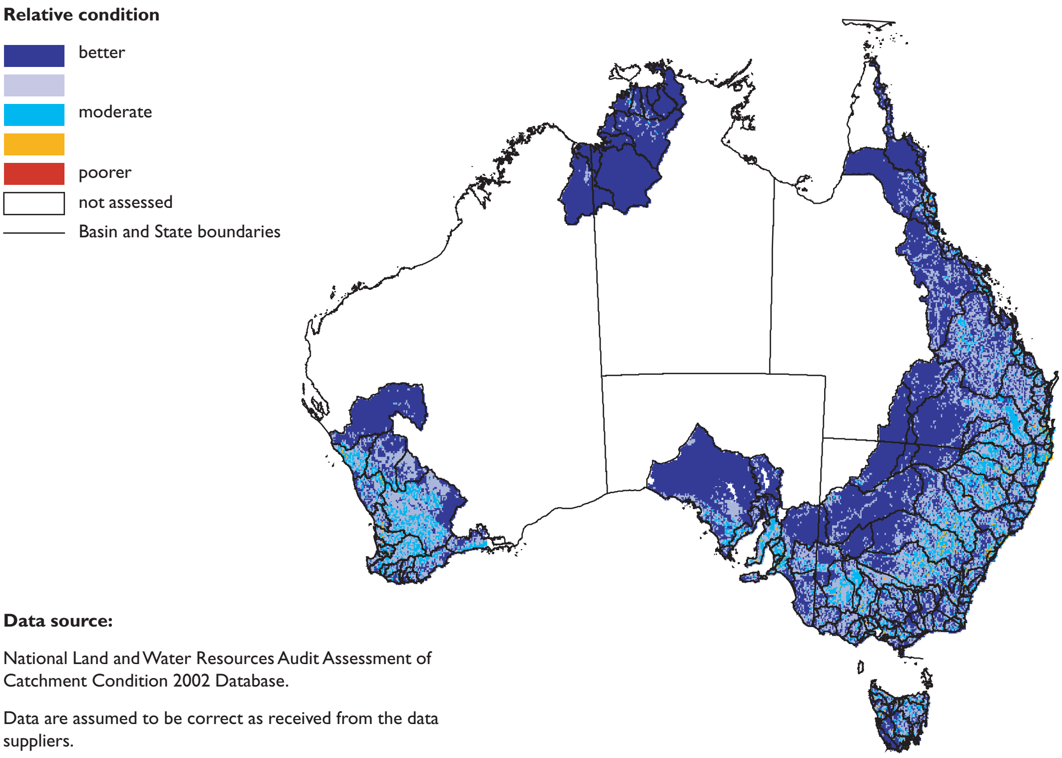
Catchment water condition assessment (5 indicators)

5 km x 5 km grid cell scale

At the 5 x 5 km grid cell resolution, the water index of relative biophysical condition shows a similar distribution to the 14-indicator representation (Figure 20), except that the most extensive areas of poorer condition are only mid range in the relative condition scale. This indicates that small numbers of extreme outlier grid cells containing poorer condition have skewed the equal interval classification. Cells containing the poorest water condition are almost indiscernible and are located within river basins in areas with intensive land use patterns (irrigated agriculture, built environment) and high population density, demonstrating the relevance of the indicators used to the condition pressures associated with these areas. Areas with the poorest values include:

- south-east Queensland;
- northern and central New South Wales coast;
- mid-Lachlan and Macquarie River basins;
- central southern Victoria, Torrens and Onkaparinga River basins in South Australia; and
- Swan Coast basin in Western Australia.

Figure 20. Water condition subindex for 5 km x 5 km cells.



Data source:

National Land and Water Resources Audit Assessment of Catchment Condition 2002 Database.

Data are assumed to be correct as received from the data suppliers.

500 km² subcatchment scale

Aggregation to the 500 km² subcatchments expands and highlights (Figure 21) the areas with relatively poorer water condition identified at the finer resolution. The major concentration of poorer water condition coincides with catchments containing built environments, intensive and often high pesticide-using land uses and impounded rivers. Areas identified include:

- western basins in southern Western Australia;
- Fleurieu Peninsula to Gawler River basin in South Australia;
- central southern Victorian river basins;
- north-west Tasmania;
- most of the eastern half of the Murray–Darling Basin in New South Wales
- central New South Wales coast;
- northern New South Wales to south-east Queensland; and
- coastal tropical Queensland basins.

In contrast, the western half of the Murray–Darling Basin, and the less intensively used Northern Territory and rangeland areas, display relatively good condition.

River basin scale

At the river basin scale, the water index reveals that the poorest water condition (Figure 22) in basins occurs in:

- south-east Queensland;
- far northern New South Wales, central New South Wales coast;
- eastern Murray–Darling;
- Victorian river basins draining to Port Phillip Bay;
- basins of the Adelaide hinterland; and
- basins within Tasmania's north west and midlands.

Figure 21. Water condition subindex for 500 km² subcatchments.

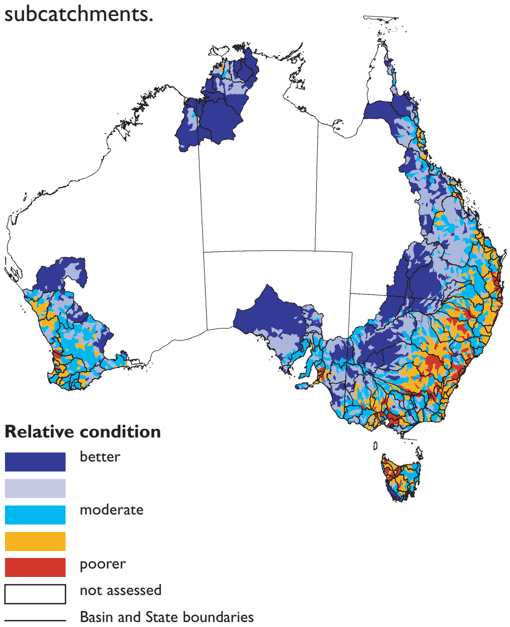
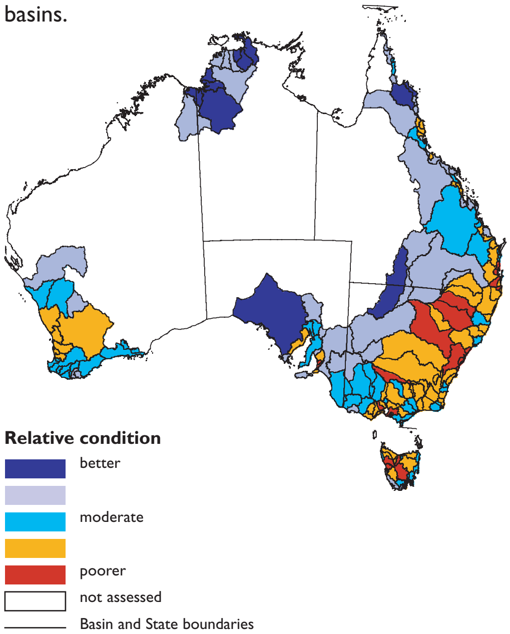


Figure 22. Water condition subindex for river basins.



Native vegetation extent and fragmentation are indicators of catchment biota condition

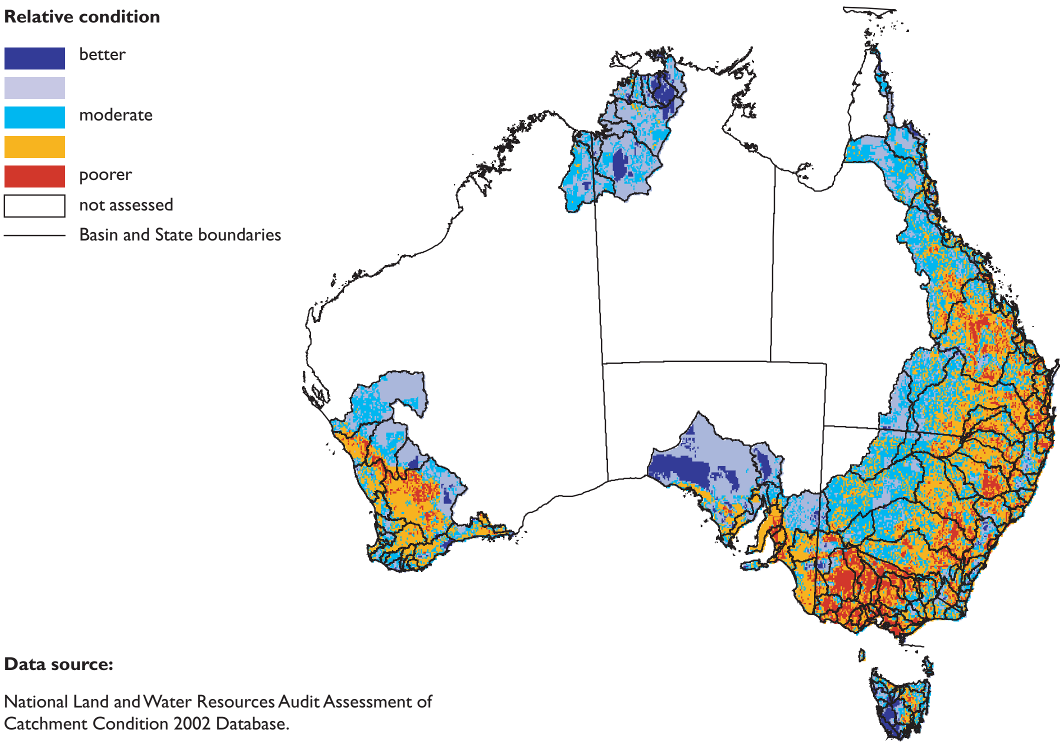
Catchment biota condition assessment (6 indicators)

5 km x 5 km grid cell scale

Of the three indices the biota index displays the broadest and most diffuse pattern of relative condition, especially with respect to areas with moderate to poorer condition (Figure 23). Areas with relatively good condition are confined to:

- a narrow strip of the eastern ranges;
- south-west Tasmania; and
- the less intensively used Northern Territory, Cape York and inland areas.

Figure 23. Biota condition subindex for 5 km x 5 km cells.



Data source:

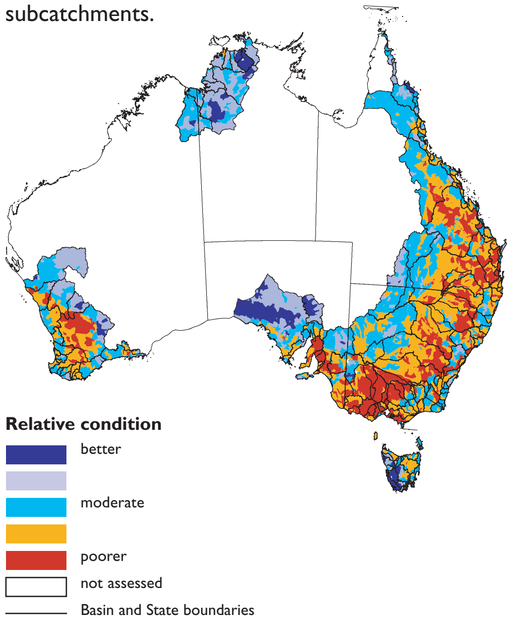
National Land and Water Resources Audit Assessment of Catchment Condition 2002 Database.

Data are assumed to be correct as received from the data suppliers.

500 km² subcatchment scale

The pattern of relative condition remains similar (Figure 24) to that of the 5 x 5 km grid cell, suggesting that the more diffuse spread in the range of condition persists with aggregation to larger areas.

Figure 24. Biota condition subindex for 500 km² subcatchments.

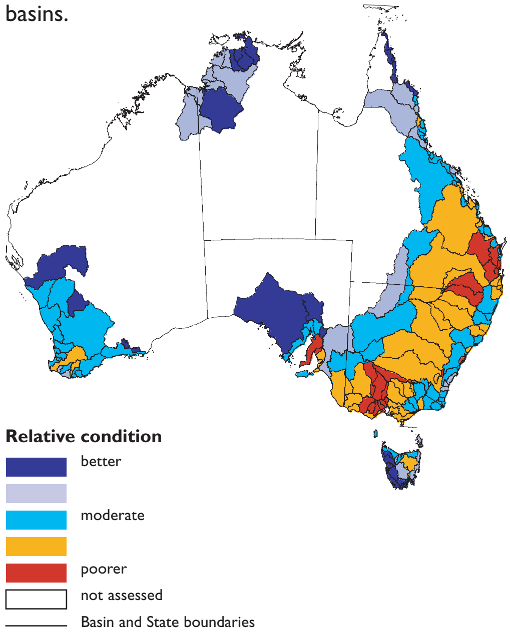


River basin scale

At the coarse resolution of the basin (Figure 25) the spread and disaggregation of condition assignment is removed showing the relatively poorer biotic condition through most of the Murray–Darling Basin, the Yorke Peninsula in South Australia, and central southern to western Victoria.

Catchments in south-west Tasmania, the Northern Territory and Cape York have relatively good biotic condition.

Figure 25. Biota condition subindex for river basins.



Dryland salinity risk/hazard is a very strong indicator of catchment condition

IDENTIFYING KEY CONDITION ASSESSMENT INDICATORS

Composite indices provide a relative assessment of catchment condition. They help to define priority catchments in need of concerted management effort through either protective management or rehabilitation.

Analysis of individual indicator patterns provides a way to examine the relative importance of biophysical attributes or processes contributing to the condition of a specific catchment. Assessments using individual indicators assist in defining the priority management needs within a specific catchment.

Assessing how well individual indicators reflect composite patterns of catchment condition also provides a way to identify minimum indicator sets—essential for cost-effective investment in data collection (Table 7). Example outputs of the better performing individual indicators for the land, water and biota components are presented in Figures 26–28.

Table 7. Relative performance of indicators used to define composite catchment condition.

Indicators in order of performance for depicting areas of poorer catchment condition	Indicators in order of performance for depicting areas of better catchment condition
Native vegetation extent	2050 high dryland salinity risk/hazard
Native vegetation fragmentation	Nutrient point source hazard
Protected areas	Impoundment density
Road density	Pesticide hazard
Pesticide hazard	Native vegetation extent
Sediment load	Native vegetation fragmentation
Univeral Soil Loss Equation erosion ratio	Industrial point source hazard
Soil degradation hazard	Road density
2050 high dryland salinity risk/hazard	Sediment load
Industrial point source hazard	Weed density
Weeds	Univeral Soil Loss Equation erosion ratio
Feral animals	Soil degradation hazard
Impoundment density	Feral animals
Nutrient point source hazard	Protected areas

Figure 26. Native vegetation extent for 500 km² subcatchments.

Relative condition

- better
-
- moderate
-
- poorer
- not assessed
- Basin and State boundaries

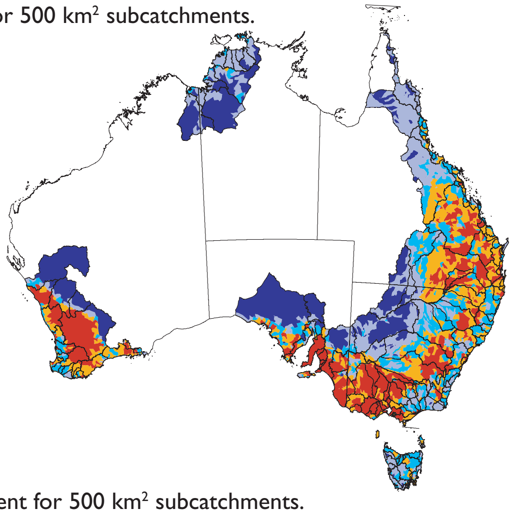


Figure 27. Predicted 2050 salinity extent for 500 km² subcatchments.

Relative condition

- better
-
- moderate
-
- poorer
- not assessed
- Basin and State boundaries

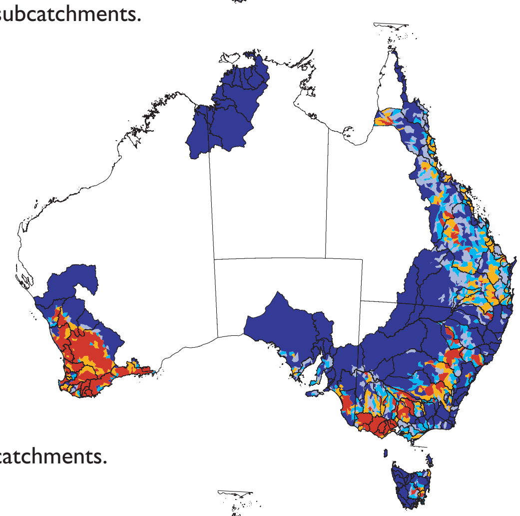
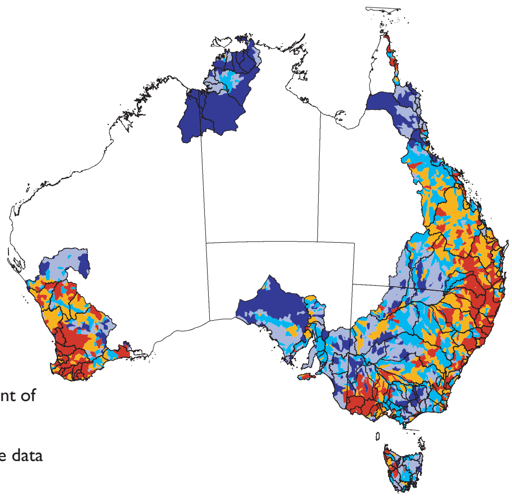


Figure 28. Suspended sediment loads for 500 km² subcatchments.

Relative condition

- better
-
- moderate
-
- poorer
- not assessed
- Basin and State boundaries



Data source:

National Land and Water Resources Audit Assessment of Catchment Condition 2002 Database.

Data are assumed to be correct as received from the data suppliers.

INFORMING TARGET AND PRIORITY SETTING THROUGH COMPARISONS IN CONDITION

As demonstrated by the various views of the same data sets in Figures 14–25, the patterns of catchment condition vary according to the scale of the assessment framework. Larger comparative frameworks such as entire river basins 'smooth over' the heterogeneity of finer scale patterns of catchment condition such as displayed in the 5 x 5 km grid.

Target setting occurs at two levels:

- Australia-wide to determine broad priorities for protective management and remedial works; and
- within a catchment or region for the allocation of resources.

Using river basins as the basis for comparison and for setting Australia-wide or State/Territory target and priorities appears appropriate. Comparisons between entire river basins also inform links between catchment condition and downstream resources (water quality or estuary condition), where the total catchment acts as an integrator for downstream condition.

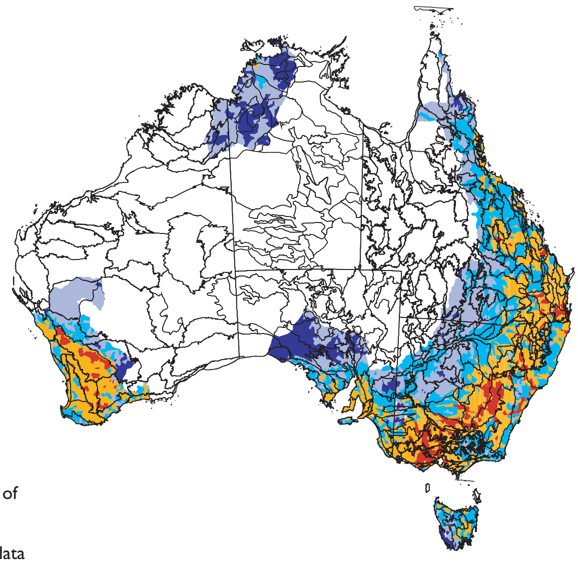
A finer scale assessment framework is required to identify priorities for catchment management within a specific catchment or region and define localised areas of better or poorer condition. The 500 km^2 subcatchments and the 5 x 5 km comparisons used in this project appear most appropriate for these applications.

The application of landscape regionalisations for catchment condition assessment was examined by overlaying subregions (see Appendix 2) on an assessment of catchment condition using the 500 km^2 subcatchment framework (Figure 29). The underlying patterns of catchment condition are reflected by subregion boundaries indicating the landscape controls on many of the drivers (e.g. soil type, topography, land use) of catchment condition. Based on this initial examination, the use of landscape units as the basis for comparison is another useful way to analyse the data sets.

Figure 29. Catchment condition assessment and subregion boundaries (Interim Biogeographic Regionalisation of Australia Version 5.1).

Relative condition

- better
- moderate
- poorer
- not assessed
- IBRA regions and State boundaries



Data source:

National Land and Water Resources Audit Assessment of Catchment Condition 2002 Database.

Data are assumed to be correct as received from the data suppliers.

NARROWING THE WINDOW OF COMPARISON

State/Territory case study

One of the main limitations of the method used by the catchment condition assessment is that the condition assessments are relative. This relativity is Australia wide and is not set in the context of any performance thresholds. Australia is yet to develop and agree to performance thresholds for catchment condition.

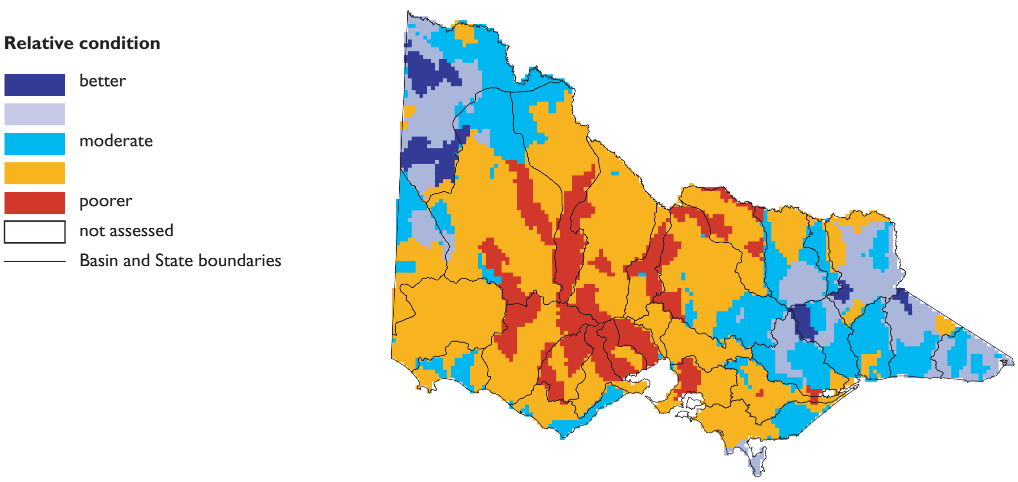
To address this limitation, the window of analysis can be narrowed to a specific region or State/Territory. This reduces both:

- the range of variability in compared biophysical settings; and
- the probability that the distribution of condition values will be skewed by patterns external to the area of interest.

The CatCon catchment condition analysis system can readily adjust the window of analysis used for calculating the relative assessments of catchment condition. An example output of the composite catchment condition index for Victoria is shown in Figure 30.

Narrowing the window of analysis also provides the opportunity to overcome another limitation of the assessment method—the use of finer-scale data sets that might only be available for one region or State. Finer scale data can be loaded into the CatCon system and used to provide analyses that better serve specific catchment management needs.

Figure 30. Catchment condition for 500 km^2 subcatchments in Victoria.



Data source:

National Land and Water Resources Audit Assessment of Catchment Condition 2002 Database.

Data are assumed to be correct as received from the data suppliers.

MAKING CROSS COMPARISONS: example of agricultural flexibility

Social values and economic goals have a major influence on the management of natural resources and thus the condition of catchments.

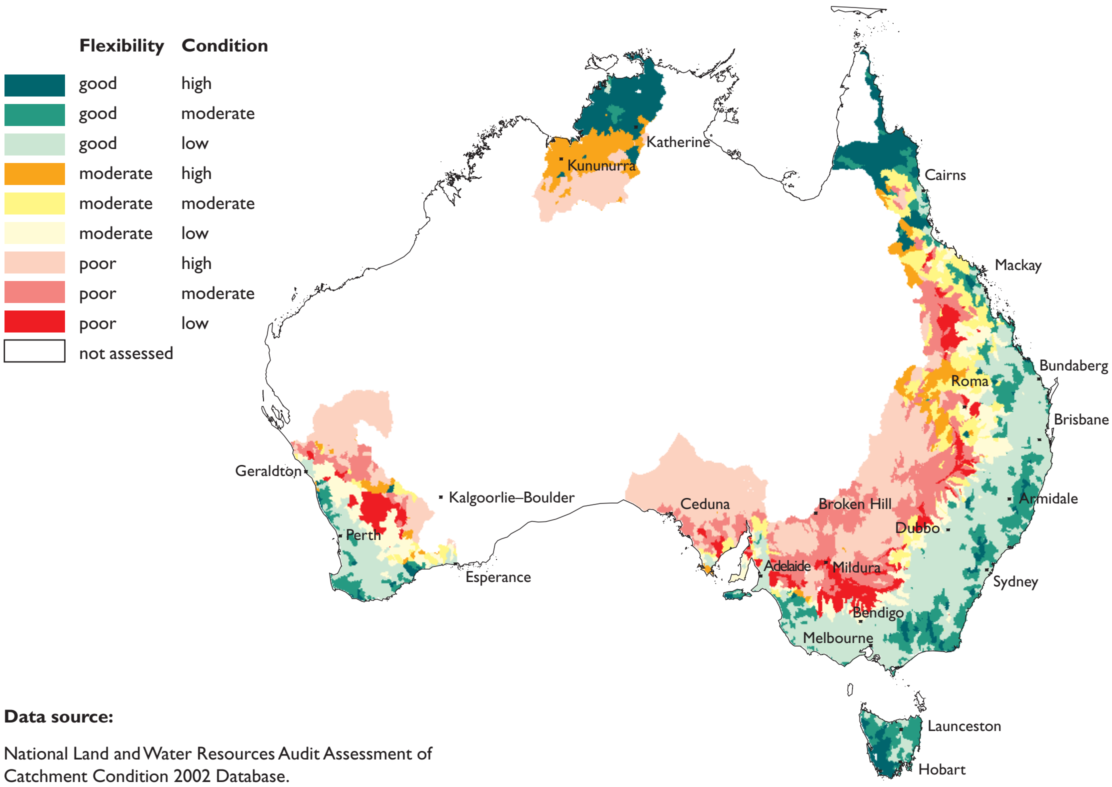
Being able to cross-compare patterns of biophysical catchment condition with socioeconomic factors provides insights on sustainability, development suitability and capacity for particular management scenarios.

Figure 31 presents an example cross-comparison between catchment condition and agri-business flexibility, defined on the basis of biophysical factors associated with soil capability and rainfall.

The cross-comparison suggests that a proportion of moderate to poorer condition catchments (15–25%) have low flexibility in terms of options for agri-business enterprises. These catchments are in the cleared, agronomically marginal rainfall areas. They appear as a crescent shape through inland Australia at the margins of cropping.

Other catchments in relatively poor biophysical condition but with more reliable rainfall and greater land use flexibility have greater opportunity for recovery.

Figure 31. Cross comparison of catchment condition and agricultural flexibility.



Data source:

National Land and Water Resources Audit Assessment of Catchment Condition 2002 Database.

Data are assumed to be correct as received from the data suppliers.

Monitoring of catchment condition at an Australia-wide scale involves collecting a minimum data set that describes:

- water behaviour in the landscape;
- land cover;
- land use practice; and
- natural ecosystems.

It will also take account of social and economic conditions and aspirations.

Key areas for improvement

Refinement of methods

- Include spatially referenced, land-use practice data to better interpret land use impacts
- Develop regionally based, environmental performance thresholds and indicators as the basis for improved comparative assessments
- Incorporate other functional landscape units such as bioregions or land systems into the assessment framework
- Design decision support tools for evaluating options for land use change and improvement in land use practices as an input into priority setting at the catchment or regional scale

Data sets

- Make all of the Audit's Australia-wide data sets available for use in the catchment condition assessment
- Make other data sets (e.g. climate variability, digital elevation models, salinity hazard, soil condition, floodplains and wetlands) available
- Include social and economic data relevant to natural resource management to enable comparison of biophysical condition with social and economic opportunities

Improve relevance to regional catchment management clients

- Develop minimum and agreed indicator sets, reference condition(s) and threshold values that quantify biophysical catchment condition
- Maintain an inventory and quantitative definitions of the catchment management issues across Australia
- Establish agreed regional and catchment management boundaries as a basis for setting priorities, monitoring activities and reporting progress

Improved scenario development

- Link social and economic options with biophysical condition to test the likely outcomes of various management actions
- Identify and apply different value sets for defining catchment condition so that regional groups can select those most appropriate to their community goals and expectations

MANAGEMENT ARRANGEMENTS AND POLICIES

The following section is a summary of catchment management arrangements and policies by State and Territory.

Australian Capital Territory

The Australian Capital Territory defines integrated catchment management as:

> *An approach to planning and natural resource management based on ecological, social and ecological considerations.*

The Australian Capital Territory government is planning and implementing an integrated catchment management framework guided by:

- the *ACT Decade of Landcare Plan* (1991) which recognises that a greater emphasis on integrated catchment management is required and
- the *Territory Plan* (1993) which states that *planning for land and water resources will be integrated, based on total catchment management principles*.

Although no legislation completely covers integrated catchment management, it is partly covered by the *Environment Protection Act 1997* (ACT), the *Water Resources Act 1988* (ACT) and the *Nature Conservation Act 1980* (ACT), and to a lesser extent, some of the 72 Acts administered by the Australian Capital Territory Department of Urban Services.

New South Wales

Principal agency: Department of Land and Water Conservation

Total catchment management is defined as:

> *The coordinated and sustainable use and management of land, water, vegetation and other natural resources on a water catchment basis so as to balance resource use and conservation.*

Total catchment management began in 1984, and was formalised with the introduction of the *Catchment Management Act 1989* (NSW). There are three levels of management organisation:

- State Catchment Management Coordinating Committee—includes representatives of State and local governments, and relevant community and interest groups.
- Sydney Catchment Authority—responsible for managing Sydney's catchments, dams, transfer pipes and other infrastructure and supplies water to 4 million people in Sydney, the Blue Mountains and some parts of the Southern Highlands.
- Catchment Management Boards—eighteen catchment management boards replaced a large number of catchment management committees.

Responsibilities for catchment management are allocated under several of the 52 Acts administrated by the Department of Land and Water Conservation.

Northern Territory

The Northern Territory supports integrated catchment management and is developing a framework. This is primarily the responsibility of Department of Lands Planning and Environment, but is also affected by legislation administered through the Department of Primary Industries and Fisheries, and the Parks and Wildlife Commission of the Northern Territory. These departments administer 83 pieces of legislation, many of which impact on catchment management. Important Acts include the *Water Act 1992* (NT) and the *Fisheries Act 1999* (NT).

Queensland

The Department of Natural Resources and Mines coordinates a community-based, integrated catchment management approach introduced in 1991. Catchment committees were established to take an integrated approach to water, soil and vegetation resources within specific river catchments.

Queensland has more than 30 catchment management and 163 regional strategy groups.

The Queensland Murray-Darling Association was formed when Queensland entered the Murray-Darling Basin Initiative in 1992. It is the coordinating body for catchment management in Queensland's part of the Murray–Darling Basin.

Queensland has no direct legislative base for the integrated catchment management framework. The government is investigating the possibility of statutory support for catchment management. However, catchment management can be indirectly affected by a number of the 19 Acts administered by the Department of Natural Resources and Mines.

South Australia

Principal agency: Department of Water Resources

Catchment management falls directly under most of the ten Acts administered by the Department of Water Resources and is also affected by many of the Acts administrated by the Department of Environment and Heritage.

Catchment management is defined as:

> *The management of water resources in an integrated way to achieve economic, environmental and social goals.*

Catchment management is primarily undertaken in accordance with arrangements set up under the *Water Resources Act 1997* (SA). The Act defines four major areas of catchment management planning:

- the *State Water Plan*—outlines the policy framework for water resources management and use throughout the state. It provides information on the condition and use of water resources;
- catchment water management plans—undertaken by catchment water management boards;
- water allocation plans and trading rights—implemented to establish a system for the use and management of water resources; and
- local water management plans—carried out by local councils for water resources in their area.

Tasmania

The non-statutory Land and Water Management Council was formed in 1994.

Integrated catchment management is defined as:

> *The coordinated and sustainable use and management of land, water, vegetation and other natural resources on a regional water catchment basis so as to balance resource utilisation and conservation*

The Department of Primary Industries, Water and the Environment has designated 48 catchments for the State. Natural resource management processes are under way in 27 of these catchments.

The government is currently developing a State policy on integrated catchment management and implementing catchment management concepts through many of the 95 Acts administered by the Department of Primary Industries, Water and the Environment.

Victoria

The Department of Natural Resources and Environment is responsible for administering 103 Acts, many of which relate to integrated catchment management. The primary goal of integrated catchment management is stated as:

> *... to ensure the sustainable development of natural resource-based industries, the protection of land and water resources and the conservation of natural and cultural heritage.*

Principal legislation is the *Catchment and Land Protection Act 1994* (Vic). The Victorian Catchment Management Council provides advice to Government on natural resource management issues. Nine regional catchment management authorities and the Metropolitan Catchment and Land Protection Board have been created under this Act. Their key role is to coordinate regional catchment strategies.

Western Australia

Integrated catchment management is defined as:

> *The coordinated planning, use and management of water, land, vegetation and other natural resources on a river or groundwater catchment basis.*

The aim of integrated catchment management is to bring all stakeholders together to form a plan of action that addresses social, economic and ecological concerns within a catchment.

No legislation or single group provides a total framework and government agencies responsible for catchment management include:

- Water and Rivers Commission;
- Department of Environmental Protection;
- Department of Conservation and Land Management;
- Department of Agriculture;
- Office of Water Regulation; and
- Water Corporation.

These agencies are responsible for 77 Acts, which have direct and indirect effects on catchment management.

Table 8 summarises catchment management areas in each of the States and Territories.

Table 8. Catchment management areas for each State and Territory.

	Catchment management areas (CMAs)	Number of CMAs	1 coordinator per
Australian Capital Territory	Subcatchments defined within the Murrumbidgee River Basin	2	Territory
New South Wales	Catchment Management Board areas	22	Catchment Management Authority
Northern Territory	Australian Water Resources Council basins	2	Territory
Queensland	Australian Water Resources Council basins grouped or divided by Catchment Management Strategy regions	47	Catchment Management Strategy regions
South Australia	Australian Water Resources Council basins grouped by Catchment Water Management Board areas	26	mixed
Tasmania	Department of Primary Industries and Environment catchments (ex HEC data)	4	State
Victoria	Catchment Management Authority areas	10	Catchment Management Authority
Western Australia	Australian Water Resources Council basins grouped by NRM regions	9	region

RIVERS

SUMMARY

A key public resource

Australia's rivers have been significantly altered by land use—including agriculture, urban development and water resource development. Without informed and strategic management, the condition of Australia's rivers will continue to deteriorate. For the more intensively used Australian catchments:

- 33% of river length has *impaired* aquatic biota, with almost 25% having lost between 20% and 50% of aquatic macro-invertebrate groups
- Over 85% of river length is classified as *significantly modified* in terms of environmental features—New South Wales, South Australia and Western Australia have the greatest amounts of modified river length (97%, 96% and 93% respectively) and the Northern Territory has the smallest amount (34%)
- Over 80% of river length is affected by *catchment disturbance* with land uses affecting delivery of sediment, nutrients and water—reaches in Tasmania and the Northern Territory are the least affected by catchment disturbance
- Hydrologic change could be assessed in only 25% of river length because of limited data to support assessment of change of hydrology from natural flows—flow regimes are *largely unmodified* in approximately 20% of the regulated river length assessed (11% of river length is regulated)
- more than 50% of river length has *modified habitat*, mainly linked to changes in sediment loads that can alter channel morphology
- nutrients (mainly phosphorus) and suspended sediment loads are higher than natural loads in more than 90% of river length; 33% of river length is classified as *substantially modified* with respect to nutrients and sediments for mainland Australia

R I V E R S

SUMMARY

Management priorities

- *Largely unmodified* rivers—occurring especially in far north Queensland, in eastern Victoria and Tasmania—require protective management to ensure their condition is maintained
- Rivers with the most urgent need for rehabilitation and strategic management—located in parts of the Murray–Darling Basin, the Western Australian wheatbelt, western Victoria, and the South Australian wheat-growing areas—generally have *highly modified* catchments, are subject to high nutrient and suspended sediment loads, have lost much of their riparian vegetation, and have dams and levees that disrupt the movement of biota and material into, along and from the river
- Most river reaches in Queensland and northern coastal New South Wales, western Victoria and south-west Western Australia have *largely unmodified* habitat but very high nutrient and suspended sediment loads, and erosion from hill slopes and stream banks is high—control of nutrient and suspended sediment loads and revegetation of stream banks is essential for rehabilitation of these streams
- River reaches in central Tasmania, central Victoria, New South Wales and Northern Territory with habitat *severely modified* by from dams need protection and restoration of environmental flows and fish passage
- Clearer delineation of institutional and agency responsibilities for river management at State and Commonwealth levels is needed

Building better assessments

- Implementation of a standardised approach to data collection and data management, leading to cost-effective, Australia-wide collation, analysis and reporting, and including:
    - collection of finer-scale, management-relevant data on riparian vegetation
    - use of more representative and responsive indicators of biota condition, especially fish populations
    - use of an agreed set of river reaches as a basis for monitoring and reporting
    - development of methods for assessing riverine habitat
    - understanding the different river processes across Australia and refinement of monitoring measures for these different river types
    - information on changes in river hydrology, especially natural and current flow regimes

INTRODUCTION AND OBJECTIVES

Australia's rivers have changed noticeably since European settlement, particularly in areas where human land use dominates the natural environment. The Audit river assessment aimed to:

- report on river condition for key river basins across Australia;
- assess aggregate impacts of land use; and
- identify priority management challenges.

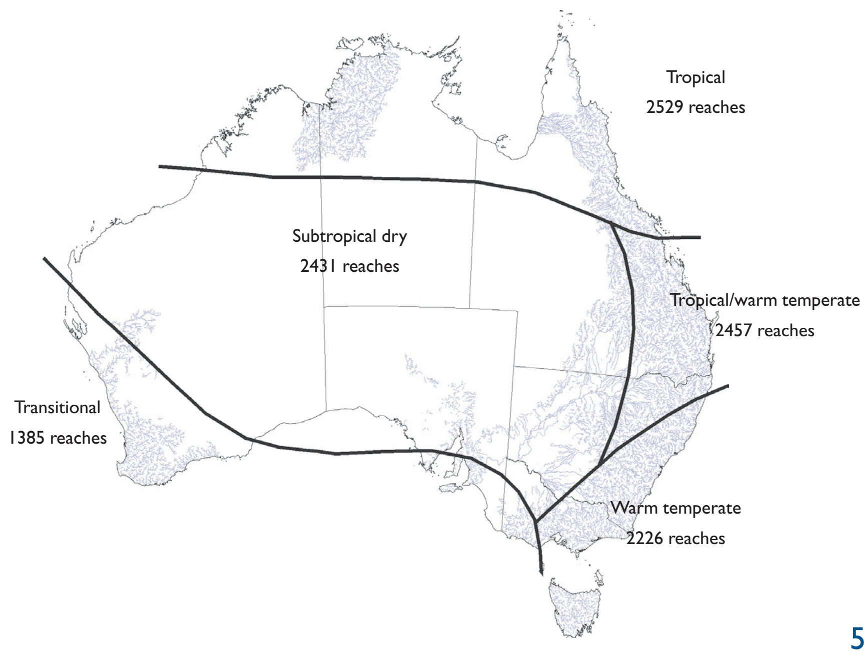
It is recognised that the river assessment is one of many inputs for identifying priority management challenges. Other information (e.g. social and economic factors) should be used in conjunction with the biophysical condition assessment.

Australia's rivers

Australia is the driest inhabited continent, with only 12% of run-off collecting in rivers. Rainfall is distributed unevenly across the continent, so that river flows are nearly three times more variable than the world average (Boulton & Brock 1999, NLWRA 2001f). Characteristics of Australian rivers vary widely with differing climates (Figure 32):

- in northern Australia, monsoonal rains are common during the wet season; almost 50% of Australia's average annual run-off is from the Timor Sea and Gulf of Carpentaria drainage divisions (Boulton & Brock 1999, NLWRA 2001f);
- tropical cyclones may occasionally dump heavy rain in the arid interior causing spectacular flooding;
- in south-eastern Australia, rainfall is more evenly distributed and the climate is temperate.

Figure 32. Climate zones in Australia relevant to river condition (from Lake 1995).



Australia has perennial, intermittent and episodic rivers, fed by groundwater sources and surface rainfall (see *measuring river flows* box, p. 59). Intermittently flowing streams are common in semi-arid and arid Australia where water may be lost from the river to the watertable below the channel (Lake 1995).

Rivers are made of a wide range of environments, including various kinds of channel, riparian lands and floodplains, and their associated lakes and wetlands. These differing environments are sometimes found within a single basin. Connections between riverine components need to be maintained in healthy rivers, to maintain supply of energy, nutrients and habitat resources to the river channel.

Hynes (1975) suggested a way of bringing order into the complexity of interacting components that can influence river condition: *in every respect the valley rules the stream*. Hynes demonstrated that catchment geology, soil types and human activities in a catchment profoundly influence the physical and chemical characteristics of rivers flowing through that catchment. These characteristics in turn mainly determine the biological components and processes that occur in a river. The Audit assessment of river condition has been structured around three components:

- catchment interactions;
- riverine habitat; and
- biota.

Catchment interactions

Catchments influence a river through large-scale effects on the hydrological regime, sediment delivery and chemistry (Allan & Johnson 1997). The amount and timing of run-off from a catchment will be determined by climate, topography, soil type, geology, and vegetation. Land use changes affect the hydrological regime, resulting in an increase or decrease in flow and changes in the seasonal and daily timing of hydrological events. Land use activities can alter the hydrological regime by changing the rates and quantity of infiltration and overland flow as well as the extraction and release of water from storages. These changes affect the timing and volume of water that flows down a river (e.g. land surfaces that are dominated by impermeable surfaces, such as roads and roofs within urban areas, can markedly change the hydrological regimes of rivers).

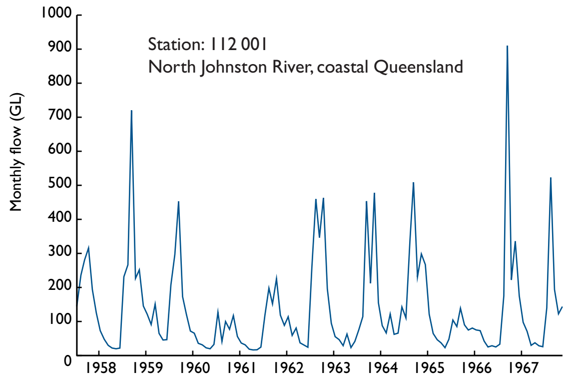
Sediment and nutrient inputs to rivers from catchments are also determined by a complexity of natural factors. Extensive clearing for forestry and agriculture, grazing and cropping, the destruction of riparian zones, urbanisation, road construction and extractive industries can exacerbate the natural delivery of these materials to rivers (Waters 1995, Boulton & Brock 1999).

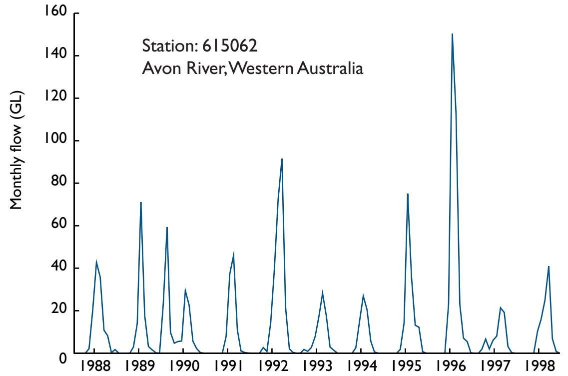
Measuring river flows

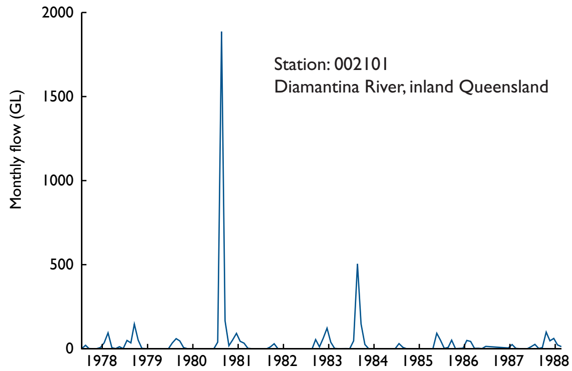
Gauging stations are used to measure and record flows and discharges in rivers. Hydrographs display these data over time and can indicate whether a river is *perennial* (flows continually), *intermittent* (ceases to flow during the dry season), or *episodic* (only flows briefly after rain). They can also show other useful variables such as total annual discharge, median flow and aspects of floods and low flows (frequency and duration).

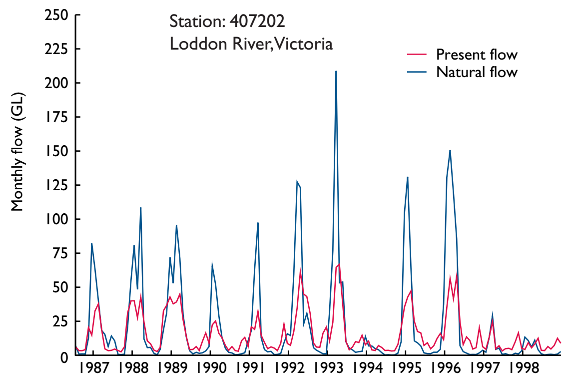
In this example, gauging station number 112001 (North Johnston River, coastal Queensland) shows a typical perennial river in a monsoonal wet tropics climate. Gauging station number 615062 (Northam, Avon River, Western Australia) shows an intermittent river which does not flow at all during the summer months. Station number 002101 (Diamantina River, inland Queensland) shows an episodic system where flow is low in most years, but peaks after heavy rainfall.

Hydrographs can show the impact of regulatory structures on natural flow. Present-day flow as measured by gauging station number 407202 (Loddon River, Victoria) is compared with estimated natural flow. The river is naturally an intermittent system with peak flow in spring and very low to no flow in summer and autumn. The dams upstream have changed flow timing and discharge to resemble a perennial river. The peak flows now occur slightly earlier and the peak discharge is less than half of what it used to be. The periods of low to no flow have been replaced by periods of higher and more continuous flow.









Intact riparian land is very important to river condition

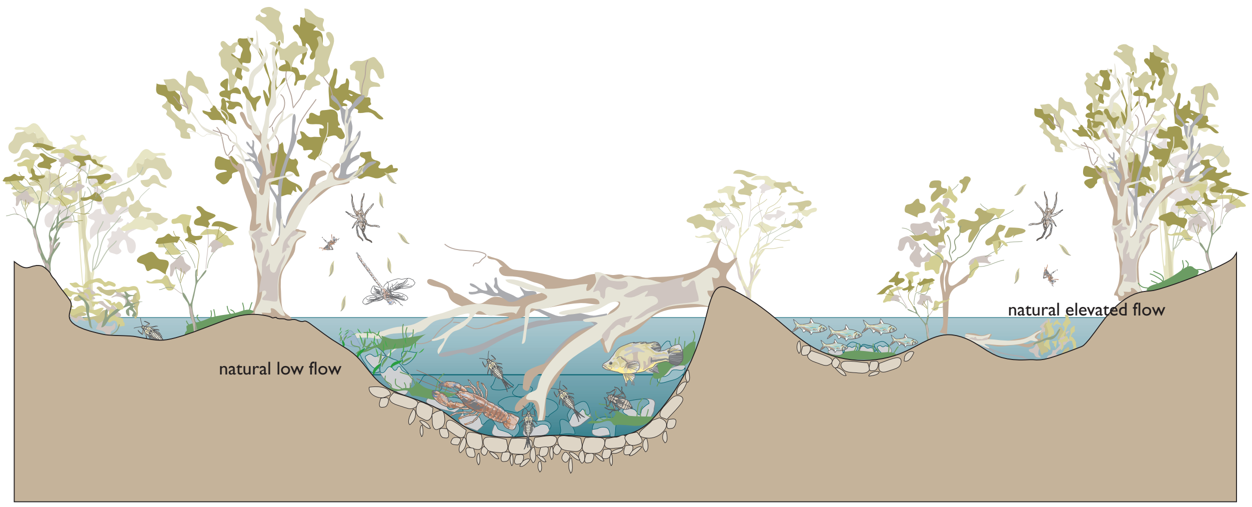
The natural chemical constituents in a river are mainly determined by catchment geology and soil types. Rivers range from naturally alkaline waters flowing from limestone catchments to the highly acidic streams in some of the upland, granitic catchments. The most significant changes to these natural conditions result from an augmented nutrient or sediment supply and the introduction of toxic chemicals and salt. Toxicants include hydrocarbons, trace metals, pesticides and herbicides. A wide and growing range of toxicants is entering rivers, and their long-term effects are still far from clear. Toxicant sources tend to be linked to particular land uses (e.g. hydrocarbons and trace metals from urban areas, pesticides and herbicides from agricultural areas).

Salinisation of catchments and rivers is a problem that has recently received national attention. While some Australian soils and rivers have naturally high salinity levels, the currently increasing levels of river salinity is attributed to extensive clearing of deep-rooted vegetation and increasing irrigation (NLWRA 2001e).

Riverine habitat

The riverine habitat includes the river and its floodplain, associated riparian land, channel features and river form, flow regime and water quantity and quality (Figure 33).

Figure 33. Cross-section view of the form and function of a typical Australian river.



Floodplain

Floodplain water bodies include billabongs, lakes, wetlands, flood runner and distributary channels. These water bodies are naturally connected to rivers during high flows and are critical parts of the river ecosystem. Material and organisms are supplied and trapped by the floodplain as water levels rise and fall. Floodplain water bodies can be highly productive when filled, providing an extensive and complex variety of aquatic habitats (e.g. distinctive habitats such as reed beds that are important for frogs, invertebrates and water birds). As water levels recede, organisms and materials such as nutrients released from organic matter are fed back to the river, replenishing resources in the stream. This exchange of materials between river and floodplain is essential for maintaining biodiversity and supporting river function. Maintenance of natural wetting and drying regimes is essential to ensure the breeding of organisms whose life cycles are cued by flood events and release of nutrients.

Floodplain water bodies can be affected by changes to the flow regime (e.g. changes to flood volume, seasonality and frequency). The connections between floodplains and rivers can be influenced by constructed levee banks and flow regulation structures. During the assessment of river condition, floodplain–river connectivity was assessed on the basis of the existence of local levee banks and flow regulation structures.

Riparian land

Riparian land is the land adjoining, directly influencing or influenced by a river. A major component of riparian land influencing the river is riparian vegetation. Riparian vegetation provides shade; and supplies energy, nutrients and habitat to the stream and the floodplain (Figure 33). Specifically, riparian land supports river health by:

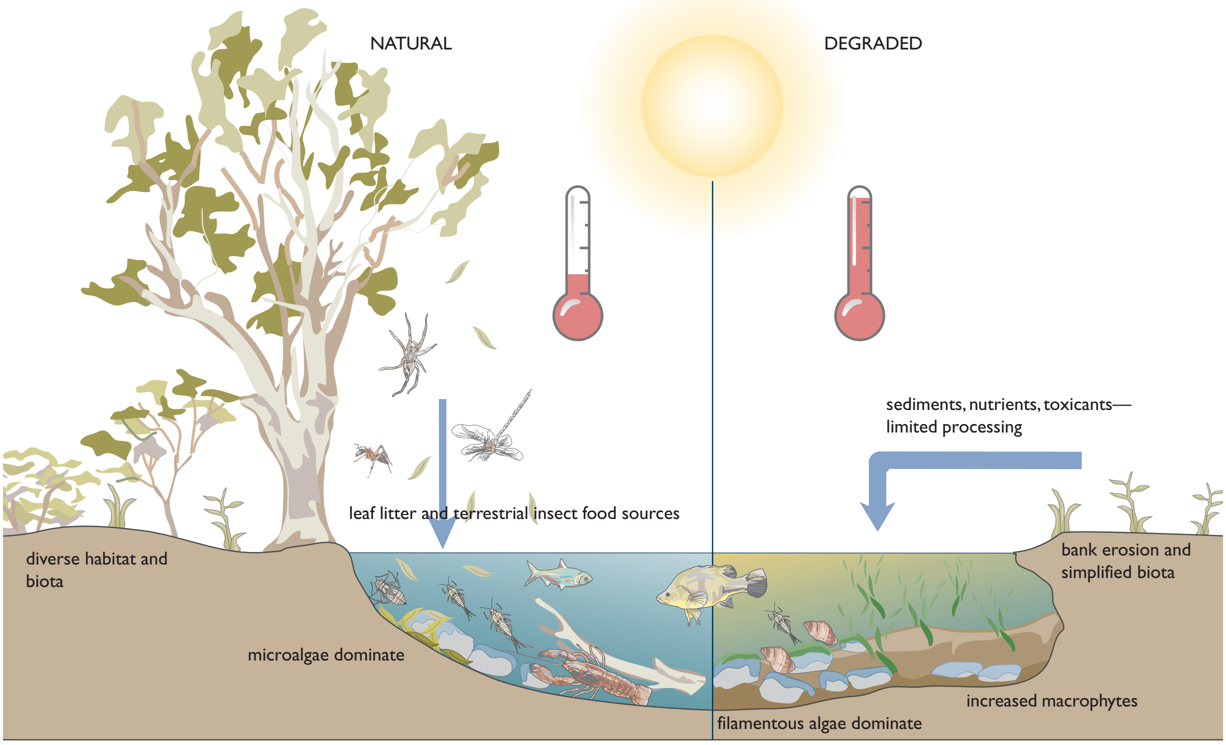
- regulating instream primary production;
- trapping sediment, nutrients and other contaminants;
- protecting river banks from erosion; and
- providing a food source and habitat (e.g. fine organic matter, leaves, sticks and snags) for aquatic animals.

Degradation of riparian land is mainly caused by the removal of vegetation, but also, in some cases, by the introduction of alien species (e.g. willows). Removal of native riparian vegetation can affect a stream by (Figure 34):

- increasing the warmth and light reaching the stream, favouring algae and macrophyte growth;
- reducing the loads of organic matter and woody debris entering the stream, thereby decreasing sources of habitat and food;
- allowing larger inputs of sediments and nutrients to the stream from the catchment;
- destabilising stream banks, leading to channel erosion; and
- allowing the local watertable to rise, with resulting potential increases in salt inputs to the stream.

Riparian vegetation is included in the river assessment (Table 9). It was calculated by measuring the extent of tree cover in the riparian zone. Composition and structure of the riparian zone are also important, but were not able to be assessed.

Figure 34. Effects of loss of riparian vegetation and catchment degradation on rivers.



Flow regime

Flow regime is a key driver of river condition. The regime and variability of flow at various scales have been recognised as an important determinant of river habitat and biota (Poff & Allan 1995). Australian rivers, such as those of the Murray–Darling system, have some of the most variable natural flow regimes in the world (Puckridge et al. 1998). The biota inhabiting Australian rivers are well adapted to hydrological variability (e.g. Boulton & Brock 1999) and the ecological integrity of some rivers depends upon flooding over the floodplain as well as substantial drying-out periods.

Changes in river flow regimes are well recognised as a cause of changes to river geomorphology and habitat (e.g. Erskine et al. 1999). Geomorphology and habitat, in association with water flow and water chemistry, control the distribution, physiology, and abundance of organisms, as well as the dynamics of riverine communities. Flow affects river biota from habitat scale (e.g. Stazner & Higler 1986) to river basin scale (e.g. Power et al. 1996). Flow has been considered as the fundamental driver that orchestrates pattern and process in river systems (Walker et al. 1995).

The ecological significance of flow variability can be considered at four scales:

- flow regime;
- flow history;
- flood pulses; and
- flow hydraulics.

Flow regime—expresses the long-term statistical generalisation of flow behaviour. It encompasses variations over hundreds of years, such as changes to the flood and drought cycles driven by long-term climate variations. The flow regime can be described in terms of the natural range of flow level and flow timing and by measures of central tendency such as the mean and median. The flow regime determines the broad types of ecosystems a river will support. In the assessment of river condition the flow regime was characterised by the mean annual flow.

Flow history—the sequence of floods or droughts over recent decades. It can be described in terms of flood and drought magnitudes and frequencies, measures of the time between floods and droughts, and measures of the seasonality of different sizes of flood and drought. Flow history forms the hydrological template for aquatic ecosystems at finer time scales than the flow regime. In the assessment of river condition, the flow history was characterised by quantification of the flow duration curve.

Flood pulses—single flood events are generally defined as a rise and fall in discharge. Flood pulses generally extend for less than one year and are described by measures of magnitude (e.g. flow height, volume and duration) and measures of the rates of flow rise and fall. Flood pulses can be an important trigger for ecological responses (e.g. fish spawning and migration, and water bird breeding). This component of flow was quantified in the assessment of river condition by measures of change to the amplitude of flows, and changes to their seasonal periodicity.

Flow hydraulics—the detailed motion of the flow in terms of flow velocity, depth, shear stress and turbulence. These flow characteristics define flow microhabitat features, but could not be assessed in the river assessment because they vary over such a fine spatial scale.

Australian rivers vary widely and therefore measurements and characterising functions will vary. This assessment has included flow regime where data were available. The lack of data on this aspect of river condition is recognised as one of the limitations of the assessment.

In the river assessment, the hydrological disturbance subindex is used to assess the change to flow regimes that typically result from river regulation and/or substantial flow diversion or extraction. An additional effect of river regulation is the impact of the river regulating structures themselves on biota. Many fish species and possibly other biota rely on upstream–downstream migration for breeding or other purposes. Physical impediments (e.g. dams and weirs) can affect these populations, with domino effects to the rest of the ecosystem.

Channel features and river form

Australian rivers are complex systems and vary in river form and channel features. Components of the physical habitat of a river include the river floodplain and channel form, in-channel habitat types, substratum, and organic matter (Figure 33).

- Upland part of a river: the valley is usually constrained and has minimal floodplain; the river is dominated by riffle and pool habitats.
- Mid-reaches: the valley floor widens, the river starts to meander, and in-channel benches and flood runners develop; sediment is highly mobile, eroded and deposited from point and lateral bars and pools.
- Lower river reaches: the river generally splits into several channels and there is extensive development of floodplain features; sediment is mostly deposited and distributed to the floodplain.

The characteristics of each section of river control the habitat available for biota:

- In upland sections, the substratum is dominated by boulders and cobbles; current velocities and riparian inputs are high.
- In the mid-reaches, substratum is mostly cobbles, pebbles and gravels; current velocities are lower; macrophytes appear; and organic inputs, including snags, are important.
- In the lowland reaches, pools, anabranch channels and floodplain features such as billabongs and wetlands form the main habitat types; sediment is dominated by smaller particles such as sand, silt and clay; current velocity is low; and woody debris, snags and macrophytes become the most important habitats.

Erosion of riverbeds and banks and transport of sediment along a river is an essential, natural and continuing process. However, excessive loads of sediment can swamp the natural physical features of rivers with sand or mud, causing a loss in variety of available habitats (Figure 34). Accumulation of sediment in a river channel will cause the channel to become narrow and shallow, facilitating colonisation by semi-aquatic plants and weedy species (e.g. willows), eventually choking the channel and reducing available habitat for aquatic species.

Organic matter can enter the stream in dissolved form or as small particles, leaves, sticks or even snags. Most organic matter transported in streams is dissolved, entering the stream through groundwater or run-off—mostly from storms. Dissolved organic matter is derived largely from the leaching of leaf litter and detritus and is consumed by microbes and bacteria. Coarse organic matter such as fallen trees, branches and leaf packs, is an important substrate, habitat and food source for microbes, algae, invertebrates, fish and other animals such as platypuses, tortoises and lizards. Snags provide fish with shade, shelter from predators and currents, spawning sites, and feeding areas. At least 34 native freshwater fish species use woody debris as a major habitat for spawning (Treadwell et al. 1999). Removal of riparian vegetation may severely reduce the supply of organic matter to streams. De-snagging has contributed to degradation of many Australian rivers. Without woody debris, current velocity can also increase, accelerating bank erosion.

In the assessment of river condition, no assessment could be made of channel form or in-channel habitat types. Increases in bedload and suspended sediment load were assessed by modelling hillslope, gully and bank erosion and hydrological and climatic features. Measurements of mean annual suspended sediment loads are scarce in Australia but some data are available to calibrate the model and evaluate the bounds of suspended sediment yield. Rivers used were LaTrobe, Brisbane, Tully, Johnstone, Avon, Lachlan, Murrumbidgee and Burdekin.

Water quality

Many aspects of water quality (e.g. nutrients, salt, turbidity, water temperature, dissolved oxygen, trace nutrients and toxicants) are important when assessing river health.

While nutrients are essential for river function, excess nutrients can disrupt normal ecosystem function, increasing the risk of algal blooms. The most significant nutrients for ecosystem function are nitrogen and phosphorus, since they are limiting to plant growth. They are released from instream processes, but may also enter the stream by run-off and inundation of the floodplain.

The main sources of salts to rivers are the atmosphere, catchment and groundwater, with the contributions from each source depending on location, climate and catchment features. The variable discharge of Australian rivers leads to temporal variability in dominant salt sources. Floods also play an important role:

- in low flows, more salts are generally contributed from groundwater and in arid areas salts may concentrate in surface water because of evaporation; and
- at high flows, surface water and atmospheric sources dominate.

Salinity generally increases downstream in Australian rivers because tributary inputs and impacts accumulate along the route. However, salinity is higher in headwater catchments in some rivers (e.g. in south-west Western Australia) because of catchment clearance and dryland salinisation (Boulton & Brock 1999). High concentrations of calcium salts can cause sediment to flocculate and settle. In naturally turbid water, calcium salt makes water clear, increasing light penetration and the risk of algal blooms.

The amount of suspended material (e.g. silt and clay) in the water alters the amount of light that can penetrate the water column.

- High turbidity can restrict instream primary production to the water's edge or the top few centimetres of the surface and smother instream habitat.
- Lowered turbidities in areas of naturally higher turbidity may lead to algal blooms.

The natural turbidity of a river can be affected by flow regulation, water abstraction, sediment entering the river from the catchment, changes in water chemistry and the removal of riparian vegetation, causing erosion. Many inland rivers are naturally turbid because of their loads of suspended sediment.

Water temperature is a major factor regulating instream production and provides cues for spawning and migration for organisms (e.g. fish). Water temperature is controlled primarily by shade, water colour and turbidity. It can be lowered unnaturally by the release of cold water from the bottoms of dams. Cold water affects fish and macro-invertebrate populations. Temperature can be increased by the removal of riparian vegetation and the shallowing of river channels (Figure 34).

Monitoring aquatic macro-invertebrates

Toxicants may arrive in a stream from run-off, the atmosphere or groundwater sources. The effects of toxicants on stream organisms are complex and the subject of considerable research.

A comprehensive data set was available for nutrients and suspended sediment loads. The subindex for this river assessment is called the 'nutrient and suspended sediment load subindex' to more accurately reflect its function. Nutrient loads were assessed using modelled data for total nitrogen and total phosphorus. Turbidity was estimated via suspended sediment loads.

Toxicants were assessed using National Pollutant Inventory data. Reach assessments did not include salinity (refer to the project report for the basin-scale assessment of salinity).

Biota

Water plants, algae, bacteria, macro-invertebrates (mostly insects), crustaceans, fish, amphibians, water birds, mammals (e.g. water rats, platypuses), reptiles (e.g. tortoises, crocodiles and lizards) are important riverine biota. Riparian vegetation is also considered part of the biota, but has been discussed as part of the riverine habitat.

Emergent and submerged plants provide habitat for water birds, insects, amphibians and fish, and are a substantial sink for nutrients (Boulton & Brock 1999). Algae are important for nutrient cycling and as a food source for other biota. Primary production is limited by light availability; riparian vegetation, turbidity and water depth all have an influence on instream production. The amounts of organic matter fixed by primary production are often smaller than those lost as carbon dioxide after breakdown, but without shade this relationship may be reversed. Shade also mediates daily and seasonal water temperatures. In upstream environments there is generally little instream photosynthesis, and most energy is derived from leaf litter and other organic matter. In lowland environments where there is more light, macrophytes are generally more abundant. However, the higher turbidity in lowland rivers can limit the zone where light is sufficient for plants to grow to a few centimetres, restricting plants to those that grow at the water's edge or float on the surface. Algal blooms generally occur when there are slow flows, clear water, high nutrient concentrations and high temperatures. Therefore, maintenance of native riparian vegetation and flushing flows is important in avoiding algal blooms.

Animals such as macro-invertebrates, crustaceans, fish and amphibians are affected by changes to light, temperature and nutrient levels and are dependent on food resources and habitat features at many scales. Increases in light, often combined with increased nutrients, may result in filamentous algae and macrophytes replacing riparian litter as a food source (Figure 34), resulting in a major change in the food chain, a loss of biodiversity and population structure changes. Woody debris and snags provide a critical habitat for macro-invertebrates and fish and changes to the physical habitat (e.g. loss of woody debris, removal of snags and deposition or erosion of sediment) also have major impacts on the plants and animals that live in rivers and streams. Sediment deposition may smother fish eggs and spawning sites, affecting fish reproduction and recruitment, and reduce macro-invertebrate habitat.

Despite the importance of each biotic component to ecosystem function, the only comprehensive national biological data set is the National River Health Program data set based on macro-invertebrates. Only macro-invertebrates could therefore be used as a biological measure of river condition for this assessment.

Key management issues include riparian vegetation, land use intensity, sedimentation, nutrient loads and hydrology

ASSESSING RIVER CONDITION

Without improvements in river and catchment management, existing uses of and benefits obtained from Australia's rivers will not be sustainable. The assessment of river condition provides a baseline data set from which river managers can gauge improvements in the future.

The assessment incorporates a range of attributes that indicate key ecological processes at the river reach and basin levels. Rivers in near natural condition serve as a reference against which condition of other rivers can be assessed.

Natural resource management requires information measured at an appropriate scale to:

- assist policy development;
- support investment decisions;
- evaluate program and policy performance; and
- direct resource allocation priorities.

Clients for this information include Commonwealth, State/Territory and local governments, rural industries, the community, and other government and non-government organisations.

Key river management issues include:

- loss of riparian vegetation;
- intensity of land use;
- increased sedimentation;
- increased nutrient loads; and
- altered hydrology.

A national protocol has been developed by the Audit for reporting river condition. This protocol provides for the incorporation of results from river assessments at the State/Territory or regional level and strengthens the overall results of the river assessment. The best available information can be incorporated from the State/Territory, regional and local levels, without compromising the role of the national assessment. Results using the national protocol are available from the Australian Natural Resources Atlas.

Methods

The river assessment is based on the premise that:

- ecological integrity is the fundamental measure of river condition; and
- aquatic biota demonstrate an ecological response to changes in physical and chemical features of their environment.

Catchment activities, including land uses, can affect riverine habitat (riparian vegetation, snags and channel geomorphology) and instream water conditions. Riverine habitat, and structures (e.g. dams, weirs and levees) in turn affect biota (aquatic vegetation, invertebrates, fish and waterfowl). The assessment approach is therefore founded in our understanding of the links between catchments, riverine habitats and aquatic biota.

A detailed description of the methods is available in the project report and covers:

- definition of reach network;
- aggregation (i.e. aggregating measures for a group of reaches to provide a measure for a basin);
- integration (e.g. reach-scale subindices integrated to create the environment index for a reach);
- justification and descriptions of condition classes;
- calculations, modelling and validation of subindex scores; and
- river sediment budget methods.

Indices of river condition

The river assessment calculates an index of condition for key measures affecting river condition (Figure 35). Aquatic biota are considered to be the key measure of environmental condition. Environmental variables are important measures and drivers. It is important to measure both aquatic biota and environmental variables, because:

- assessing only biota may tell us that the biota is impaired but not why;
- there may be a time lag between environmental disturbance and biotic response, so measures of environmental changes can provide an early warning; and
- a biotic response in the absence of any environmental indication may suggest that there is an environmental component that needs to be monitored (e.g. a particular toxicant).

River basin units

River basins are large areas with considerable diversity of river condition. A finer scale catchment unit is therefore required for assessing river condition.

River links are the stretches of river between tributary junctions and define a river network.

A **river reach** is an aggregation of river links that identifies a section of river with relatively uniform physical characteristics. A digital elevation model was used to calculate slope and drainage area. Together, slope and drainage give an estimate of stream power, which was used to define reaches as a continuous network from catchment to coast.

There were 14 606 (11 028 longer than 5 km) reaches identified in the assessment area and included in the assessment.

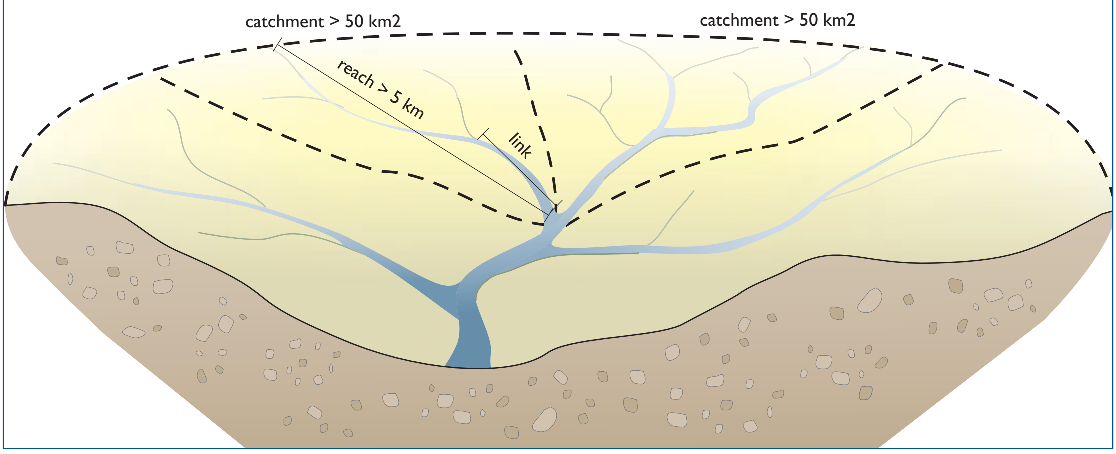
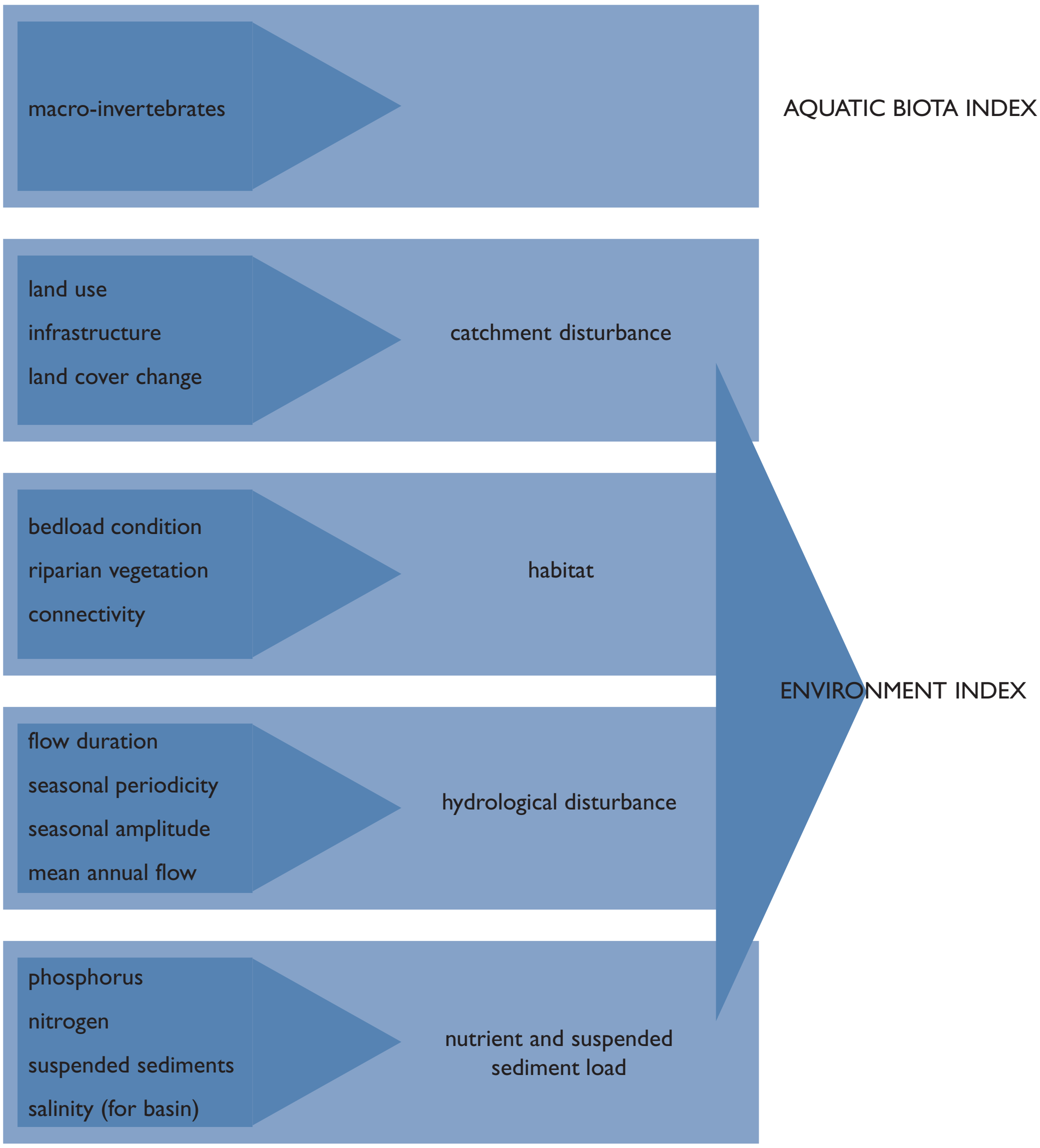


Figure 35. River condition assessment indices and subindices.



The assessment is reported using an **aquatic biota index** (macro-invertebrate), based on AUSRIVAS (Australian River Assessment System) macro-invertebrate data collected under the National River Health Program and an environment index that combines the:

- catchment disturbance subindex;
- riverine habitat subindex;
- hydrological disturbance subindex; and
- nutrient and suspended sediment load subindex.

The aquatic biota index should include other biotic indicators in addition to macro-invertebrates since:

- macro-invertebrates may not be sensitive to all forms of river modification;
- other biota may show up effects at larger or smaller time and spatial scales; and
- effects shown by more than one kind of biota strengthen conclusions and may enable insights into ecosystem effects.

Assessment philosophy is based on departure from reference—or pre-European settlement conditions. It is hard to find pristine rivers in the assessment area with which to compare test sites, especially for lowland rivers surrounded by extensive agricultural development. Reference conditions were therefore set by using a combination of:

- minimally disturbed sites;
- historical data;
- modelling of past conditions; and
- professional judgement (Table 9).

Weirs affect upstream–downstream fish passage

Table 9. River assessment indices and their reference conditions.

Aquatic biota index (macro-invertebrates)	Reference condition
The *aquatic biota index* represents the response of macro-invertebrates to changes in the environment. The index is based on extensive national sampling of aquatic macro-invertebrates collected by State/Territory agencies under the National River Health Program. Data were collected and analysed using the standardised AUSRIVAS methods (Coysh et al. 2000, Simpson & Norris 2000). Approximately 6000 sites have been sampled throughout Australia; at most sites two habitats have been assessed, with many being re-assessed four to six times since 1996. AUSRIVAS models assess biological condition by comparing the kinds of aquatic invertebrates observed at sites of unknown condition (test sites) with the biota predicted to occur in reference sites. The ratio of the number of observed taxa to expected is the basis of the index.	Comparison with biota at a near pristine or minimally modified site
Environment index	
The *environment index* brings together the cumulative effects of catchment-scale features and local features including habitat, hydrology, and nutrients and suspended sediment loads.	Comparison with a completely undeveloped catchment (pre-European settlement conditions)
The *catchment disturbance subindex* focuses on anthropogenic changes to land surfaces that influence rivers. The Agricultural Land Cover Change data set (Kitchin & Barson 1998) was used to provide a measure of recent change in land use over time. Included in the data set is a measure of the loss of woody vegetation over the period 1990–1995. Infrastructure information is not included in the land use coverage, so the Wild Rivers data set (Stein et al. 1997) was used for this information.	
The *habitat subindex* uses measures of sediment inputs, riparian vegetation clearing and connectivity (dams, weirs, levee banks) to assess the state of local habitat and its probable ability to support aquatic life.	
Bed condition	
The bedload model calculates the mean annual historical deposition of bedload in river reaches as a result of supply of sediment from bank erosion and gully erosion upstream. This volume of deposition is expressed as a total bed accumulation of sand and gravel over historical times (measured in metres).	Comparison with a stable bed of no net accumulation or degradation at century time scale
Riparian vegetation	
Riparian vegetation is calculated by estimating the extent of tree cover in the riparian zone within 100 m of the river bank using satellite imagery. The Agricultural Land Cover Change data set (Kitchin & Barson 1998) was used to calculate an assessment of riparian extent. This data set has information on the distribution of broad structural categories of vegetation at a scale fine enough to be useful for assessing riparian extent in a majority of situations. The data set covers much of Australia, and the land cover component is relatively current (1995).	Comparison with riparian vegetation coverage assumed to have existed under pre-European settlement conditions
Connectivity	
There are two important components of connectivity: upstream–downstream connectivity (longitudinal) and connectivity with the floodplain (lateral). The former is important for the migration and breeding of many fish species, the latter for movement of water, biota and material across the floodplain. Connectivity was calculated from the Wild Rivers data set (Stein et al. 1997) and data on impoundments and levees.	Comparison with a no-dam, no-levee regime (pre-European settlement conditions)

Table 9. River assessment indices and their reference conditions (continued).

Environment index	Reference condition
The *hydrological disturbance subindex* assesses the change to flow regimes that typically result from river regulation and/or substantial flow diversion or extraction. The hydrological disturbance subindex is based on comparisons of the current flow regime to the natural or pre-European settlement flow regime. The key aspects of flow regime change included are: • changes in total flow volumes using a mean annual flow index; • changes in flow regime variability using a monthly flow-duration curve difference index (a measure of flood frequency); and • changes in the seasonal pattern of flows using a seasonal periodicity index to assess changes to the seasonal timing of high and low flows, and a seasonal amplitude index to assess changes in the magnitudes of seasonal highs and lows. Values were assigned to: • regulated reaches with observed and/or modelled monthly data to describe both the current and natural flow regimes, and • unregulated reaches in river basins where existing total annual extractions are less than 0.5% of the basin mean annual flow. No extraction data were available at the reach scale, and so unregulated reaches in basins with higher levels of extraction could not be reliably assessed.	All subindices were compared with modelled pre-European settlement flow regimes, which generally do not account for changes in run-off associated with land clearing.
The *nutrient and suspended sediment load subindex* considers the effects of long-term changes in suspended sediment and total nutrient loads, and the effects of short-term changes in toxicant levels. The subindex is primarily a comparison between existing and natural average annual loads of nutrients and suspended sediments, using modelled data. The modelled sediment and nutrient loads compare well with load estimates based on measured water quality and flow data. However, they cannot be directly compared to water quality assessments based on exceedance of guideline threshold values. This is because the relative increases over natural conditions implied by the thresholds in exceedance guidelines do not correspond to the relative increases over natural conditions used to define sediment and nutrient load assessment categories. Water quality measurements are also typically biased towards low flow conditions and do not necessarily correlate well with total loads.	Comparison with nutrient and sediment transport modelled present and pre-European settlement regimes

Reporting bands

In the classifications that have been used, individual reach scores have been aggregated into descriptive condition bands on a linear gradient between 0 and 1 to simplify Australia-wide reporting (Table 10, Figure 36).

Table 10. River condition assessment classification.

Aquatic biota index (macro-invertebrates)

Reference condition	• stream macro-invertebrates are similar in type to those at reference sites
Significantly impaired	• between 20% and 50% of the expected macro-invertebrate families have been lost
Severely impaired	• between 50% and 80% of the expected macro-invertebrate families have been lost
Extremely impaired	• between 80% and 100% of the expected macro-invertebrate families have been lost

Environment index

Largely unmodified	• minimal disturbance from catchment land uses such as conservation, forestry, low levels of grazing or cropping • limited changes to the hydrological regime • limited changes to the habitat (e.g. riparian vegetation reasonably intact, no dams or levees and very little sediment deposition) • loads of suspended sediment, total nitrogen and total phosphorus close to natural
Moderately modified	• catchment dominated by land uses that disturb the river to some extent (e.g. dryland cropping and grazing) • some changes to the hydrological regime as a result of impoundments or abstraction • some changes to habitat (e.g. riparian vegetation reduced to 50–75% original coverage, dams upstream but not in the reach, and some sediment deposition) • loads of suspended sediment, total nitrogen and total phosphorus above natural
Substantially modified	• catchment land uses, such as intensive cropping and irrigation, cause moderate to severe disturbance • substantial changes to the hydrological regime as a result of impoundments or abstractions • substantial changes to the habitat including loss of 50–75% riparian vegetation, connectivity affected by nearby dams or levees, and substantial sediment deposition • moderate to high loads of suspended sediment, total nitrogen and total phosphorus
Extensively modified	• catchment land uses, such as intensive agriculture or urbanisation, cause significant disturbance to streams • significant changes to the hydrological regime (e.g. large reductions in flow and changes in the seasonality of flow events) • extensive changes to the habitat, including loss of riparian vegetation, loss of connectivity and extensive sediment deposition • high loads of suspended sediment, total nitrogen and total phosphorus

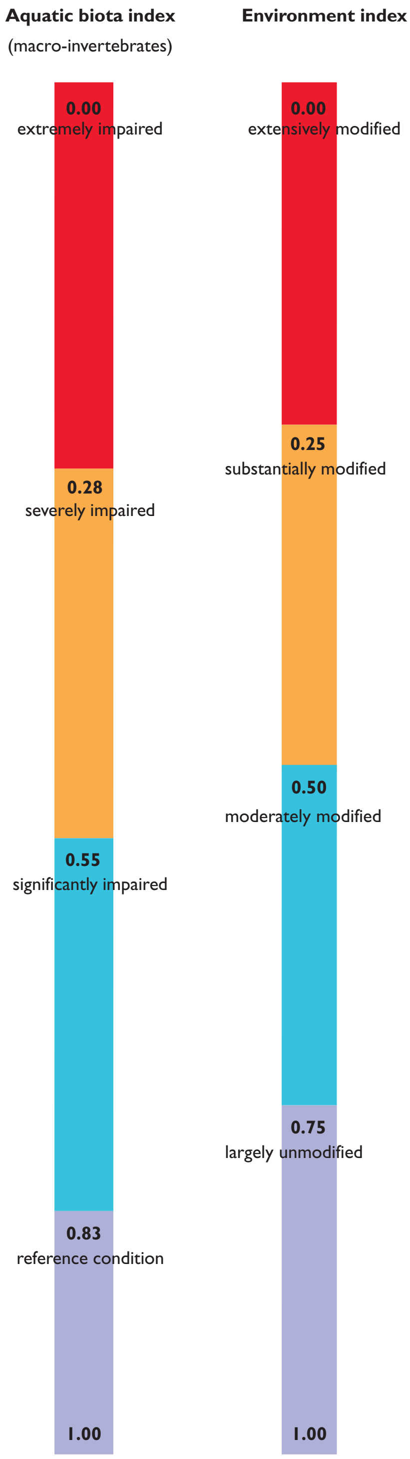
Figure 36. River condition assessment classifications for the aquatic biota and environment indices.

A stream near Goulburn (New South Wales) in extensively modified condition as a result of changes to the catchment, the riverine habitat and water quality

A section of the Murrumbidgee River (Australian Capital Territory) in substantially modified condition as a result of catchment disturbance and significant changes to the riverine habitat

A section of the Paroo River (Queensland) in moderately modified condition as a result of changes to the catchment and riverine habitat

Gibralter Creek (New South Wales), a stream in largely unmodified condition



FINDINGS

The loss of riparian vegetation results in bank erosion and increased nutrient and sediment loads to the river

The results of the river assessment show the extent of change in Australia's river basins. Change in condition is most strongly linked to:

- intensity of land use;
- increased nutrient and sediment loads; and
- loss of riparian vegetation.

Hydrological change related to impoundments and water extraction is a significant driver of river condition. A hydrological baseline was, however, available for only 25% of the number of river reaches in the assessment (or 30% of the total river length) making it difficult to measure the extent to which flow regulation and abstraction have affected rivers. It was found that the two most affected aspects of hydrology are the flow duration (40% of assessed river length is modified) and the seasonal amplitude (30% of assessed river length is modified). This means that flows are usually for longer periods than pre-European settlement flows, and the seasonal peaks and lows of intermittent systems are evened out to resemble perennial systems (see box p. 59).

Aquatic biota index (macro-invertebrates)

One-third (21 909 km) of the river length assessed is to some degree impaired (has lost between 20% and 100% of the various kinds of aquatic invertebrates that should live there) (Figure 37, Table 11).

- New South Wales is assessed as having the poorest aquatic biota condition; approximately 50% of the river length assessed had impaired aquatic biota. Some of the most affected areas were the Georges River and Wollongong Coast basins.
- Over 35% of the river length assessed in the Australian Capital Territory and Western Australia had impaired biota.
- Between 12% and 24% of the river length assessed in the remaining States and Territories had impaired biota.

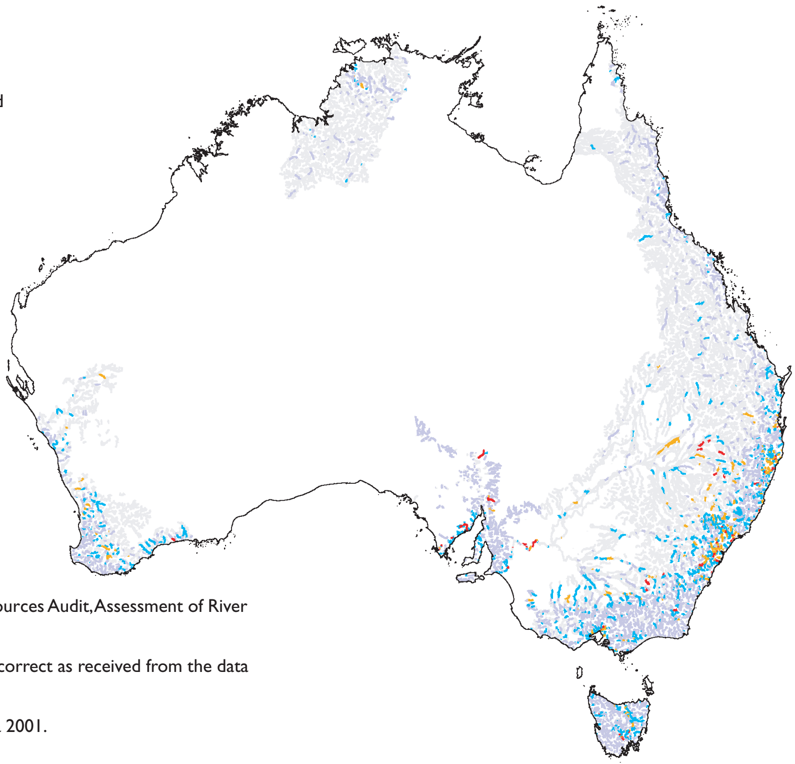
Assessment results are underestimates of change in some parts of the country, including the lowland rivers of the Murray–Darling Basin and Western Australia. In these areas the reference sites used as benchmarks have already been modified to some extent since European settlement.

These findings on the biotic condition of Australia's rivers need to be considered in the context of the commitment to ecologically sustainable development. Extensive change to riverine ecosystems has already occurred, and with the assessment of river condition providing only a measure of condition, not trend, it may be that this change is continuing. It was beyond the scope of this assessment to ascertain whether the extent of change detected was ecologically sustainable. Ecosystems have a natural resilience to disturbance. Beyond a certain level of disturbance, ecosystem structures and processes fail. Less desirable ecosystems (e.g. lowland river ecosystems may change from macrophyte-dominated systems to systems dominated by cyanobacterial blooms) may result.

Figure 37. Condition of river reaches based on the aquatic biota (macro-invertebrates) index .

Reach condition

- reference condition
- significantly impaired
- severely impaired
- extremely impaired
- not assessed



Data Sources:

National Land and Water Resources Audit, Assessment of River Condition 2001 Database.

Data used are assumed to be correct as received from the data suppliers.

Table 11. Aquatic biota index (macro-invertebrates) results for each State and Territory.

	Total length of reach (km) in each category and percentage of total in parentheses				Percentage of total length with data
	Reference	Significantly impaired	Severely impaired	Extremely impaired	
Queensland	9 334 (80)	1 997 (17)	250 (2)	16 (1)	16
New South Wales	11 366 (50)	7 551 (34)	2 801 (13)	690 (3)	38
Australian Capital Territory	169 (64)	76 (29)	17 (7)	0 (0)	97
Victoria	9 347 (76)	2 447 (20)	344 (3)	49 (1)	77
Tasmania	4 248 (75)	1 097 (20)	142 (3)	100 (2)	100
South Australia	7 866 (83)	1 098 (12)	124 (1)	389 (4)	98
Western Australia	4 401 (64)	1 977 (29)	419 (6)	31 (1)	27
Northern Territory	2 063 (88)	247 (10)	47 (2)	0 (0)	11
Total	**48 793 (69)**	**16 490 (23)**	**4 144 (6)**	**1 275 (2)**	**34**

Environment index

The environment index combines the subindices of catchment disturbance, habitat, hydrological disturbance, and nutrient and suspended sediment load. Some components were not sufficiently comprehensive to fully characterise the driver of river condition (e.g. a water quality index would ideally consider important drivers of water quality, such as nutrients, suspended sediments, salt, turbidity, temperature, dissolved oxygen concentrations and toxicants). Comprehensive data was available for nutrient and suspended sediment loads only.

Increases in nutrients and suspended sediment loads, and decreases in the extent of riparian vegetation have resulted in 85% of the river length being assessed as substantially or moderately modified from natural condition (Table 12, Figure 38). In the Northern Territory, two-thirds of the river length assessed is in largely unmodified condition. In all other States and Territories except Tasmania, more than 80% of the river length assessed is substantially or moderately modified. One of the objectives of the assessment of river condition is to provide information on possible causes of degradation and inform management decisions on appropriate courses of action. Examination of the subindex results that make up the overall environment index is useful and can assist management as detailed in following sections.

Table 12. River environment index results for each State and Territory.

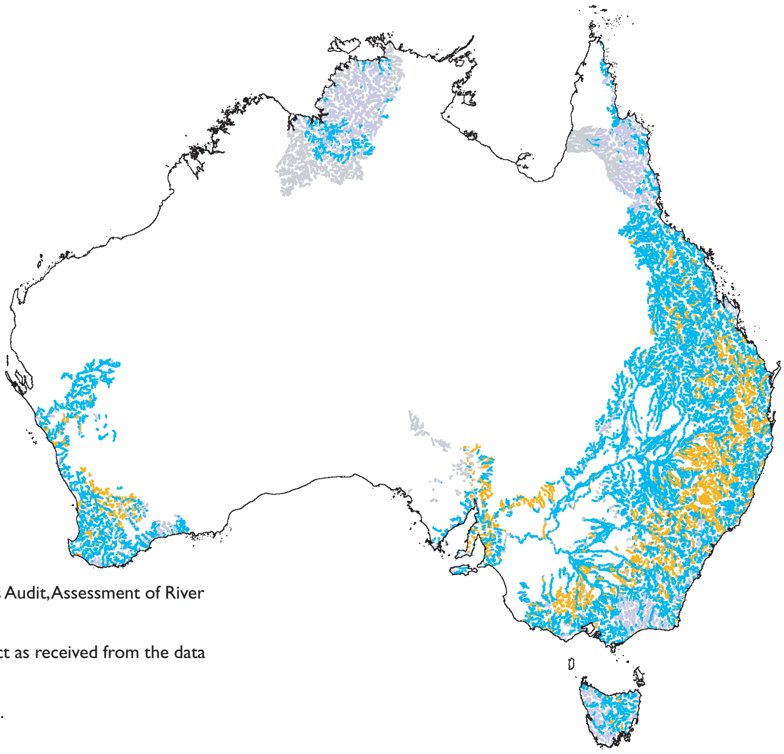
	Total length of reach (km) in each category and percentage of total in parentheses				Percent of total length with data
	Largely unmodified	Moderately modified	Substantially modified	Extensively modified	
Queensland	8 743 (13)	48 214 (71)	10 599 (16)	0 (0)	93
New South Wales	1 619 (3)	39 232 (68)	17 089 (29)	18 (0)	97
Australian Capital Territory	43 (16)	191 (71)	36 (13)	0 (0)	100
Victoria	3 085 (20)	9 042 (60)	3 099 (20)	0 (0)	97
Tasmania	2 028 (37)	3 250 (59)	194 (4)	0 (0)	98
South Australia	299 (4)	4 666 (61)	2 635 (35)	0 (0)	79
Western Australia	1 487 (7)	15 927 (78)	2 929 (14)	12 (1)	80
Northern Territory	9 165 (66)	4 630 (34)	0 (0)	0 (0)	67
Total	**26 468 (14)**	**125 152 (66)**	**36 581 (19)**	**31 (1)**	**90**

The Condamine River between Dalby and Cecil Plains (Queensland) showing poor catchment condition.

Figure 38. Condition of river reaches based on the environment index.

Reach condition

- largely unmodified
- moderately modified
- substantially modified
- extensively modified
- not assessed



Data Sources:

National Land and Water Resources Audit, Assessment of River Condition 2001 Database.

Data used are assumed to be correct as received from the data suppliers.

Catchment disturbance

Approximately 85% of river length assessed has catchments that have been changed from a natural condition (Table 13). Changes to land use are considered to have the most potential to affect rivers.

Both extent of recent land clearing and land use change are considered by this subindex. Changes tend to be widespread and relatively uniform, reflecting the predominance of broad-acre agriculture. Urban development, and more intensive agriculture have impact on rivers in some localised areas, particularly along the east and south-east coasts. Included in the measure of catchment disturbance is the influence of infrastructure (roads, power lines, railways) on rivers. Infrastructure had a less significant effect on river condition than land use, but was very important in densely populated areas.

- A high proportion of the rivers assessed in Tasmania and the Northern Territory have unmodified catchments.
- Other unmodified areas include the Australian Alps and parts of the coast protected in National Parks.
- Areas most affected are those close to urban areas, particularly Sydney and Melbourne, where infrastructure is dense and there are areas of intensive agriculture.

Table 13. River catchment disturbance subindex for each State and Territory.

	Total length of reach (km) in each category and percentage of total in parentheses				Percent of total length with data
	Largely unmodified	Moderately modified	Substantially modified	Extensively modified	
Queensland	5 119 (7)	66 623 (93)	300 (0)	0 (0)	98
New South Wales	5 773 (10)	52 343 (90)	216 (0)	32 (0)	95
Australian Capital Territory	158 (59)	105 (39)	7 (2)	0 (0)	95
Victoria	1 716 (11)	11 479 (74)	2 208 (14)	87 (1)	95
Tasmania	2 455 (44)	2 918 (52)	213 (4)	0 (0)	96
South Australia	463 (5)	8 422 (90)	519 (5)	70 (0)	94
Western Australia	6 038 (24)	19 149 (76)	8 (0)	12 (0)	94
Northern Territory	8 752 (43)	11 739 (57)	0 (0)	0 (0)	97
Total	**30 474 (15)**	**172 778 (83)**	**3 470 (2)**	**202 (0)**	**99**

Murrumbidgee River (New South Wales) with instream habitat impacted by increased bedload.

Habitat change

Over half of the rivers in the assessed area are affected by changes to riverine habitat, with the most modified areas occurring in the Murray–Darling Basin, South Australia and parts of the Western Australian wheatbelt (Table 14, Figure 39). The main indicators linked to this degradation are loss of riparian vegetation and increased sediment loads in rivers; a third habitat measure used was change to upstream–downstream and overbank connectivity.

Riparian vegetation plays a number of key roles in river ecosystem processes, particularly in those rivers with extensive floodplains (e.g. the lowland sections of the rivers flowing west from the Great Dividing Range). In these extensive floodplain areas, the loss of riparian vegetation is high.

Increased sediment loads in streams have led to:

- smothering of habitat—a widespread problem that can be expected to worsen as bedload material that has already been eroded and is stored in river channels continues to move through the river network.
- Gully erosion—significant sediment source across south and south-western Australia.
- Bank erosion—significant sediment source in south-eastern Australia.
- Hillslope erosion—predominant sediment source in northern Australia.

The bedload condition in about 66% of the rivers in the assessed area is either only slightly modified or unchanged. These reaches are not considered susceptible to accelerated deposition of sand and gravel because they are in areas of low catchment disturbance, have high sediment transport capacity or are far away from the source of bed material.

Change to upstream–downstream and overbank connectivity is most affected where reservoirs have been built—in the mid-slopes region along the Great Australian Divide and in Tasmania.

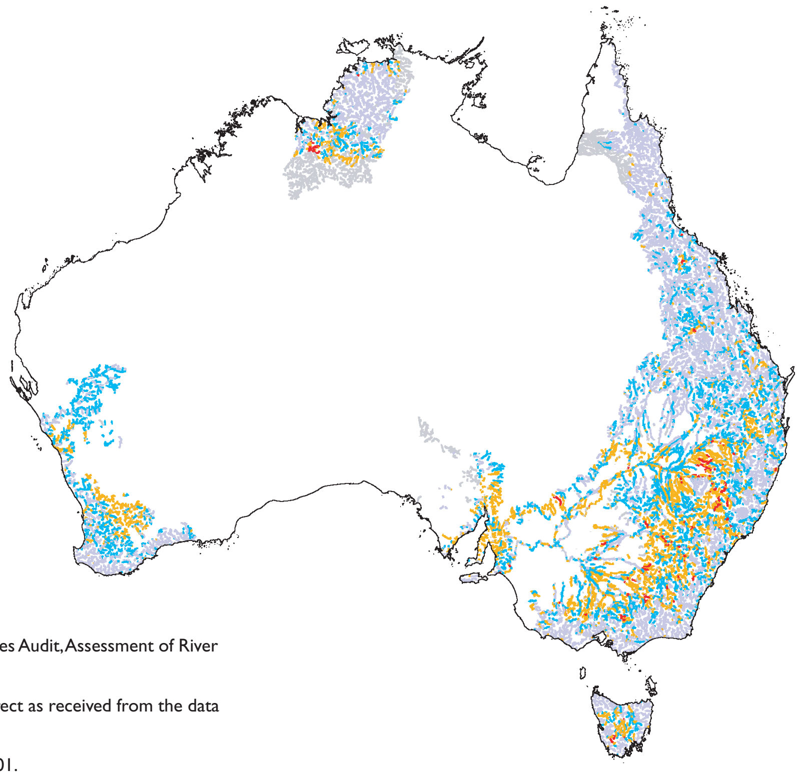
Table 14. River habitat subindex for each State and Territory.

	Total length of reach (km) in each category and percentage of total in parentheses				Percent of total length with data
	Largely unmodified	Moderately modified	Substantially modified	Extensively modified	
Queensland	45 389 (66)	18 184 (27)	4 263 (6)	130 (1)	94
New South Wales	15 724 (27)	19 695 (33)	21 100 (37)	1 845 (3)	98
Australian Capital Territory	148 (55)	68 (25)	54 (20)	0 (0)	100
Victoria	8 301 (53)	3 488 (23)	3 489 (23)	211 (1)	98
Tasmania	3 296 (59)	998 (18)	1 177 (21)	114 (2)	100
South Australia	1 384 (17)	2 764 (35)	3 809 (47)	30 (1)	83
Western Australia	7 522 (34)	9 887 (46)	4 190 (19)	286 (1)	86
Northern Territory	9 134 (62)	2 589 (18)	2 790 (19)	15 (1)	71
Total	**90 899 (47)**	**57 673 (30)**	**40 873 (1)**	**2 631 (1)**	**92**

Figure 39. Condition of river reaches based on the habitat subindex.

Reach condition

- largely unmodified
- moderately modified
- substantially modified
- extensively modified
- not assessed



Data Sources:

National Land and Water Resources Audit, Assessment of River Condition 2001 Database.

Data used are assumed to be correct as received from the data suppliers.

Mapping riparian vegetation

Riparian vegetation plays a particularly important role in maintaining the condition of rivers. Data on the extent and condition of riparian vegetation provides important information for assessing condition of rivers and for strategic planning of catchment-based natural resource management initiatives (e.g. revegetation, weed control, bank stabilisation, habitat protection and monitoring).

Trend information on the extent and condition of riparian vegetation is essential for assessing the effectiveness of policy or management activities, including investment by the Natural Heritage Trust. In the past two decades, the Natural Heritage Trust and its predecessor, the National Landcare Program, have sponsored riparian vegetation management initiatives across Australia. Our ability to evaluate the success of on-ground works and their long-term contribution to the improvement of riparian vegetation has been limited. Prior to work by the Audit, Australia has not had a reach framework with which to compile data, or agreement to comparable monitoring activities.

The estimated cost for a national riparian vegetation map is approximately $9.6 m (NLWRA 2000). In order to achieve an Australia-wide coverage that could become a component of the Audit's National Vegetation Information System (NLWRA 2001c), we require:

- an agreed geomorphic definition of the riparian zone;
- a single hierarchical classification scheme for extracting floristic and structural information from aerial photography and satellite imagery; such schemes have been developed as part of the National Vegetation Information System;
- riparian vegetation mapping at scales varying with land use intensity and management priorities;
- aerial photographs or satellite imagery depending on currency, continental coverage and cost;
- use of appropriate regionalisations (e.g. reaches, catchments, drainage divisions or bioregions);
- condition attributes with sufficient resolution to identify weediness and structural changes associated with disturbance;
- linkages to fundamental data sets and other indicator programs (e.g. land tenure, surface water quality and flow, groundwater monitoring and other programs such as AUSRIVAS, Wild Rivers and Victoria's Index of Stream Condition); and
- data management, metadata standards, fewer custodians and the capacity for standard data transfer protocols.

Hydrological disturbance

- Regulated reaches are those with a dam or weir upstream; an estimate of natural flow is necessary to calculate changes to flows.
- Unregulated reaches have no major regulating structures upstream, but flow may be affected by abstraction for use; an estimate of the volumes extracted on a seasonal basis is required to calculate changes.

The natural flow baseline was available for only 25% of reaches in the assessment (or 30% of the total river length) making it difficult to measure the extent to which flow regulation and abstraction have affected rivers. Of the regulated and unregulated rivers that could be assessed, over 80% are modified to some extent and nearly 30% are substantially modified (Figure 40). This may be an overestimate of actual changes to flow in the assessment area because the availability of hydrology data is often associated with the level of resource use.

Unregulated rivers

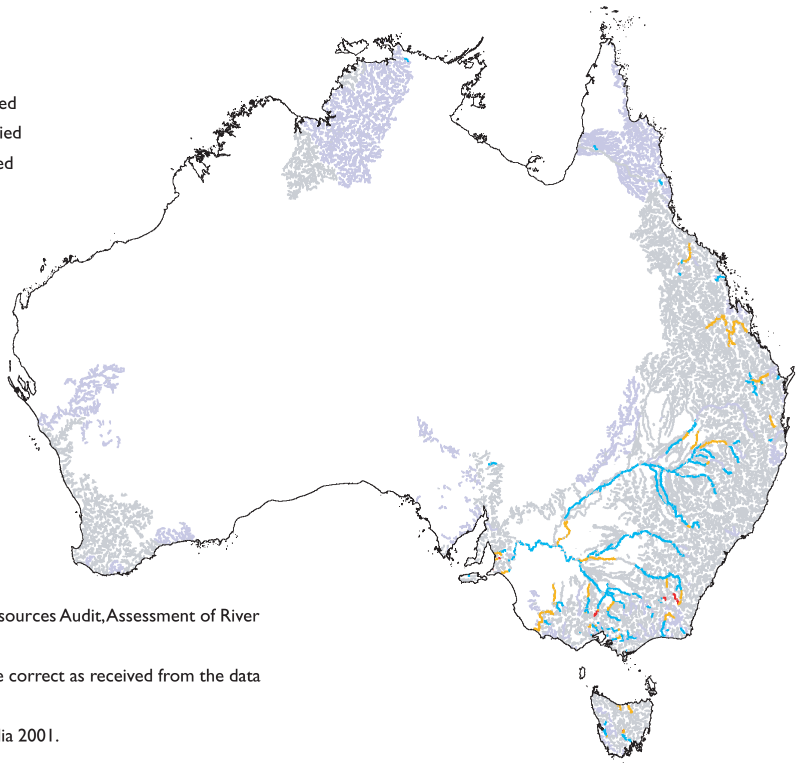
Almost 90% of the river length in the assessed area is unregulated (diversions occur, but flows are not regulated and existing total annual extractions are less than 0.5% of the mean annual flow). Twenty-six percent of this unregulated river length was assessed using data from the Australian Water Resources Assessment 2000 (NLWRA 2001f) (Table 15).

There were no hydrological data to determine the subindices of the hydrological disturbance index for many unregulated river basins. Reaches in these basins were classified as 'largely unmodified', based on an assessment of mean annual flow and where water extraction was less than 0.5% of mean annual flow. This approach allowed over 20% of unregulated river reaches to be assessed. The Stressed Rivers Assessment Program has developed a hydrological stress indicator to assess unregulated basins in New South Wales. These results differ to the Audit findings for the Richmond, Hunter (regulated in the Audit assessment), Paroo, Snowy, Genoa and Lake George river basins. The discrepancies reflect differences in the data available to the assessments and warrant further investigation.

Figure 40. Condition of river reaches based on the hydrological disturbance subindex.

Reach condition

- largely unmodified
- moderately modified
- substantially modified
- extensively modified
- not assessed



Data Sources:

National Land and Water Resources Audit, Assessment of River Condition 2001 Database.

Data used are assumed to be correct as received from the data suppliers.

The Snowy River (New South Wales): flows have been greatly reduced by regulation, yet catchment and riparian zone are in good condition.

Regulated rivers

Eleven percent of the river length in the assessment area is regulated and hydrological disturbance could be assessed for approximately half of this length. In regulated rivers that could be assessed, the hydrology of approximately 30% of the river length has been modified. The two components of the hydrology most affected are flow duration—one measure of flood frequency (40% of river length is modified)—and seasonal amplitude (30% of river length is modified).

This means that the rivers usually flow for longer periods than natural, and seasonal peaks and lows of intermittent systems are evened out to resemble perennial systems (see box p. 59).

Some regulated reaches have well-vegetated catchments, good riparian vegetation and good water quality. These include rivers such as the upper Snowy River and other rivers in alpine regions and central Tasmania.

Table 15. River hydrological disturbance subindex for each State and Territory.

	River length	Regulated (unregulated)	Assessed regulated (unregulated)	Largely unmodified	Moderately modified	Substantially modified	Extensively modified
	km	%	%	%	%	%	%
Queensland	74 475	8 (92)	48 (22)	86	10	3	1
New South Wales	62 208	18 (82)	65 (7)	13	66	20	1
Australian Capital Territory	283	51 (49)	61 (0)	0	100	0	0
Victoria	16 556	22 (78)	70 (7)	18	49	30	2
Tasmania	5 843	29 (71)	21 (22)	6	51	43	0
South Australia	10 205	10 (90)	48 (31)	30	49	16	5
Western Australia	26 900	4 (94)	0 (29)	–	–	–	–
Northern Territory	21 140	1 (99)	0 (90)	–	–	–	–
Total	**217 610**	**11 (89)**	**54 (26)**	**19**	**52**	**28**	**1**

CASE STUDY: CONDAMINE – BALONNE RIVERS, QUEENSLAND

The Audit's capacity to assess hydrological impact across Australia was limited. A detailed study of the ecological condition response to flow regimes of rivers has been conducted in Queensland and serves as an example of how this assessment can be done at a regional scale.

The Queensland Department of Natural Resources and Mines is undertaking intensive research into the interactions between biotic patterns and processes and the flow regimes of rivers. Its primary aim is to identify practical, cost-effective indicators that can be used to measure the success of flow-related strategies outlined in the State's water resource plans. Improved knowledge of ecosystem function and potential quantification of non-flow related impacts are additional benefits.

The project has been specifically designed to identify indicators of ecological condition that respond to an existing primary flow-change gradient. A wide range of indicators are being specifically measured for the study and then analysed to tease out the relative strengths of the various relationships. The second stage of the study will develop hypotheses and design models for testing and, ideally, quantifying the stronger relationships.

The environmental factors collected concurrently include:

- gradients of flow and land use;
- flow statistics;
- individual integrated water quantity and quality model statistics;
- water quality variables (e.g. conductivity, pH, turbidity);
- geomorphological and landscape features, including bioregion and geomorphic zones; and
- local habitat features, such as water depth, river width, water velocity.

Ecosystem indicators measured include:

- community composition of aquatic macro-invertebrates, fish, macrophytes, diatoms, macro-algae, frogs and phytoplankton;
- microbial community function; and
- benthic metabolism.

The Condamine–Balonne catchment in southern Queensland was chosen as the study area because a wide range of flow and landscape disturbance conditions that are suitable for a nested experimental design are present. It is expected that the study will continue for three years.

Preliminary results based on one sampling round indicate good correlations of flow gradients, as well as land use condition, with the fish, macro-invertebrate, phytoplankton and diatom community compositions (e.g. the flow gradients explained up to 46% of the variation in the macro-invertebrate communities, while the land use gradients explained up to 43% of the fish communities' variation; the macroalgae, bacteria and macrophyte communities did not show good correlations to either the flow or land use gradients). Analysis of each ecosystem health indicator is continuing.

Gully and bank erosion, Snowy River (New South Wales).

Nutrient and suspended sediment loads

Nutrient and suspended sediment loads are greater than natural levels for over 90% of the river length in the area assessed, and are severely modified in almost 10% the total river length (Tasmania and the Australia Capital Territory have no reaches in severely modified condition) (Table 16, Figure 41). Increases in total phosphorus and suspended sediment loads are strongly linked to degradation of water quality.

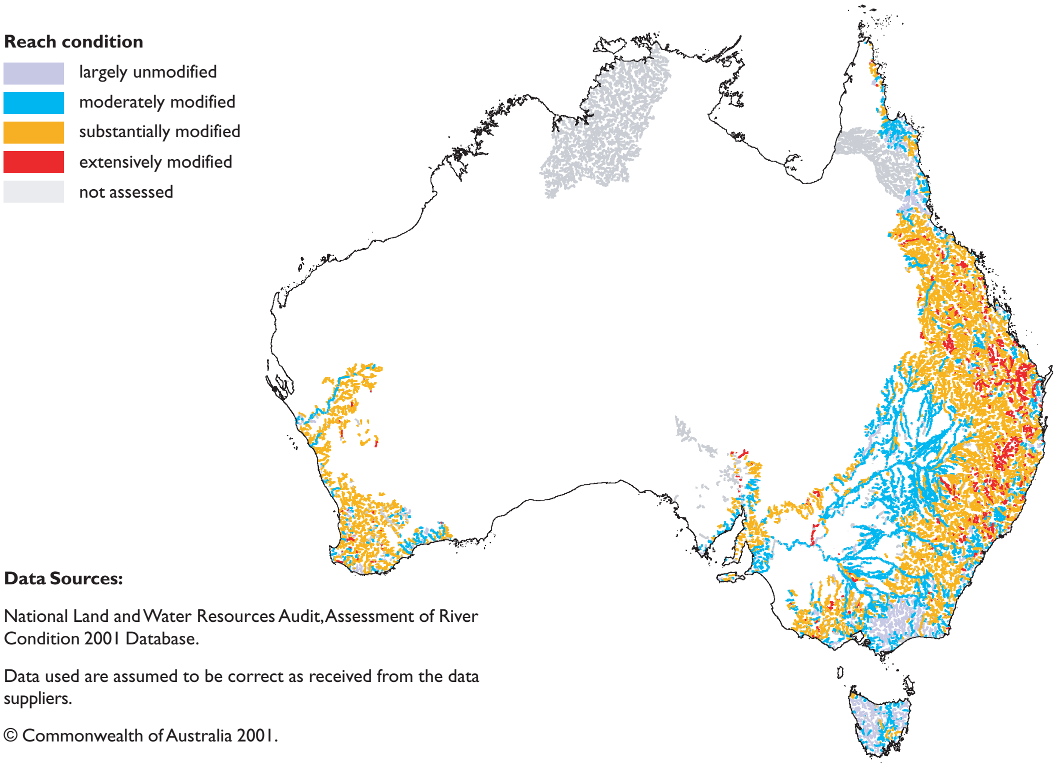
Total phosphorus loads in the rivers assessed have increased on average 2.8 times above natural levels. The average annual export of total phosphorus to the Australian coast from the assessed rivers is estimated as nearly 19 000 tonnes. Over 80% of the river length has suspended sediment loads that are 10–200 times natural loads. Several thousand-fold increases have been estimated in areas where gully and streambank erosion generate high sediment loads.

The processes causing high phosphorus and suspended sediment loads in rivers are linked because, in most regions, much of the phosphorus load is attached to sediment particles. The most likely principal factor generating high phosphorus and sediment loads is loss of vegetation in the catchment or riparian zone, leading to increased hillslope, gully and bank erosion and suspended sediment loads in the river. Main sources of sediment are gully erosion in degraded areas (particularly in south-western Australia) and hillslope erosion where cover is seasonally low through grazing or tillage of cropped lands (mainly in northern Australia) (NLWRA 2001b).

- Areas with the highest increase in phosphorus and suspended sediment loads include the north-east part of the Murray–Darling Basin, and areas subject to intense summer storms where gully erosion occurs on erodible and bare soils.
- Parts of western Victoria have significant gully and riverbank erosion on highly dispersible soils.
- Some Queensland catchments (e.g. the Herbert River Basin) are severely modified in terms of sediment loads and this reflects the intense summer rainfall and seasonally low vegetation cover associated with large areas of cattle grazing.
- Tropical crops on sloping lands have high soil erosion rates but the total amount of sediment generated by this land use is small compared with grazed catchments because grazing, although lower in intensity, covers a much larger land area.
- In Western Australia, the natural sediment yield is very low, so even a relatively small increase in suspended sediment load can be significant.

Forested regions in north-east Victoria, Tasmania, and north Queensland were the only areas assessed where existing suspended sediment loads were similar to natural loads.

Figure 41. Condition of river reaches based on the nutrient and suspended sediment load subindex.



Data Sources:

National Land and Water Resources Audit, Assessment of River Condition 2001 Database.

Data used are assumed to be correct as received from the data suppliers.

Table 16. Nutrient and suspended sediment load subindex for each State and the Australian Capital Territory.

	Total length of reach (km) in each category and percentage of total in parentheses				Percent of total length with data
	Largely unmodified	Moderately modified	Substantially modified	Extensively modified	
Queensland	2 809 (4)	12 660 (20)	40 347 (64)	7 573 (12)	88
New South Wales	1 692 (3)	23 784 (41)	27 630 (48)	4 678 (8)	97
Australian Capital Territory	9 (3)	89 (33)	172 (64)	0 (0)	100
Victoria	4 419 (29)	5 067 (33)	5 287 (35)	410 (3)	96
Tasmania	3 233 (59)	1 811 (33)	429 (8)	0 (0)	98
South Australia	210 (3)	2 860 (39)	4 112 (55)	203 (3)	76
Western Australia	870 (4)	2 988 (15)	15 759 (78)	461 (2)	98
Total	**13 242 (8)**	**49 258 (29)**	**93 736 (55)**	**13 324 (8)**	**81**

Comparison of the aquatic biota and the environment indices

Scores for the two main indices (aquatic biota and environment) would ideally be similar for each basin. The biota index does not demonstrate the same degree of degradation as the environment index. Reasons for this include:

- macro-invertebrates may be insensitive to some environmental changes, including large-scale changes (e.g. changes in connectivity and catchment disturbance), and to changes in some riverine habitat components (e.g. changes in salinity); the inclusion of other biota (e.g. streamside and aquatic plants, algae, fish or water birds) would give a more comprehensive assessment of the cumulative effects of environmental change;
- there may be lags between environmental degradation and biotic condition (e.g. nutrient or sediment loads to streams);
- an environmental component that would explain a biotic response was not measured (e.g. a toxicant); and
- modelled inputs to the environment index may not reflect actual site values or land management practices.

Spatial patterns in the environment index

When the subindices that make up the environment index are statistically analysed, there are patterns of reaches with similar characteristics for habitat, catchment disturbance and nutrient and suspended sediment loads.

The river reaches with the most urgent need for strategic management and rehabilitation are those in highly modified catchments that have lost much of their riparian vegetation and have dams and levees that disrupt movement of biota and material in the river (Figure 42). These reaches are located in parts of the Murray–Darling Basin, south-west Western Australia, western Victoria, and the South Australian wheat-growing areas.

River reaches that have largely unmodified habitat in terms of riparian vegetation, but very high nutrient and suspended sediment loads, and high potential erosion from hill slopes and stream banks are in need of rehabilitation by reducing nutrient and suspended sediment loads (Figure 43). These reaches are located in Queensland, northern coastal New South Wales, western Victoria and south-west Western Australia.

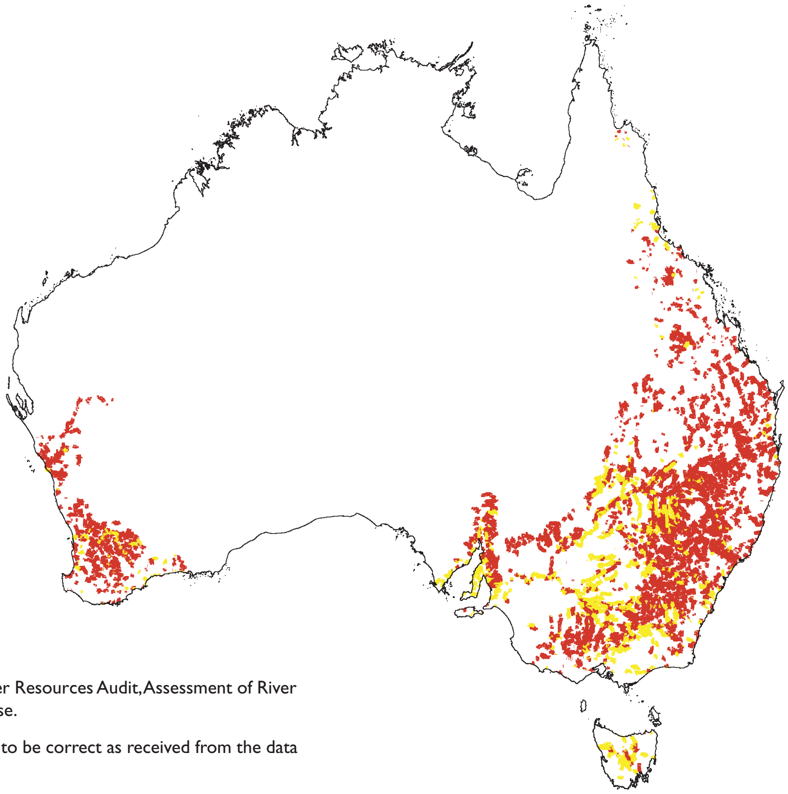
River reaches that are largely unmodified in all aspects (habitat, catchment disturbance and nutrient and suspended sediment loads) are scattered across Australia, and especially in far north Queensland, eastern Victoria and Tasmania. Protective management will ensure their condition is maintained (Figure 44).

Figure 42. River reaches with modified catchments, nutrient and suspended sediment loads, and habitat.

Groups of reaches

reaches with largely unmodified or moderately modified catchment condition, moderately substantially modified nutrient and suspended sediment loads and moderately to extensively modified habitat.

reaches with moderately modified catchment condition, substantially or extensively modified nutrient and suspended sediment loads and substantially or extensively modified habitat.



Data Sources:

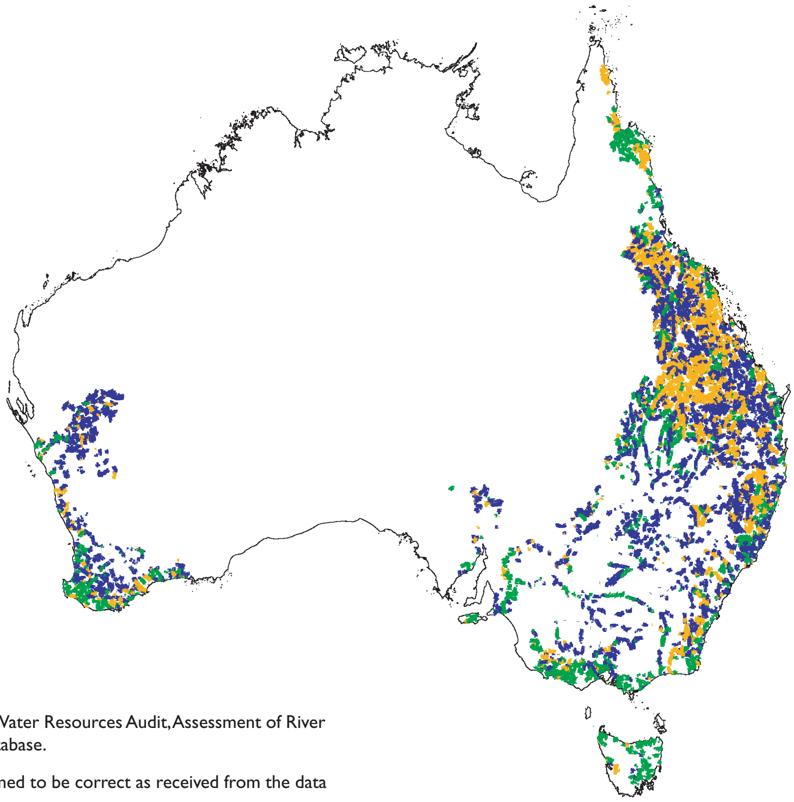
National Land and Water Resources Audit, Assessment of River Condition 2001 Database.

Data used are assumed to be correct as received from the data suppliers.

Figure 43. River reaches with largely unmodified catchments and habitat, but very high nutrient and suspended sediment loads.

Groups of reaches

- (orange) reaches with largely unmodified or moderately modified catchment condition, substantially or extensively modified nutrient and suspended sediment loads and largely unmodified habitat
- (green) reaches with largely unmodified or moderately modified catchment condition, moderately or substantially modified nutrient and suspended sediment loads and largely unmodified habitat
- (blue) reaches with largely unmodified catchment condition, substantially or extensively modified nutrient and suspended sediment loads and largely unmodified or moderately modified habitat.



Data Sources:

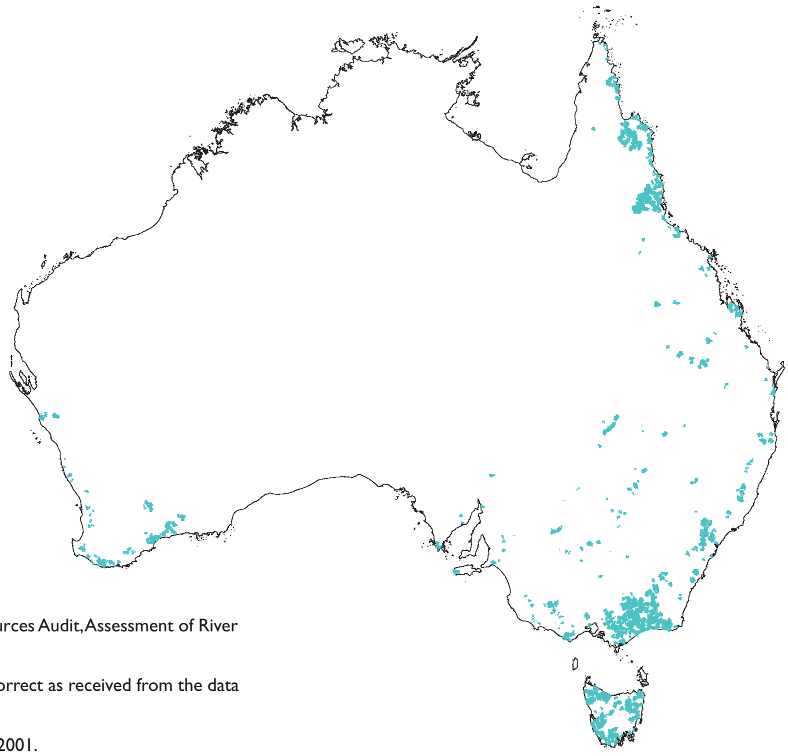
National Land and Water Resources Audit, Assessment of River Condition 2001 Database.

Data used are assumed to be correct as received from the data suppliers.

Figure 44. River reaches that are largely unmodified in all aspects (habitat, catchments and nutrient and suspended sediment loads).

Groups of reaches

reaches with largely unmodified or moderately modified habitat, largely unmodified and largely unmodified or moderately modified nutrient and suspended sediment loads



Data Sources:

National Land and Water Resources Audit, Assessment of River Condition 2001 Database.

Data used are assumed to be correct as received from the data suppliers.

Water quality monitoring as part of Water Watch

MANAGEMENT IMPLICATIONS AND FUTURE ASSESSMENT

Management response

Multiple issues have caused the degradation of river condition. Recognising the interconnected nature of many of these issues, an approach that deals with single issues (e.g. environmental flows) is unlikely to produce maximum benefits if other issues are neglected.

The condition of the upper part of a catchment and the connectivity along the stream will have major influences on the ultimate condition of river reaches downstream. Management responses that focus only on the symptoms of catchment-generated problems within main stems of rivers will be unlikely to achieve the desired outcomes; problems that are generated in upstream stems and tributaries also need to be considered.

To deal with the scale and complexity of the problems facing Australia's rivers, management responses should be guided by strategies that:

- address issues at appropriate spatial scales;
- are based on a sound understanding of river processes;
- are not focused on single issues; and
- use an integrated catchment management approach.

To advance effective management strategies ecological outcomes need to be defined and agreed.

After desired ecological outcomes have been identified, priorities for action can be formulated. Rutherfurd et al. (2000) have put forward a robust set of principles appropriate to the scale of this assessment of river condition. These principles establish priorities for action and appropriate types of action for the various groups of rivers:

- protecting reaches that support endangered species or communities;
- protecting reaches in the best general condition;
- stopping streams from deteriorating;
- improving the condition of damaged reaches and focusing on those that are easy to fix; and
- rehabilitating reaches that are already extremely degraded (lowest priority).

Once priorities for action have been established there is a considerable body of information on the appropriate planning and land management practices that should be applied to different land use activities (e.g. Lovett & Price 1999). Examples include agricultural practices focusing on minimum tillage and soil conservation, and conservative practices for urban development, stormwater and sewerage. These types of practices are aimed at minimising the delivery of material to rivers.

Other management practices deal with riparian areas, where limited stock access and revegetation can prevent gully and riverbank erosion, and buffer streams from soil and nutrient inputs. The large stores of fine sediment in some lowland rivers may mean that source reduction will not lead to measurable water quality improvements in lowland rivers in the short term.

Rehabilitation of rivers already carrying large amounts of sediment can be slow and made difficult by the scale of the problem. Sand slugs 40–80 km long, will take decades to move past a fixed point. Any conservation/rehabilitation strategy must be considered very carefully before action is taken.

Much of this information on good management practices has been available for a considerable time. If rivers are to be managed sustainably, the crucial step for river managers is to plan strategically and implement management action in the best possible areas. Assessments such as the river assessment provide a framework for inputs into regional natural resource priority setting and regional planning.

State management arrangements and policies

Following are examples of the management arrangements, legislation and policies for rivers in Australia

New South Wales

New South Wales has a range of intergovernmental and stakeholder arrangements for coordinating and consulting on water management issues. The Department of Land and Water Conservation is responsible for overall use and management of water resources.

Intergovernmental forums have been established to ensure whole of government involvement and commitment (e.g. the heads of the key water agencies in New South Wales form the Water CEOs, which meets a number of times a year to advise Cabinet on water policy issues). Key water agencies include:

- Department of Land and Water Conservation (lead agency for water, soil, vegetation resources and crown land management);
- Environment Protection Authority (lead agency for environmental pollution control and New South Wales State of the Environment reports);
- National Parks and Wildlife Service (lead agency for park and reserve management and biodiversity conservation);
- NSW Fisheries (lead agency for aquatic biodiversity and fish resource management);
- NSW Agriculture;
- Department of Urban Affairs and Planning (lead agency for statutory planning);
- Cabinet Office; and
- NSW Treasury.

The Water Advisory Council was established in 1995 to advise the Minister for Land and Water Conservation on water management issues. It is made up of representatives of the peak water user and interest groups (e.g. NSW Irrigators Council, NSW Farmers, NSW Aboriginal Land Council, Australian Conservation Foundation, Nature Conservation Council of NSW, and the Local Government and Shires Association).

At the local level, the Minister for Land and Water Conservation has established 32 water management committees with the key focus of developing draft water-sharing plans for major regulated river and groundwater systems and a number of priority unregulated river catchments throughout New South Wales. These water management committees are made up of representatives of local government; Indigenous, and water interest and conservation groups; catchment management boards; and water agencies.

Eighteen catchment management boards focus on managing land, water and vegetation in a more integrated way including establishing links between water and vegetation committees to ensure that their plans are compatible. These boards prepare catchment management plans that identify the key natural resource issues of the region, set the first order objectives and targets and develop management options, strategies and actions to address them.

Policies

One of the most fundamental changes to the water management framework in New South Wales was the passage of the *Water Management Act 2000* (NSW). This integrates a number of previous Acts into a single comprehensive piece of legislation that covers catchments to the sea. The objects of the Act are to ensure that water is used, shared and allocated in ways that will not threaten the ability of future generations to meet their needs. The Act recognises that the fundamental health of rivers and groundwater systems and associated wetlands, floodplains, estuaries and coastal waters has to be protected as a priority.

One of the requirements of the Act is the development of the *State Water Management Outcomes Plan*. This plan sets the overarching direction and specific targets for water management for the next five years including creation of water sharing and other water management plans and addressing (but not limited to):

- water sharing;
- water use;
- drainage management;
- floodplain management;
- controlled activities and aquifer interference; and
- environmental protection.

The Act also sets requirements for a range of water management plans (e.g. water sharing, water use, drainage and floodplain management) and provides a statutory basis for these. Water sharing plans that are currently being drafted will set the environmental flow rules and provisions to protect ecosystem health and will determine water available for users. The plans will be in effect for ten years.

Activities that may impact on rivers and groundwater and their dependent ecosystems are also to be managed under the *Water Management Act 2000*. This includes a licensing system and incorporation of environmental provisions into regional environmental plans.

Many existing State management policies will be recognised under the *State Water Management Outcome Plan*. The NSW Wetland Management Policy was endorsed in 1996 to encourage projects and activities to protect and restore the quality of the State's wetlands. The Weir Review Policy was introduced in the late 1990s to provide a framework for review and management of weirs to reduce their impact on the environment including fish populations. The NSW Groundwater-dependent Ecosystems Policy has been introduced to facilitate the protection of ecosystems dependent on groundwater supply for their survival including some baseflow to wetlands and rivers.

In addition New South Wales has introduced or is introducing a number of strategies that relate to the protection of river health. These include the NSW Water Conservation Strategy that addresses water use efficiency and conservation in urban and rural areas. Currently the NSW Aquatic Biodiversity Strategy is being drafted to protect the native biodiversity and ecological processes of New South Wales' aquatic ecosystems.

State water monitoring strategy

The State Water Monitoring Coordination Committee is responsible for the development of a State Water Monitoring Strategy. The scope of the Strategy includes all aspects of water monitoring (e.g. quality, ecosystem health, flow, height, tidal range, wave amplitude) for groundwater and surface water from freshwater to estuarine and marine waters. The committee is chaired by the Environment Protection Authority and membership includes the Department of Land and Water Conservation, NSW Fisheries, NSW Agriculture, NSW Health, State Forests NSW, Hunter Water Corporation, Sydney Water Corporation, Sydney Catchment Authority, CSIRO, NSW Coastal Council, Murray-Darling Basin Commission and Streamwatch.

In March 2001, the New South Wales Cabinet issued a decision on the development of the State water monitoring strategy. The decision included:

- the implementation of an interim strategy funded from existing resources and largely based on existing programs; and
- the development of a more comprehensive ongoing State water monitoring strategy to meet all government water monitoring needs.

It is anticipated that the ongoing State Water Monitoring Strategy will be put to Cabinet by December 2002 and that additional resources are likely to be required to implement the strategy.

Queensland

Water Resources Act 1989 (Qld)

- Administered by the Department of Natural Resources and Mines.
- Principal legislation for the protection of the physical integrity of non-tidal rivers, lakes, and springs and their riparian environments.

The Act applies to all lands (Crown and private) within the high banks of a stream or lake as well as imposing limited controls on lands outside of these features. It provides for protection against disturbances that may adversely affect the stability of bed and banks of streams and lakes (e.g. the clearing of native vegetation, excavation, and placement of fill). It also relates to activities outside of these features that may adversely impact on water quality. The protection is managed by way of a permitting system plus powers to issue 'stop work' notices.

Water Act 2000 (Qld)

- Administered by the Department of Natural Resources and Mines.
- Principal legislation for the allocation and management of water resources, both surface and groundwater, in Queensland.

The Act provides for the establishment of water resource plans, which specify water security objectives and ecological outcomes to be achieved in a basin or aquifer. Water security objectives may include tradable water entitlements to facilitate improved water use efficiency. Ecological outcomes may include environmental flows and other stream health objectives. Performance of the plans is regularly monitored against their objectives.

Vegetation Management Act 1999 (Qld)

- Principal legislation for the management of native vegetation on freehold land for ecologically sustainable use of land, protection of biodiversity and other environmental and social values, prevention of land degradation, and protection of water quality.

River Improvement Trust Act 1940 (Qld)

- Administered by the Department of Natural Resources and Mines.
- Establishes river trusts and provides powers to undertake works within streams for the purposes of flood mitigation and stream improvement or protection.

The Act does not provide river trusts with powers to permit or control works undertaken by other bodies or persons. It does give river trusts the power to impose a notice on landholders or other persons to prevent them from undertaking a work or activity where the river trust believes that activity may be detrimental to the condition of a stream or may adversely affect the works of the river trust. A notice may also require a person to rectify modification caused by an activity.

Rural Lands Protection Act 1985 (Qld)

- Administered by the Department of Natural Resources and Mines.
- Principal legislation for the management and control of certain pests and weeds in Queensland.

Certain animals and plants can be declared noxious in various categories under the Act for the purposes of control (destroy, reduce or contain). The Act requires occupiers of private lands to control all declared plants and animals. A person failing to do so may be served a notice by the local government or State to control specified plants or animals, in specified areas and by a set time. If the notice is not complied with, the local government or State may carry out the work listed in the notice and recover costs from the person. A notice binds successors in title.

Coastal Protection and Management Act 1995 (Qld)

- Administered by the Environmental Protection Agency.
- Principal legislation for the management of the State's coastline, including tidal streams, estuaries, coastal waters and surrounding lands. It provides powers to control development and activities within these lands.

Fisheries Act 1994 (Qld)

- Administered by the Department of Primary Industries.
- Principal legislation for the protection and management of the State's fresh and marine fishery resources, including marine plants, fish habitats and declared fish habitat areas. The clearing of marine plants (e.g. seagrasses, saltcouch, mangroves, melaleuca) is controlled through a permitting process.

Nature Conservation Act 1992 (Qld)

- Administered by the Environmental Protection Agency.
- Principal legislation for the conservation and management of the State's native flora and wildlife. This can be achieved by the declaration of protected areas and the management of these areas.

A key goal of the Act is the preservation of endangered, vulnerable and rare species of flora and fauna. This can be achieved through recovery plans, conservation plans and voluntary conservation agreements. Rivers often contain these species.

Environmental Protection Act 1994 (Qld)

- Administered by the Environmental Protection Agency.
- Principal legislation for the protection of the State's environmental values.

The Act imposes a general environmental duty of care on all persons, requiring them to take all reasonable and practicable measures to prevent or minimise likely environmental harm. The Act controls a wide range of activities (called environmentally relevant activities) by way of licence or permit, many of which could impact on rivers. It also provides power for the agency to issue an environmental protection order on unauthorised activities.

The *Environmental Protection (Water) Policy 1997* prepared under the Act establishes the framework for the protection of the environmental values of waters (including bed and banks). The value to protect the 'aquatic ecosystem' of waters would include protection of river values.

Information on aquatic weeds should be incorporated into future river assessments

Integrated Planning Act 1997 (Qld)

- Principal legislation for land use planning by the State's local governments.

The Act provides powers for local governments to declare and impose development constraints. It also establishes an integrated development application assessment system which involves all State and statutory bodies with powers relevant to a proposed development.

Future assessment of river condition

The results of the river assessment were limited by the available data. The assessment of river condition relied on disparate data sets provided by Commonwealth, State and Territory agencies. There are significant differences in the way data are recorded, stored and analysed across State and Territory borders, making it difficult to collate and synthesise data into an Australia-wide assessment. Standardised site codes and location coordinate systems (including datum, projection and accuracy) would save much effort and reduce a major source of error.

Measures of reliability and confidence in the results are also important to guide users of the information.

The results of the assessment are adequate given the limited data available, but better input data would allow higher resolution outcomes which could form the foundation for more informed decisions. The following improvements in Australia-wide data sets would increase the certainty and robustness of a future river assessment.

- Improved information on hydrology—change to hydrology, a major driver of river condition, was insufficiently represented in the river assessment because of lack of baseline data. Although there are many stream-gauging stations collecting data in a standardised way across Australia, there are very few modelled hydrological data on flow regimes prior to European settlement. Assessments also need updated data on extraction, catchment water yield and structures that modify hydrologic regimes.
- An Australia-wide data set on riparian vegetation—riparian vegetation is a critical ecosystem component, and information on its extent and condition is important for informed management (see box p. 86).

- Data on other aquatic biota (e.g. fish, water birds and vegetation) are needed to augment the Australia-wide coverage of macro-invertebrate information.
- Information on pollutants—the National Pollutant Inventory need to be expanded to include emission of biocides with arrangements put in place to require reporting of biocide use.
- Standardised collection of water quality data—many of the water quality data collected across Australia are collected to provide information on specific issues, or to assess drinking or recreational water quality. The inclusion of additional measures (e.g. water temperature, dissolved oxygen concentrations, and sediment and nutrient loads) would improve our understanding of water quality.
- Improved information on salinity—salinity is a increasing problem in many parts of temperate Australia. The database for stream salinity relies on sampling or continuous recording of salinity at a limited number of sites. This information could be augmented by development of a stream salinity model capable of predicting salinity concentrations based on catchment characteristics analogous to the sediment and nutrient models developed in the river assessment.
- Better understanding of habitat interactions—loss of habitat has been identified a major issue for most ecosystems, including aquatic ecosystems. Methods for assessing both instream and riparian channel form and habitat are needed.
- Information on pests—pest species (plant and animal) are known to have ecological impacts. Information is required about their extent and their interactions with riverine ecology.

Australia-wide reporting of river condition

To undertake the assessment of river condition, the project generated a national set of river reaches. This grouping is an important output and has potential for use as a common reporting unit in future river assessment and management. Reach definitions already in use by States/Territories or regional assessments can be used to refine the reach network and finalise an agreed reporting system. It should also be extended to encompass all parts of Australia.

A national protocol for reporting river condition has been developed for the Australian Natural Resources Atlas reporting and provides for the inclusion of results from river assessments at State/Territory or regional level. It strengthens the overall results of the river assessment, as the best available information can be incorporated from local, regional and State/Territory levels, without compromising the role of the national assessment.

The protocol:

- recognises that the Audit river assessment is an Australia-wide assessment and that more detailed assessments at the State/Territory or regional levels exist in some States;
- recognises that for comparable assessments to be considered they must be conceptually similar to the Audit river assessment;
- recognises that for comparable assessments to be considered they must be able to be linked spatially to the Audit river assessment;
- will adopt a precautionary approach whereby the result presenting the more conservative (least favourable) measure of river health or condition shall be applied;
- maintains the scientific principles and concepts underpinning the Audit river assessment; and
- will ensure that all decisions, results and assumptions are recorded and reported with the assessment results.

The reporting bands, ranges of results and nomenclature from comparable assessments will be evaluated and reviewed to produce a best fit with the Audit river assessment. Where the Audit river assessment or the comparable assessment does not report a value for a particular river reach then the assessment which has recorded a result will be used for that reach. Confidence limits that fall within the range of the results from the Audit river assessment (e.g. in the case of the Index of Stream Condition, results falling within $\pm 5\%$ of each other will automatically be ascribed to the reporting range of the Index of Stream Condition) will be determined for results from the comparable assessment. Where results differ by more than the confidence limits or by more than one reporting band, a case-by-case review will be undertaken against underlying data and other relevant information from the Audit river assessment and the comparable assessment, before placing the river reach into a condition class. In all other cases the precautionary principle is applied, thereby assigning the more conservative (least favourable) condition assessment.

Victoria, New South Wales and Queensland each have river condition assessment programs in place. When the protocol is applied to reach results for all States/Territories, a comparable Australia-wide assessment of river condition will have been achieved.

THE INDEX OF STREAM CONDITION: Victoria

The Index of Stream Condition used in Victoria is an aggregate indicator of the environmental condition of rivers and streams. It integrates information on major components of river systems that are important from an ecological perspective—current flow regime, water quality, condition of the channel and riparian zone, and invertebrate communities.

The Index of Stream Condition allows a holistic assessment of the health of rivers and streams. It was developed for catchment managers and the community to:

- benchmark condition of streams;
- assist in setting management objectives for river reaches;
- set priorities for managing river reaches; and
- assess long-term effectiveness of programs to maintain and rehabilitate streams.

The index is a monitoring tool based on scientific knowledge and principles, but which is user friendly and provides relevant information to catchment managers. It is designed to provide an overview of all the major environmental attributes that affect stream health at a level that is relevant to management within the constraints of cost.

During 1999, the Department of Natural Resources and Environment (Waterways Unit) together with the Victorian Environment Protection Authority, nine catchment management authorities, the Port Phillip Catchment and Land Protection Board, and Melbourne Water benchmarked the condition of 950 reaches of Victoria's major rivers and their tributaries.

Table 17. Subindices and indicators used to measure the Victorian Index of Stream Condition.

Hydrology	Streamside zone	Physical form	Water quality	Aquatic life
• Hydrologic deviation AAPFD—Amended Annual Proportional Flow Deviation • Presence of 'peaking' hydro power stations • Catchment permeability	• Width • Longitudinal continuity (% bank vegetated and number of gaps) • Structural intactness • Cover of exotic vegetation • Regeneration of indigenous vegetation • Condition of billabongs (floodplains)	• Bank stability • Bed condition • Presence of artificial barriers • Instream habitat: density and origin of coarse woody debris for lowland sites; epifaunal substrate for upland sites	• Total phosphorus concentration • Turbidity • Electrical conductivity (salinity) • pH	• SIGNAL—(water quality) • AUSRIVAS—(habitat quality)

Assessment methods

Nineteen key indicators were used to qualify aspects of stream condition (Table 17). Existing data sources were used where possible. Where data were not available, appropriate data collection procedures were developed. Data protocols were developed to extrapolate existing water quality and macro-invertebrate scores to surrounding reaches, and to transform the habitat data collected as part of the AUSRIVAS program so it could be used in the physical form and streamside zone subindices.

The Index of Stream Condition is reported as a bar that shows the score between 0 and 10 for each of the five subindices (Figure 45). The overall score is an inverse ranking to the five subindex scores, scaled back to a maximum score of 50. The overall score of the Index of Stream Condition will be between zero and 50 and can be used to classify stream condition on a five-point scale from very poor to excellent (Table 18).

Table 18. Victorian Index of Stream Condition reporting classifications.

Overall score	Stream condition
42–50	excellent
35–41	good
26–34	marginal
20–25	poor
0–19	very poor

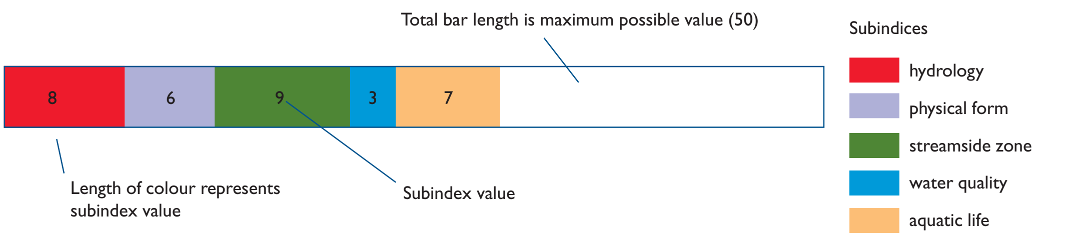
The Index of Stream Condition provides assessment for stream reaches typically between 10 and 30 km in length. These reaches are chosen so that they are relatively homogeneous in terms of the five subindices. The boundaries between reaches will commonly be based on significant changes to:

- hydrology (dams, significant diversions, confluence of similar size streams);
- physical form (artificial barriers, head cut at upstream end of an incising reach);
- streamside vegetation (significant change in topography or land use adjacent to the stream);
- water quality/aquatic life (point source pollution, towns or drainage outfalls).

Results

Data for all reaches from the 1999 benchmark are available as part of the Victorian State Data Warehouse which collates water quality, water quantity and community (Waterwatch) data for Victoria. On the website (www.vicwaterdata.net/isc) data can be grouped for a single reach, river, basin or catchment management area. Bar charts (containing the subindices), condition rating and individual ratings for each parameter and their respective rating tables are available. Fifteen hundred photographs showing the rivers of Victoria are also included.

Figure 45. Victorian Index of Stream Condition reporting bar chart.



STRESSED RIVERS ASSESSMENT PROGRAM FOR UNREGULATED RIVERS: New South Wales

The Stressed Rivers Assessment Program was initiated in 1997 as part of the New South Wales Government's water reform package to guide both management and planning priorities, and interim policies for unregulated rivers of New South Wales. The stressed rivers approach allows these priorities and policies to be tailored to the differing circumstances existing among unregulated streams, based on a consistent and transparent rationale. The Stressed Rivers Assessment Program provided the information to support this approach.

In New South Wales, 672 unregulated river subcatchments were identified. The program did not cover the regulated rivers (below major rural water supply dams) or the Georges, Cook and Parramatta rivers in the metropolitan areas of Sydney, parts of the Snowy River, Lake George, Australian Capital Territory rivers, the Barwon–Darling River, the Lake Eyre basin, Urana subcatchment or the Peacock Creek subcatchment. Subcatchments were classified according to their assessed level of environmental stress (particularly hydrologic) and conservation value. The assessments were based on available technical information and provide some baseline information for water management planning.

The framework involved a rapid assessment of the hydrologic and environmental condition of streams at the subcatchment level. Subcatchment boundaries were set primarily by hydrology but were also based on geology, terrain, social groupings, stream gauging and major water quality sampling points.

Measures or indicators of environmental stress (e.g. riparian clearing, bank erosion, fish barriers, reduced water quality) were estimated by a rapid desktop assessment method. The range of indicators used varied across the State, and were dependent on data availability. They were consistent at the catchment level. Measures for each indicator were ranked into low, medium or high stress levels and then combined to create a single high, medium or low environmental stress index.

Generally for unregulated streams, water extraction has the most significant impact on the level, frequency and duration of low flows. Therefore the hydrologic stress indicator was estimated from the proportion of the 80th percentile (flow that is exceeded on more than 80 days in every 100 days) daily flow extracted during month of peak demand. Each subcatchment was then classified as being of low (0–30% extraction of flow), medium (40–60% extraction) or high (70–100% extraction) hydrologic stress.

By combining these two indices, subcatchments were classified into nine overall stress categories and three overall stress levels (Table 19).

The classification process also identified subcatchments that have aquatic conservation values. 'High conservation value' rivers warrant special consideration in water management planning. This may relate to the presence of threatened species, high value species or wetlands, or high levels of biodiversity. Special conservation values may also reflect pristine or near-pristine condition of the rivers.

Under this stressed rivers assessment, 242 subcatchments were classified as high stress, with 211 (31.4%) subcatchments being unclassified—largely due to lack of hydrologic data. Approximately 81% of the unregulated subcatchments were assessed as having some identified conservation values with 98 (14.6%) of these considered to be of high conservation value.

Table 19. Matrix of stress classifications and management categories.

	Low environmental stress	Medium environmental stress	High environmental stress
High proportion of water extracted	Category U1 Despite high levels of water extraction the river seems reasonably healthy. However, more detailed evaluation should be undertaken to confirm. It is also likely that conflict between users may be occurring during critical periods.	Category S3 Water extraction is likely to be contributing to environmental stress.	Category S1 Water extraction is likely to be contributing to environmental stress.
Medium proportion of water extracted	Category U2 There is no indication of a problem and, therefore, such rivers would be a low priority for management action.	Category S4 Water extraction may be contributing to environmental stress.	Category S2 Water extraction may be contributing to environmental stress.
Low proportion of water extracted	Category U4 There is no indication of a problem and, therefore, such rivers would be a low priority for management action.	Category U3 Environmental stress is likely to be due to factors other than water extraction and, as stress is not high, these rivers would be a low priority for management action.	Category S5 While environmental stress is likely to be due to factors other than water extraction, the high level of environmental stress means it is important to ensure extraction is not exacerbating the problem.

Dark shading indicates categories with high combined stress rating.

Medium shading indicates categories with medium combined stress rating.

Lighter shading indicates categories with low combined stress rating.

RAPID ASSESSMENT OF RIVER CONDITION: Queensland

The objective of the Rapid Assessment of River Condition was to obtain a broad appreciation of the relative condition of Queensland's major river systems in terms of their natural biophysical values. Queensland's 76 river basins (as defined by the former Australian Water Resources Council) were used as basic reporting units for the assessment. A natural value rating based on a subjective assessment of the relative levels of disturbance in natural value indicators was produced for each major river system in Queensland.

Chosen criteria provided a broad representation of a stream's natural biophysical features and included:

- catchment hydrology (affected by flow regulation, water extraction, land use);
- water quality (affected by adjacent land use, flows, point source pollutants);
- river channel stability (affected by weirs, channelisation, gravel extraction);
- passage of native flora and fauna (affected by weirs, road crossings);
- native riparian vegetation (affected by stock disturbance, clearing);
- native instream species (affected by lost habitat, flow regulation, weeds and pests); and
- ecology of floodplain and river (affected by lost habitat, levee banks and land use).

Individual criteria were scored during a workshop in November 2000 that brought together scientists with expertise and knowledge of Queensland's rivers and used a range of supporting information including data sets, maps and reports.

Each criterion was scored on the basis of the present condition of the basin in comparison to its undisturbed (assumed pre-European) condition. Hence ratings were referential rather than absolute. The broad, subjective scoring system used was:

1. very large change from natural (severely impacted);
2. large change from natural (impacted);
3. moderate change from natural (altered with minor impact);
4. minor change from natural (altered but not impacted); and
5. insignificant change from natural (largely unimpacted or pristine).

As each criterion was scored, confidence ratings were assigned to the score. Basin scores were converted to a measure of degree of naturalness that ranges from 100% (pristine) to 0% (totally impacted). The pristine rating represents a perfect score in all the criteria, whereas the totally impacted rating represents the lowest score in all the criteria. As both criteria and scoring system used were subjective, the ratings can only be used to give a general indication of relativity and are not an absolute measure.

A comparison of results from the Queensland assessment with the Audit assessment of river condition identifies some differences, particularly for the nutrient and suspended sediment load index in basins north of the Stewart River, Cape York. These differences highlight the limitations of using 1996 land tenure data as a surrogate for land use and the need to have improved Australia-wide data sets showing intensity of land use. Spurious results may also be due to models that were not calibrated or verified for the climatic and geographic conditions existing in the Cape York streams.

ESTUARIES

SUMMARY

A reflection of catchment activity

- Dynamic, important systems that link freshwater and inshore marine waters
- Highly productive and diverse habitats providing fisheries, recreation and amenity
- Australia has 36 700 km of coastline and over 1000 estuaries
- Eighty-three percent of Australia's 19.4 million people live in coastal Australia

Estuary condition

- Near-pristine—50%
- Largely unmodified—22%
- Modified—19%
- Extensively modified—9%

Processes that shape estuaries and their management

- 17% of estuaries are wave-dominated 'true' estuaries—characterised by relatively high wave energy at the mouth and moderate river energy
- 11% are tide-dominated 'true' estuaries—characterised by relatively strong tidal energy throughout the estuary and moderate river energy
- 10% are wave-dominated deltas—characterised by moderate wave energy at the mouth and high river energy
- 9% are tide-dominated deltas—characterised by moderate to high tide energy throughout the delta and high river energy
- 5% are strand plains, coastal lakes and lagoons—characterised by relatively low wave energy and low to negligible river energy
- 35% are tidal creeks and flats—characterised by moderate tide energy and low to negligible river energy

ESTUARIES SUMMARY

Key issues

- Establishing and maintaining protective management for near-pristine estuaries
- Including estuarine management targets within catchment management planning processes
- Implementing a clearer delineation of institutional and lead agency responsibilities for estuarine management at State and national levels
- Developing an Australia-wide estuarine specific policy and management initiative that builds on the strong industry and community commitment for improved estuarine management
- Providing information, training and support for local government and community-based management

Bathurst Harbour, Tasmania

INTRODUCTION

The estuary assessment collated information on 979 estuaries and was undertaken to:

- assess the condition of Australian estuaries;
- develop a process-based understanding of estuaries and their diversity across Australia; and
- contribute to an information base that can underpin and inform estuarine management.

What is an estuary?

The estuaries included in this assessment were selected according to management interest rather than strict scientific definitions.

Estuaries come in all shapes and sizes, each unique to their location and climate. Estuaries are also known as harbours, bays, sounds, marshes, wetlands, inlets, coastal lakes, deltas and lagoons.

For the purposes of the estuary assessment, an estuary was broadly described as a semi-enclosed coastal water body where:

- salt from the open sea mixes with freshwater draining from the land; or
- marine and fluvial sediments occur together.

From a strictly geomorphic perspective, an estuary is a discrete type of coastal waterway. They are defined as

> *... the seaward limit of a drowned valley, which receives sediment from both river and marine sources and is influenced by wave, tide and river processes.*
>
> Heap et al. 2001

Only about 26% of the Australian coastal waterways included in this assessment are 'true estuaries' in terms of the geomorphic definition.

Estuaries are the report card of the catchment

Over 40% of Australian estuaries have small catchments (<15 km^2). The majority of estuaries in near-pristine and largely unmodified condition have unmodified catchments, which are either protected public lands or geographically remote.

A closer investigation of the more modified estuaries reveals that most of these have larger, more developed catchments, often with intensive development on and around their floodplains. These estuaries are generally near population centres and receive increased loads of sediment and nutrient from agricultural and urbanised catchments. Many of these estuaries suffer from the effects of severe environmental damage such as chronic algal blooms.

A strong correlation exists between catchment land use and estuarine condition. Through an improved understanding of the impacts of land use on the health of estuaries we are able to target and improve practices. Land use and catchment management in the context of estuarine and river condition will ensure more integrated and cost-effective management, building on the knowledge of cause and effect gained through monitoring river and estuarine condition.

Estuaries provide spawning and nursery areas for fish

THE VALUE OF ESTUARIES

We have long been attracted to estuaries. The middens of Indigenous Australians consist of shellfish and fish bones and are reminders of human reliance on the estuarine environment (e.g. Sydney harbour had middens 40 m high). Since colonial times, we have used estuaries and their connecting network of rivers for transporting agricultural goods for manufacturing and trade.

Estuaries are valued for their scenic beauty, recreation opportunities and their contribution to our quality of life. Estuaries are also valued as places for ports, shipping and industry, agriculture, tourism, cities, and residential development.

Two distinct forms of capital assets are associated with estuaries:

- natural capital; and
- human-made capital.

Natural capital

Estuarine ecosystems services such as:

- habitat, spawning and nursery areas for fish;
- habitat and breeding area for birds and native animals;
- nutrient cycling;
- the natural buffer between the land and the ocean provided by salt marshes and mangroves; and
- sediment and nutrient filtration by melaleuca, saltmarsh and mangrove wetlands providing cleaner water to the estuary and near-shore zones.

The quality of these services depends on maintaining estuarine health. Estuarine habitats include wetland areas (tidal mangrove forests and tidal marshes, melaleuca swamps and floodplains, tidal mudflats, seagrass and algal beds, sandy beaches, rocky shores, and the estuary floor) that support recreational and commercial fishing, and aquaculture.

Human-made capital

Human-made capital assets take advantage of natural assets (e.g. sheltered deep water for shipping movement, protected shoreline for industrial and urban development, effluent disposal and dispersion and natural beauty for locating tourist activities) usually modifying them (e.g. port facilities require dredging of estuaries to facilitate shipping movements) to suit the new land use. Human-made capital can operate without a healthy ecosystem; it can be responsible for damaging the ecosystem to the detriment of both natural as well as other human-made capital assets. Trade-offs are part of estuary management and need to be made in recognition of the benefits and costs of all options.

Monetary value of estuaries

Information on the monetary value of the natural capital, and the goods and services provided by estuaries is limited. One attempt has estimated the value of estuaries to be approximately $39 000 per hectare per year (Costanza et al. 1997). This work was constrained by the level of scientific and valuation studies available. The estimate concentrates on the use values rather than the non-use values.

Indicative values for natural capital can be based on production from selected commercial fisheries and the value of expenditure on recreational fishing; values for human-made capital can be based on the value of ports.

Fisheries

Fisheries value information is based on size of catch over a period of time. Changes in catch due to variability in weather conditions, reduction in estuary condition or fishers moving to another site mean that conclusions are difficult to form. More meaningful interpretation of change in fish catch would be possible if information about catch per unit effort, total fish populations and habitat condition were available.

Fisheries can be estuary dependent or estuary opportunist.

Estuary-dependent fisheries are those where the fish or crustaceans are critically dependent on the estuarine environment for the survival of the species. Their continued survival is dependent on estuaries remaining largely unmodified. The total value of Australian estuarine-dependent commercial fisheries has been estimated as about $432 m each year. Estuary-dependent fisheries include:

- prawn fisheries (e.g. northern Australian prawn fishery);
- oyster fisheries (e.g. Sydney rock oyster, a native species of oyster found along the east coast); and
- barramundi and mud crab fisheries along the north east coast and the Gulf of Carpentaria.

Estuary-opportunist fisheries are those where, although fish and crustaceans spend at least a part of their life cycle in an estuarine environment, they could equally use protected marine waters (e.g. as nursery areas) (Potter & Hyndes 1999). They include some species of crab, the Australian herring, salmon and whiting. Their continued survival is not as threatened by the modification of estuaries as estuarine-dependent species. Estuary-opportunist commercial fisheries are worth approximately $40 m each year.

Recreational fisheries: worth $2.9 billion each year

Estuarine dependent commercial fisheries

- The New South Wales oyster industry is estimated to have been worth approximately $29 m in 1999/2000 (valued as landed catch and excluding transport, processing, marketing and retailing of the product). Production between 1997 and 2000 is estimated to have declined by 350 tonnes. Most of this decline is due to poor estuary condition (e.g. bacterial contamination). Exports from the industry are negligible; imports of edible oysters have steadily increased since 1995 to 660 tonnes in 2000 (estimated to be worth over $5 m) (ABARE 2001). The increase in imports of oysters reflects our increasingly limited capacity to cultivate oysters in some New South Wales estuaries due to declining water quality.
- Production of prawns from the northern prawn fishery was worth over $107 m in 1999/2000. Production has declined from 8912 tonnes in 1997/98 to 5605 tonnes in 1999/2000 (ABARE 2001).
- Wild-caught barramundi in 1999/2000 is estimated to have a value (in price paid to fishers at the wharf) of approximately $12 m from the 1800 tonnes harvested from Queensland and Northern Territory. The recreational catch from these areas is about 600 tonnes. At this stage there is no agreement among economists on the correct method to combine the values of commercial and recreational sectors. One approach is to place a value using the equivalent price that commercial fisher would receive. This places a value of about $3.6 m on the recreational component of the barramundi fishery. Other estimates value the contribution of a single barramundi caught by a recreational fisher to be worth $153 to the economy. This approach would suggest that the recreational fishing of barramundi in Queensland alone could be worth up to $14 m each year.
- Commercial crab production (Queensland, New South Wales, South Australia, Western Australia and Northern Territory) in 1999/2000 was valued at around $42.3 m. Since 1997/98, the catch has only increased in Queensland and the Northern Territory.

Estuarine opportunist commercial fisheries*

- Queensland: include bream, mullet, snapper, tailor and whiting; valued at $5 m to commercial fishers; production has declined by almost 50% since 1997/98.
- New South Wales: include black and yellowfin bream, Australian salmon, rubberlip morwong, snapper and sand whiting; valued at $6 m; tonnage of harvested fish has declined substantially since 1997/98, from 1039 tonnes to 742 tonnes.
- Victoria: include bream, Australian salmon, King George whiting, pilchards, snapper and sea garfish; valued at $5.2 m; have remained relatively stable since 1997.
- Tasmania: include Australian salmon, garfish, varieties of morwong and trumpeter fish, school whiting; valued at $1.5 m; catches have remained relatively stable between 1997 and 2000.
- South Australia: include the Australian salmon, mullet, Australian herring, King George whiting, yellowfin whiting, pilchards, snapper and garfish; estimated to be worth over $14 m.
- Western Australia: include cobbler, sea mullet, yelloweye mullet, Australian herring, Australian salmon and whiting; valued at $4.5 m.
- Northern Territory: include jewfish, snapper and threadfin salmon; valued at $2 m.

Recreational fisheries

Recreational fisheries values are based on expenditure on fishing activity rather than production (as for commercial fisheries). Australia's recreational fishing industry is worth over $2.9 billion each year with at least 60% occurs within estuaries. This means that expenditure on recreational fishing in Australian estuaries, excluding flow-on impacts, is approximately $1.7 billion each year.

- Queensland: fishers are estimated to spend approximately $1000 each year on their fishing activities, including tackle, boats, travel and accommodation. Using these estimates, the contribution to the Queensland economy from individual fishers is approximately $880 m with about $528 m of this attributable to fishers in estuaries.
- Northern Territory: a total of 430 000 days are fished annually by recreational fishers responsible for an estimated $30 m each year of direct expenditure. Information is not available to identify what part of the catch was sourced from estuaries. The most popular recreational species in the Northern Territory, barramundi, is estuarine dependent.
- Western Australia: estimated to contribute over $500 m each year to the State's economy. Approximately 600 000 people or 34% of the population are estimated to fish. The coastal area between Kalbarri and Augusta attracts the highest level of recreational activity in the State with around 380 000 anglers responsible for a catch of between 400 and 500 tonnes each year.

* Current values are for 1999/2000.

Indigenous fishing

Information about the volume of fish caught in estuarine areas by Australia's indigenous populations is not available. The National Recreational and Indigenous Fishing Survey has been commissioned with the results expected to be released in early 2002.

Port infrastructure and annual revenue

Shipping is an important estuary use with the largest ports located close to State and Territory capitals (Table 20).

- Port Melbourne is the biggest port in Australia, handling $50 billion of trade annually and contributing $5 billion each year to the Victorian economy.
- The value of foreign trade handled at Queensland ports exceeds $14 billion each year.
- Marine-based tourist activities from these key ports are estimated to be in excess of $5 billion each year.

The location of large ports on estuaries has often required substantial dredging of the estuary to facilitate access for large shipping. Industrial waste from shipping has severely damaged the estuarine environment.

Table 20. Estimated value (including property, plant and equipment held by a number of port authorities and operating revenue from these authorities) of some major Australian ports 1999/2000.

Port Authority	Operating revenue ($ m)	Property, plant and equipment ($ m)
Sydney Port Authority	107	485
Melbourne Port Corporation	77	535
South Australian Port Authority	38	85
Fremantle Port Authority	55	88
Port Hedland	12	162
Port of Brisbane Corporation	79	480
Gladstone Port Authority	86	294
Hobart Ports Corporation	16	52
Darwin Port	6	56
Total	**476**	**2 237**

Understanding how natural processes and human modification affect the health of estuaries is important in the formulation of effective and affordable management strategies. The estuary assessment classified estuaries by both process type and condition. The information collated by the Audit is available to all estuary managers to assist in the development of management solutions and to monitor changes in existing estuarine condition.

Process classification

Australia's estuaries and coastal waterways were classified into six subclasses according to relative influence of the wave, tide and river energies that shape them. The overall geomorphology of an estuary is closely linked to these three main energy processes.

A seventh subclass 'other' accounts for the remaining 13% and includes drowned river valleys, embayments, and very small coastal lakes, lagoons and creeks.

The predominance of strand plains and tidal creeks (40% of the 972 estuaries classified) is a result of very low river discharges and reflects the fact that Australia is an arid continent with low relief.

Figure 46 presents the results of a plot of the relative importance of river, wave and tide energy on estuarine function. Figure 47 shows the distribution of Australia's estuaries by process type.

Validation of the classification was undertaken by mapping the geomorphology and sedimentary environments for 405 of Australia's modified estuaries (Figure 48). This work was completed by Geoscience Australia in cooperation with the States and the Northern Territory (see Heap et al. 2001). The mapping of sedimentary environments will also be useful to measure the extent of change in subsequent assessments.

Figure 46. Estuary types (as determined by sedimentary environment mapping) in the river – wave – tide energy triangle.

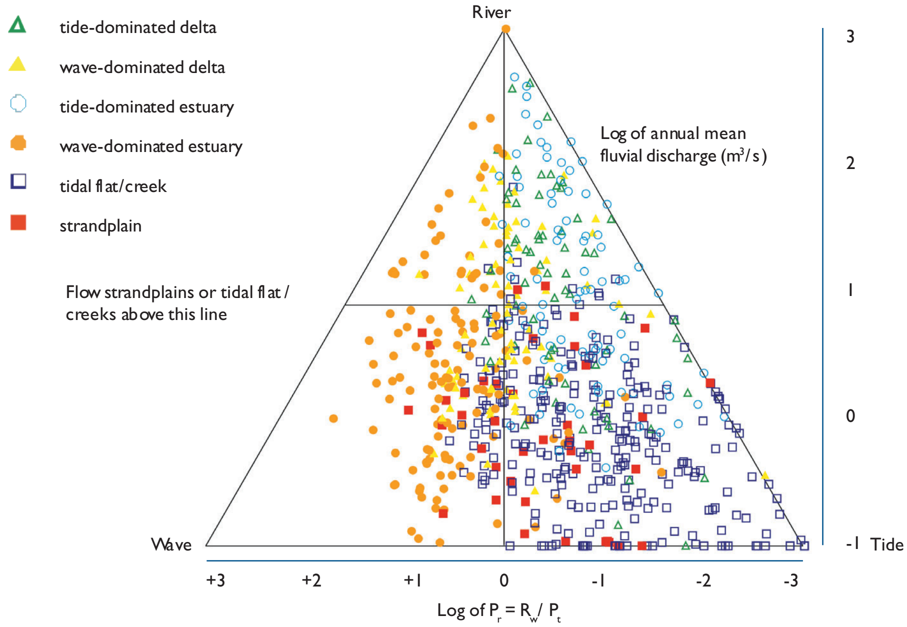
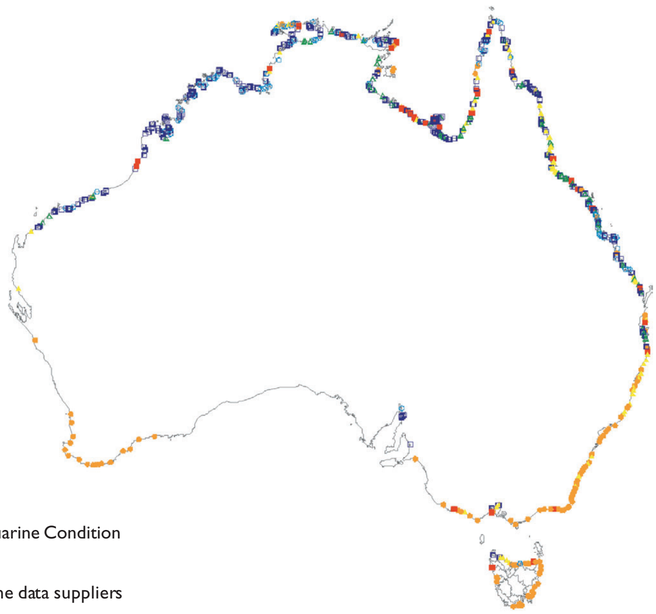


Figure 47. Distribution of Australia's estuaries by process type.



Data sources:

National Land and Water Resources Audit, Estuarine Condition Assessment 2002 Database

Data assumed to be correct as received from the data suppliers

Dominant sedimentary environments indicate different types of estuaries and coastal waterways

- wave-dominated estuaries: central basin is the dominant sedimentary environment
- wave-dominated deltas: mangroves/melaleuca and channels are the dominant sedimentary environment
- strandplains: intertidal flats, barrier/back barriers and channels are the dominant sedimentary environments
- tide-dominated estuaries: mangroves/melaleuca, saltmarsh and channels are the dominant sedimentary environment
- tide-dominated deltas: mangroves/melaleuca are the dominant sedimentary environment
- tidal creeks: mangroves/melaleuca and saltmarsh are the dominant sedimentary environments

Geoscience Australia developed conceptual models for four of the six coastal system subclasses based on idealised wave- and tide-dominated models in Dalrymple et al. (1992) (see Figures 49–52).

The four models illustrate the sedimentary environments for the main estuary types:

- explaining the links between form (geomorphology) and function (process);
- offering fundamental insights into the behaviour of estuaries and coastal waterways around Australia; and
- providing environmental managers with important information about the form and functioning of individual or groups of estuaries and coastal waterways.

Figure 48. Sedimentary environments in Moreton Bay, Queensland.

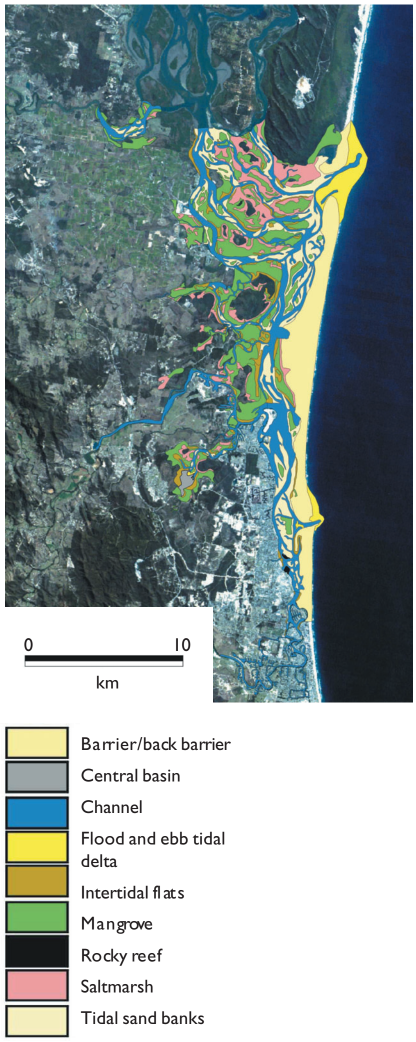


Figure 49. Wave-dominated estuary model. Examples include Lake Illawarra (New South Wales) and Swan River (Western Australia).

1. Wave-dominated estuaries are distinguished by relatively high wave energy at the mouth compared to tide energy.
2. Near the mouth, total energy is high due to the summation of high wave and tide energies.
3. Near the head, total energy is high due to high river energy. River energy declines downstream due to a reduction in downstream hydraulic gradient.
4. In the middle of the estuary, total energy is low because waves can not penetrate the estuary, and because tidal energy is dissipated on the ebb- and flood-tide deltas.
5. Waves transport sediment from the sea towards the estuary and build a barrier at the mouth. Tidal currents transport sediment into the estuary to form flood and ebb tidal deltas that extend seaward and landward of the inlet.
6. Landward of the barrier and flood/ebb tide deltas is a low-energy relatively deep central basin. The central basin is the main sink for fine sediment.
7. Waves and tidal currents deposit fine sediment on the edge of the central basin to form intertidal flats, and saltflats/saltmarshes. Mangroves are common along margins. Sandy beaches can also form.
8. Sediment from the catchment is deposited in the main channel, on the floodplain, and can be transported into the estuary to form a fluvial bay-head delta that extends into the central basin.

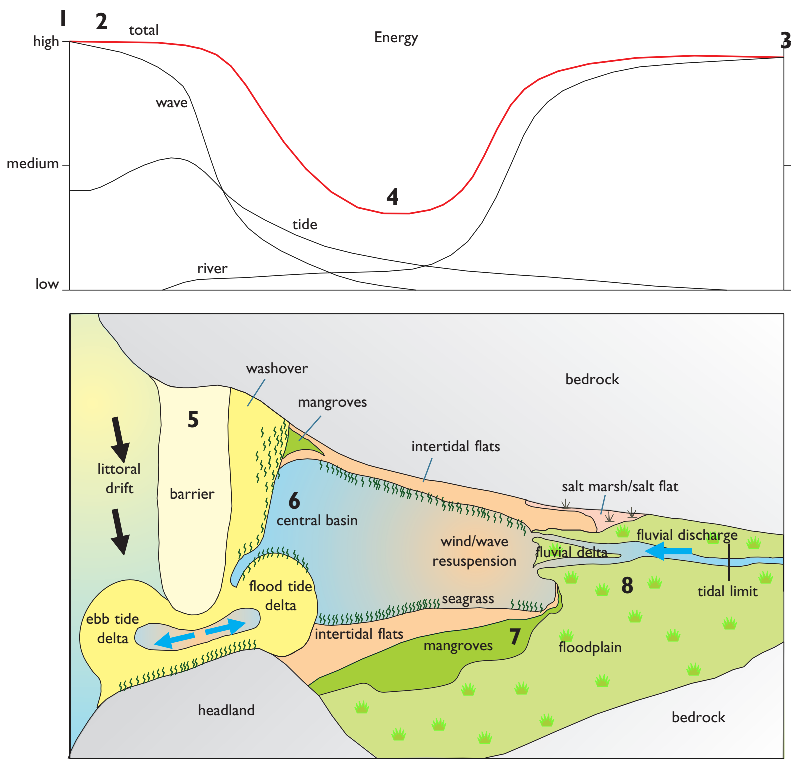


Figure 50. Tide-dominated estuary model. Tide-dominated estuaries are distinguished by relatively high tidal energy at the mouth compared with wave energy. Examples include the Ord River (Western Australia) and Broad Sound (Queensland).

1. Near the mouth, total energy is high because both tidal energy is high and wave energy is moderate.
2. Inside the estuary, wave energy is reduced over extensive tidal sand banks, thus decreasing total energy.
3. Total energy rises to a maximum where the difference between the effects of constriction by the funnel-shaped entrance (tidal-amplification) and effects of dissipation by sediment shoals is greatest.
4. Further headward, total energy falls to a minimum because friction created by the sediment shoals becomes greater than tidal amplification.
5. Total energy rises in the river-dominated zone because of constriction at the head.
6. In the funnel-shaped mouth, strong tidal currents transport coarse sediment into the estuary and build elongate tidal sand banks that extend to the zone of maximum total energy.
7. Near the tidal limit, where the channel is characterised by a sinuous river channel pattern, total energy is at a minimum. Sediment of mixed river and marine origin accumulates here.
8. Intertidal flats, mangroves, and saltflat/saltmarshes occur extensively along the sides of the estuarine channel (Woodroffe et al. 1989).
9. Tide-dominated estuaries are naturally turbid because of the strong tidal currents.

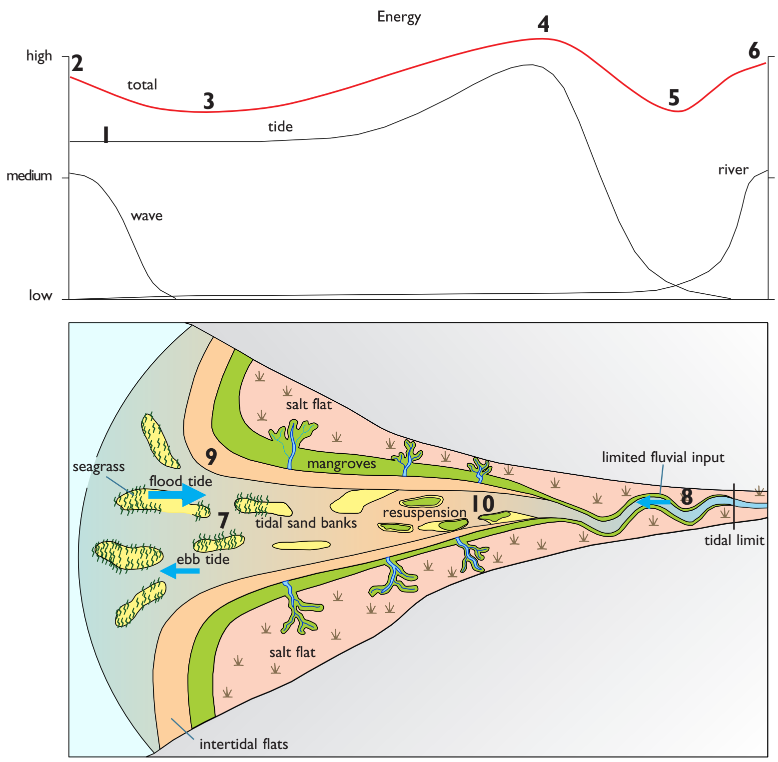


Figure 51. Wave-dominated delta model. Examples include the Manning River (New South Wales) and Yarra River (Victoria).

1. Wave-dominated deltas are characterised by relative high wave energy at the mouth compared to tide energy, and are distinguished from wave-dominated estuaries by high river energy.
2. Total energy at the mouth is high because of high wave energy at the coast.
3. Total energy declines immediately landward of the mouth because wave energy is dissipated on the barrier. The dominance of river energy further landward means total energy is relatively high along the channel.
4. Maximum tidal energy occurs in the constricted inlet mouth.
5. At the mouth, waves transport sediment towards the entrance and build a sub aerial barrier.
6. Sediment transported from the catchment by the river is deposited on the floodplain, forming levees and back swamps, and in the main channel.
7. River sediment is transported directly to the mouth because the channel connects the river's catchment with the ocean.
8. Relatively strong river energy causes net seaward-directed sediment transport. Coarse sediment deposited near the inlet forms flood/ebb tide deltas.

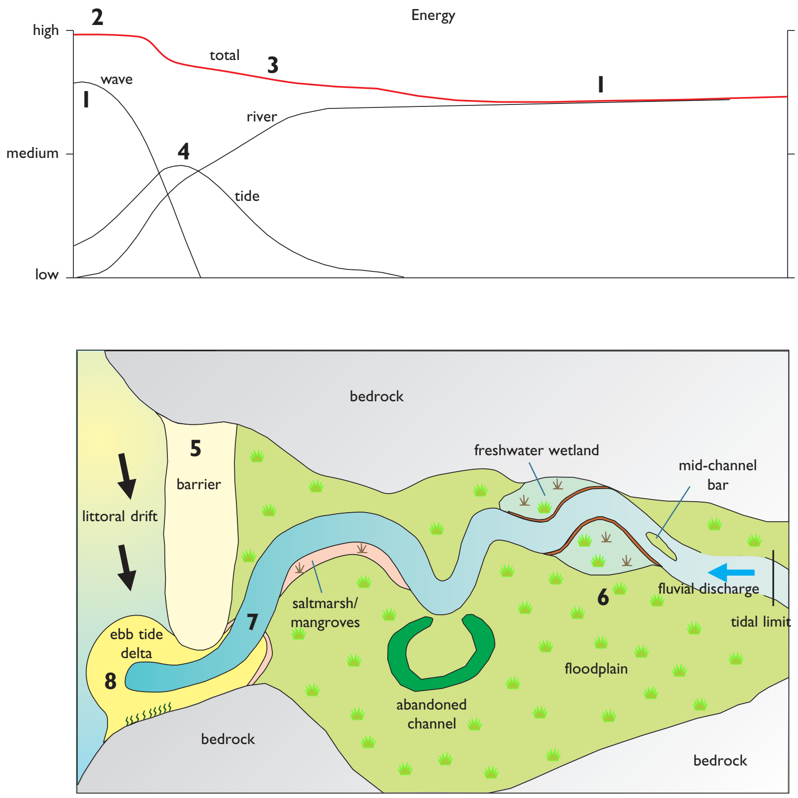
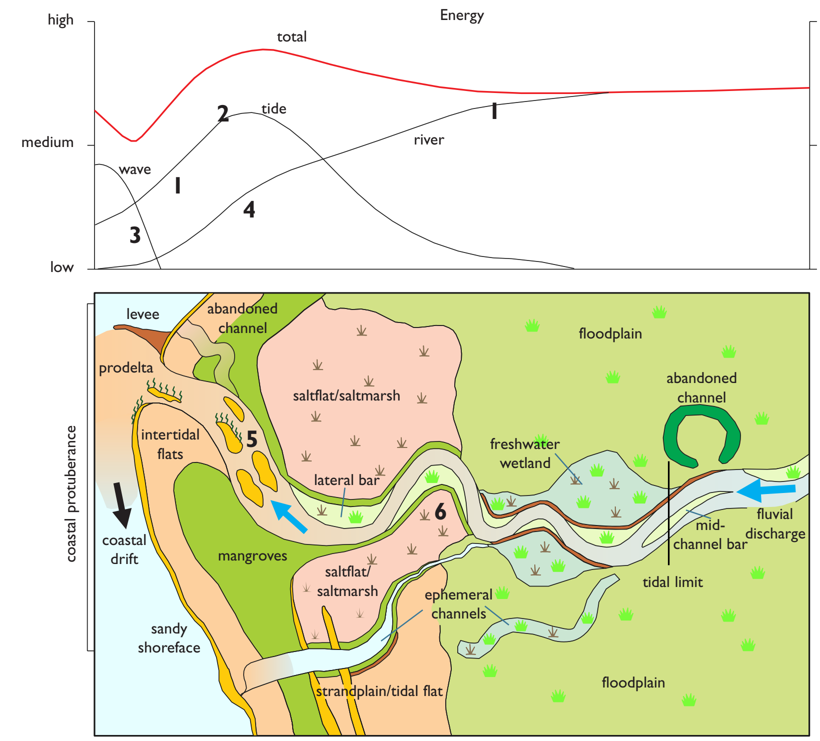


Figure 52. Tide-dominated delta model. Examples include the Macarthur River (Northern Territory) and Burdekin River (Queensland).

1. Tide-dominated deltas are characterised by relatively high tide energy at the mouth compared with wave energy, and are distinguished from tide-dominated estuaries by high river energy.
2. Tidal energy is greatest slightly landward of the mouth due to constriction by the funnel shaped mouth.
3. Wave energy is dissipated on shoals seaward of the mouth, and declines rapidly landwards.
4. River energy remains moderate to high along the channel, but drops off significantly as the channel widens towards the mouth.
5. Inside the mouth, moderately-strong tidal currents transport coarse sediment into the channel from offshore and build elongate tidal sand banks. These banks only extend a short distance into the channel because tidal energy is dissipated by channel friction.
6. Extensive areas of intertidal flats, mangroves, and saltflat/saltmarshes occur along the sides of the channel.



Building on our understanding of the impacts of land use activities, processes and estuary types, conceptual models can be developed to build an understanding of estuary ecology. This requires a three-dimensional approach, building an understanding of flows and fluxes between terrestrial and inter-tidal components, estuary surface, water column and estuary beds.

Three-dimensional conceptual models illustrating sediment transport processes and nitrogen cycling through the sedimentary environment suites of a wave-dominated estuary, a wave-dominated delta, a tide-dominated estuary, and a tide-dominated delta have been developed (Figures 53, 54). Other conceptual models are available through the Atlas.

Figure 53. Sediment processes in a tide-dominated estuary.

1. Fine and coarse sediment enter the estuary from the catchment, depending on river flow and sediment supply
2. The majority of coarse material is deposited at the head of the estuary, due to a reduction of river flow velocity and therefore sediment transport capacity. Some reworking and redeposition of material by tidal currents also occurs.
3. Fine sediment undergoes both deposition and erosion in intertidal flats, aided by biological activity such as burrowing. Coarser material is also deposited on flanking environments by tidal currents and flood events. A general trend of slow growth of intertidal sedimentary environments is observed.
4. Large quantities of suspended sediment are characteristic of tide-dominated estuaries, and a dynamic relationship exists between deposition, flocculation, resuspension and transport of sediment. Quantities of fine and coarse sediment can pool temporarily within the channel.
5. Mangrove sedimentary environments, with interspersed tidal drainage channels, commonly flank tide-dominated estuaries, and serve as a depocentre for fine and flocculated sediment. Tidal asymmetry (high energy flood and lower energy ebb), baffling by vegetation, and percolation of tidal water through animal burrows result in the deposition of fine sediment, and allow for the replacement of intertidal flats by mangroves.
6. Saltflat sedimentary environments experience inundation by king tides, and some deposition of fine sediment can occur. Ebb tide waters often flow through tidal drainage channels. Quantities of fine and coarse sediment can also be derived from the catchment and deposited during storm events.
7. Accumulation of coarse bedload material can occur within the mouth of the estuary, forming tidal sand banks. This material tends to be unstable and is redistributed in large quantities during storms. Seagrasses are able to colonise and fix the sediment to an extent, also mangrove colonisation can occur on larger sand banks.
8. Very little sediment is exported from the estuary overall, due to net landward transport driven by tidal action. The majority of sediment export occurs during flood events.

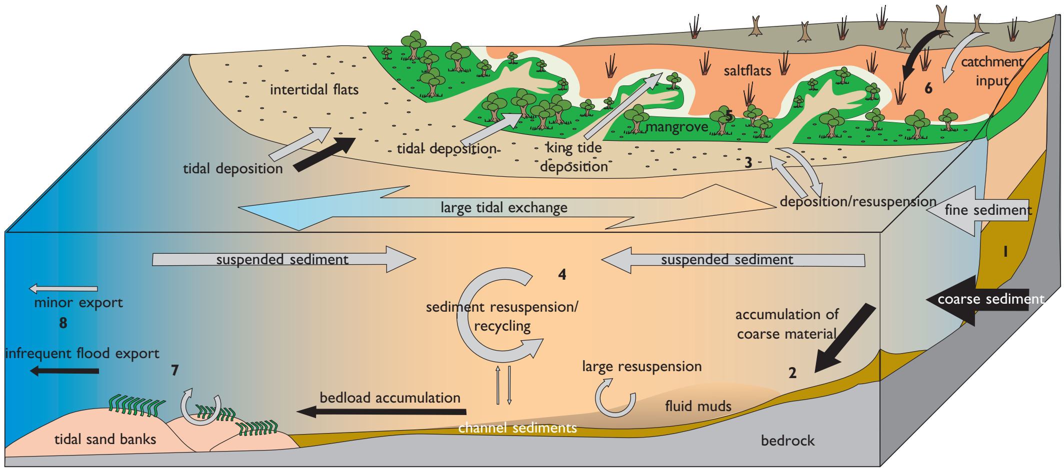
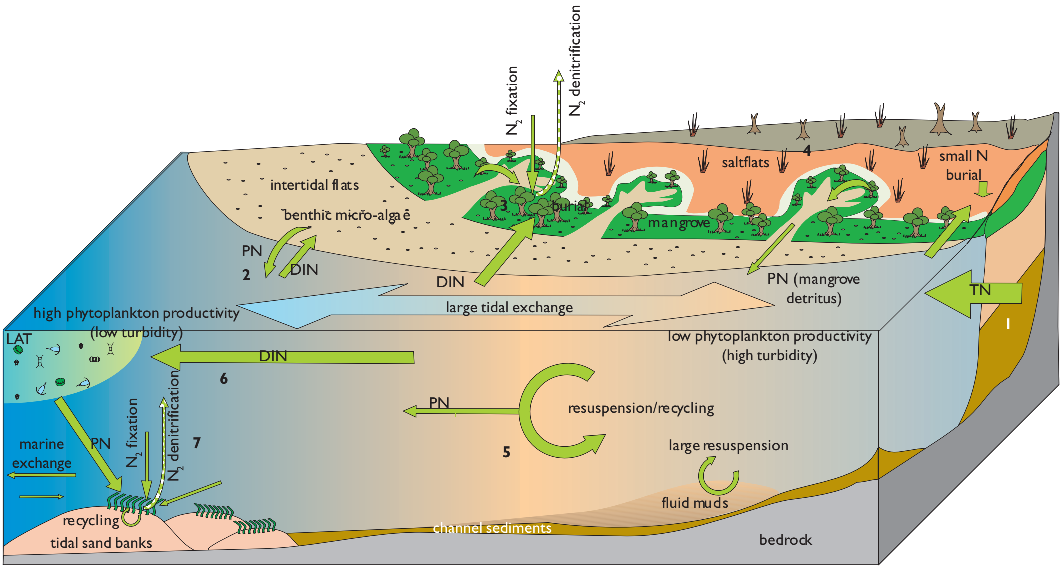


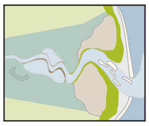
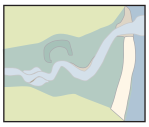
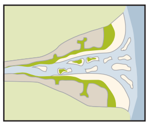
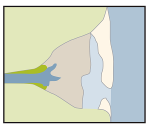
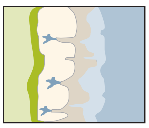
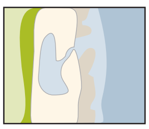
Figure 54. Nutrient processes in a tide-dominated estuary.

1. Nitrogen (particulate and dissolved; TN) enters the estuarine system from point- and non-point sources from within the catchment.
2. Tidal movements on the flanks of the estuary transport particulate nitrogen (PN) and dissolved inorganic nitrogen (DIN) onto the intertidal flats, where some of the dissolved inorganic nitrogen is converted to particulate nitrogen through the activity of benthic micro-algae.
3. Mangrove sediment is a net sink for dissolved inorganic nitrogen and particulate nitrogen. Nutrient uptake is driven by high rates of plant growth and microbial activity. N-fixation is active in the root-zone and contributes to the dissolved inorganic nitrogen pool. Some Nitrogen is liberated to the atmosphere as N2 gas through denitrification. particulate nitrogen is processed by biota such as crabs, or it is exported to the coastal waters as leaf litter and fine particulate matter. In the coastal waters it may be redistributed during ebb tides.
4. Small amounts of particulate nitrogen are buried in salt flats during king tides. Most particulate nitrogen is exported back into the estuarine channel during the ebb tide.
5. particulate nitrogen and dissolved inorganic nitrogen exist within the water column. However due to turbidity, phytoplankton productivity is limited. Circulation and resuspension of particulate nitrogen occurs in this zone. Particulate nitrogen is probably reworked during the resuspension process, and dissolved inorganic nitrogen can be re-mineralised to the water column.
6. A proportion of the dissolved inorganic nitrogen reaches the less turbid zone at the mouth of the estuary where phytoplankton convert it to particulate nitrogen.
7. Seagrasses, which colonise the tidal sand banks near the mouth of the estuary, also process dissolved inorganic nitrogen, in the same manner as that described for wave-dominated estuaries.
8. Typically, only moderate quantities of the total Nitrogen load are exported to the marine environment, however, this may be significant during flood events.



The dominant processes that drive estuary behaviour determine the susceptibility of estuaries to various pressures. Figure 55 describes the relative importance of estuary type to its susceptibility to impacts from changes in turbidity, circulation and sediment trapping.

Figure 55. Estuary types and their relative susceptibility to change. The estuary type diagrams illustrate key morphological features and diagnostic criteria for each type of system.

	Type of coastal environment	Sediment trapping efficiency	Turbidity	Circulation	Risk of sedimentation
	Tide-dominated delta	low	naturally high	well mixed	low
	Wave-dominated delta	low	naturally low	salt wedge / partially mixed	low
	Tide-dominated estuary	moderate	naturally high	well mixed	moderate
	Wave-dominated estuary	high	naturally low	salt wedge / partially mixed	high
	Tidal flats	low	naturally high	well mixed	low
	Strandplains	low	naturally low	negative/salt wedge/partially mixed	low

Nadgee Lake and Inlet in New South Wales is in near-pristine condition.

Condition assessment

Stage 1. Identifying Australia's near-pristine estuaries

A preliminary assessment of the condition of 979 estuaries was completed using qualitative information and expert opinion through State and Territory workshops and interviews using the assessment criteria outlined in Table 21. Additional information was sought to assist with more detailed assessment of all modified estuaries in Stage 2 of the condition assessment.

The photograph of Nadgee Lake and Inlet illustrates that despite the use of qualitative data, the identification of a 'near-pristine' estuary is relatively robust.

The near-pristine estuaries provide cost-effective opportunities to focus management activities on the protection of natural values. These estuaries provide reference sites to develop an improved understanding of natural estuary processes and are a key nature conservation and fishery resource.

The initial qualitative assessment was useful in:

- providing a framework for a rapid appraisal of estuarine condition;
- recognising that information on near-pristine estuaries was very limited;
- setting a basis for adding to and correcting entries in the Australian Estuary Database;
- leading to Australia-wide recognition of the scope of the project and assisting in defining the roles of all participants, including State and Territory agency staff; and
- allowing the project to move forward to more detailed assessment of modified estuaries.

Table 21. Criteria used in the initial assessment of estuary condition.

Near-pristine condition	Largely unmodified condition	Modified condition	Extensively modified condition
Catchment natural cover > 90%	**Catchment natural cover** ~ 65 – 90%	**Catchment natural cover** < 65%	**Catchment natural cover** < 35%
Land use limited roads & disturbance to natural conditions and processes	No known gross impacts from land use e.g. sediments to waterways and estuary	Documented impacts from land use (e.g. sediments and nutrients to waterways)	Documented impacts from land use throughout waterways and into estuary
Catchment hydrology No dams or impoundments, virtually nil abstraction	No dams or significant impoundments, some abstraction	Dams and impoundments, significant abstraction modifying natural flows	Dams and impoundments, significant abstraction modifying natural flows
Tidal regime No impediments to tidal flow, changes from natural morphology (e.g. training walls, barrages, bridges and causeways)	No significant impediments to tidal flow or changes from natural morphology	Impediments to tidal flow and/or changes from natural morphology (e.g. training walls, causeways, artificial opening of entrance)	Major changes to tidal flow and/or major changes from natural morphology
Floodplain Wetlands intact in vegetation and hydrology, no alterations to flood pattern	Wetlands mostly intact in vegetation and hydrology, no alterations to flood pattern	Wetlands mostly cleared in vegetation an/or changes in hydrology (e.g. drains, tidal barrages, levees)	Wetlands mostly cleared in vegetation an/or changes in hydrology (e.g. major losses in fresh to brackish wetlands)
Estuary use Extractive activities limited to Indigenous or limited and sustainable commercial and recreational fishing, no aquaculture	Extractive activities limited to sustainable commercial and recreational fishing, minor aquaculture	Extractive activities include dredging, extensive aquaculture, habitat modifying fishing methods (e.g. prawn trawling)	Extractive activities include dredging, extensive aquaculture, habitat modifying fishing methods (e.g. prawn trawling)
Pests and weeds Minimal impact on estuary from catchment weeds and limited pests and weeds within estuary	Minimal impact on estuary from catchment weeds and limited pests and weeds within estuary	Significant impact on estuary from catchment weeds and impact on estuary ecology from pests and weeds within estuary	Significant impact on estuary from catchment weeds and impact on estuary ecology from pests and weeds within estuary
Estuarine ecology Ecological systems and processes intact (e.g. benthic flora and fauna)	Ecological systems and processes mostly intact (e.g. some changes to benthic flora and fauna)	Ecological systems and processes modified (e.g. loss of benthic flora and fauna)	Ecological systems and processes degraded (e.g. major changes to habitats or species assemblages)

Stage 2. Assessing Australia's modified estuaries

The second stage of the assessment was to determine the relative extent of change for the modified estuaries from their pre-European settlement condition; a challenging task given the limited amount of data and information available.

The assessment framework needed to be able to take into account:

- that our values, uses and perspective bias any assessment;
- that no single environmental indicator will unambiguously define the interaction between ecosystem form and function, resilience and stability of biological communities and estuarine responses to anthropogenic stress; and
- that the data for each of the estuaries is not consistent or comprehensive.

A pressure–state–response framework (ANZECC 2000, Deeley & Paling 1999, Ward et al. 1998) (Table 22) was used as the basis of a more detailed condition assessment for Australia's modified estuaries. The assessment attempted to capture and quantify as much of the information as possible while considering key processes that drive the way a specific estuary functions.

Table 22. Pressure–state–response assessment framework.

State ranking	Ecosystem integrity index (70%) Water and sediment quality index (10%) Fish health index (10%) Habitat condition index (10%)	near-pristine	largely unmodified	modified	extensively modified
Pressure ranking	Utilisation index (50%) Susceptibility index (50%)	low – no pressure	low – medium pressure	medium – high pressure	high – very high pressure
Response	Responses are documented in terms of institutional arrangements, management actions and community initiatives, but are not scored				

Figure 56. Condition of Australia's estuaries. Fifty percent are near-pristine, 22% are largely unmodified, 19% are modified and 9% are extensively modified.

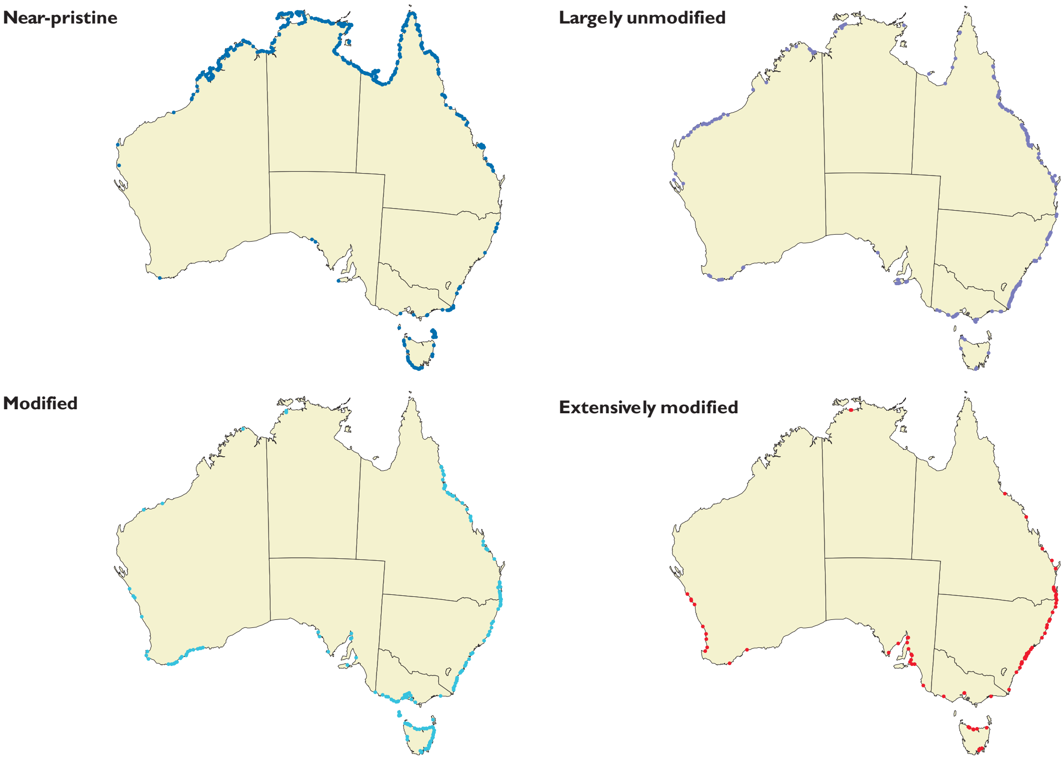


Table 23. Condition of Australia's estuaries by process type.

Class	Subclass	Near-pristine	Largely unmodified	Modified	Extensively modified	Total
Wave	estuary	28	41	62	25	156
	strandplain	36	13	10	1	60
	other	40	30	22	17	109
Tide	estuary	57	25	9	4	95
	tidal flat/creek	210	43	16	15	284
	other	40	17	23	9	89
River	wave-dominated delta	28	24	30	12	94
	tide-dominated delta	36	16	11	9	72
Not classified		9	1	3	0	13
Total		**484**	**210**	**186**	**92**	**972**

Tidal flats and creeks

Most of Australia's estuaries are tide-dominated systems with tidal flats and creeks particularly dominant (29%). Tidal flats are low gradient accumulations of fine sediment or mud, often dissected by numerous tidal channels. Tidal flats occur in regions that have a high tidal influence and are most extensive in macrotidal regions (e.g. Northern Territory, north-west Western Australia) and along muddy low-gradient coastlines (e.g. Gulf of Carpentaria).

Tidal flats drain out at low tide and have mangrove-lined channels with expanses of saltmarsh located further landward, between intertidal and supratidal levels.

Tidal creeks are small tidal channels cut into coastal flats. They are often associated with tidal flats, draining and filling the flats during each tidal cycle. The banks of tidal creeks are generally above the high tide limit. An example of a typical tidal flat system is Moonlight Creek located on the south coast of the Gulf of Carpentaria.

Tidal flats and creeks are well mixed and often naturally turbid. Tidal flows usually have enough velocity to re-suspend fine sediments (mud). Seventy-four percent of Australia's tidal flats and creeks are in near-pristine condition. Most of the tidal flats and creeks have small coastal catchment areas, often in undisturbed condition.

Figure 57. Condition of tidal flats/creeks (284 estuaries assessed).

True estuaries

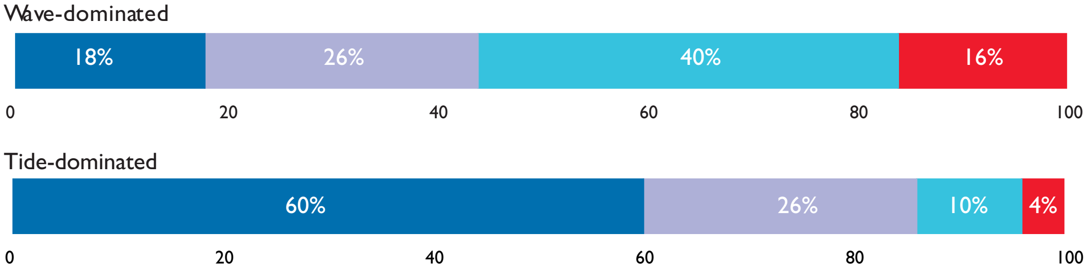
From a geomorphic perspective an 'estuary' is a discrete type of coastal waterway. They are defined as the 'seaward limit of a drowned valley, which receives sediment from both river and marine sources and is influenced by wave, tide and river processes'. Of the coastal waterways assessed, 26% were classified as 'true' estuaries in a geomorphic sense (16% are wave-dominated estuaries and 10% are tide-dominated estuaries).

Wave-dominated estuaries are characterised by a sandy barrier parallel to the shoreline at the mouth with a low energy central basin landward. Built by wave action, the bar often constricts the entrance of wave-dominated estuaries. Wave dominated estuaries have a high tendency to trap sediment and are generally partially mixed. This type of system tends to be seasonally stratified with naturally low turbidity (except during high winds or flood events). Nutrients recycled from the sediments in the central basin may make systems susceptible to algal blooms. An example of a typical wave-dominated estuary is Lake Illawarra in New South Wales. Wave-dominated estuaries are also known as barrier estuaries, coastal lakes or lagoons.

Geomorphic formations such as the barrier, and flood and ebb tide delta, coupled with the longshore drift and accumulation of marine sediment, reduce the opportunity for ocean exchange and flushing of wave-dominated estuaries. In Australia, wave-dominated estuaries are popular for recreational and residential development. Sediments and nutrients from the catchment generally accumulate in the estuary, making wave-dominated estuaries susceptible to problems associated with poor flushing and increased nutrient levels.

The natural susceptibility of wave-dominated estuaries to development pressures is reflected in the high proportion of modified wave-dominated estuaries. A common management response to water quality problems and navigation difficulties is to artificially open the entrance. Artificial opening is achieved either permanently with training walls (e.g. Wallis Lake New South Wales, Lakes Entrance Victoria) or by bulldozing the beach berm (e.g. many of the smaller New South Wales and Victorian wave-dominated estuaries). This can have serious ecological consequences (e.g. immature black swans can become stranded in wetlands and unable to travel to open water, such as at Smith's Lake and Lake Cathie – Lake Innes, New South Wales). Artificial opening strategies are the subject of many community debates. Certainly strategies need to recognise a range of management objectives and values including waterbird breeding, fisheries, navigation needs, water quality, flooding risk and likelihood of rapid re-closure from seasonal wave conditions.

Figure 58. Condition of true estuaries (156 wave-dominated estuaries assessed; 95 tide-dominated estuaries assessed).



Tide-dominated estuaries are typically funnel-shaped, and contain elongated sand bodies known as tidal sand banks in the main tidal channel(s). These elongated sand banks are generally orientated parallel to the direction of tidal flows. Tide-dominated estuaries trap coarse sediment as part of the development of the tidal sand banks and fine sediment on the margins in the form of intertidal flats, mangroves and salt marshes. Driven by higher velocity tidal flows than their wave-dominated counterparts, tide-dominated estuaries generally have naturally high turbidity and are well mixed throughout the year. An example of a typical tide-dominated estuary is Adelaide River in the Northern Territory.

Tide-dominated estuaries are generally highly turbid due to strong tidal currents. The relatively unconstricted entrance and strong tidal currents enhance flushing, relieving them from some of the impacts of nutrients and sediments. These systems act as a conduit for sediments and nutrients from the catchment to the near-shore marine zone. This underlies the importance of improved catchment management to reduce sediment and nutrient loads in the river basins with these types of estuaries (e.g. Fitzroy River adjoining the Great Barrier Reef).

Deltas

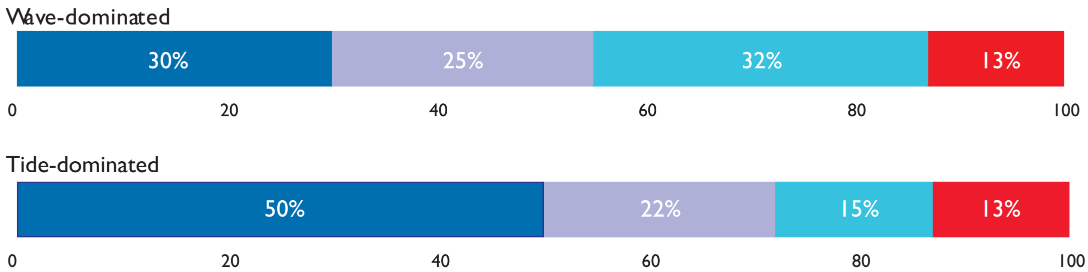
Seventeen percent of Australia's estuaries are deltas (10% wave-dominated, 7% tide-dominated). Deltas are broadly defined as coastal accumulations of river-derived sediment that generally protrudes into the near-shore environment. Deltas are generally net exporters of sediment due to the high river influence.

Wave-dominated deltas have bow-shaped shorelines, poor flushing generally low turbidity and experience partial mixing and salt wedges. Tide-dominated deltas are generally turbid and well mixed.

Sediment delivered to the coast in regions of high wave energy (e.g. New South Wales) may be transported along the shoreline and the wave-dominated delta may not protrude (e.g. Brunswick River, New South Wales). An example of a typical wave-dominated delta is Nassau River (Queensland); an example of a typical tide-dominated delta is McArthur River (Northern Territory).

Both tide and wave-dominated deltas contribute substantial amounts of sediments and nutrients to the near-shore environment. Along the New South Wales coast, sediments and nutrients escaping deltas are transported along the coast by wave and ocean currents. Along the Queensland coast progradation of deltas into the near-shore environment may be extensive (e.g. Burdekin River).

Figure 59. Condition of deltas (94 wave-dominated estuaries assessed; 72 tide-dominated estuaries assessed).



Jerusalem Creek: a wave-dominated strandplain in near-pristine condition

Strandplains, coastal lakes and lagoons

Six percent of Australia's estuaries are drainage points for strandplains. Strandplains are sand bodies that run parallel to the shore and contain beaches, swales and dunes. They are found along prograded linear coasts. Strandplains are not associated with embayments, but are dune systems inter-filling between headlands.

Strandplains are usually associated with small to negligible river input and drain the immediate area of dunes and swales. Wetland and coastal heath systems are often extensive, with creeks usually only intermittently open to the ocean. An example of a strandplain is Jerusalem Creek, New South Wales.

Figure 60. Condition of strandplains, coastal lakes and lagoons (60 estuaries assessed).

Estuaries of Australia's capital cities

The diversity of estuary types distributed around Australia is indicated by the estuaries associated with Australia's capital cities

Table 24. Estuaries of Australia's capital cities.

	Port	Estuary class/subclass	Condition
Darwin	Darwin Harbour	tide/other	largely unmodified
Brisbane	Brisbane River	river/tide-dominated delta	extensively modified
Sydney	Port Jackson	tide/other	extensively modified
Melbourne	Yarra River	river/wave-dominated delta	extensively modified
Hobart	Derwent River	tide/other	extensively modified
Adelaide	Port River Barker Inlet	tide/tidal flat/creek	extensively modified
Perth	Swan River	wave/estuary	extensively modified

Excess nutrients in estuaries cause algal blooms

Application of the results

A more detailed study of Australia's modified estuaries enhances our understanding of their condition and the pressures they face. The assessment provides an on-line framework to encourage others to contribute information and knowledge, on what is and is not known, for the estuaries where they live and work. This information will enhance our collective understanding of estuarine management issues and the appropriateness of different management strategies for preventing further degradation and improving estuarine condition.

Limitations of the assessment

The assessment provides an excellent overview of the condition of Australian estuaries with some limitations:

- although based on existing data where available, the assessment is highly subjective and grounded in expert opinion;
- insufficient data was available to support a quantitative assessment of the condition of many Australian estuaries;
- due to the lack of data on both modified and near-pristine estuaries, the assessment was unable to define precise benchmarks to establish the extent of change for Australia's modified estuaries; and
- assessments were conducted as snapshots in time and do not provide trend information.

Key pressures on estuaries: common challenges facing Australia's modified estuaries

- Excess nutrients—nitrogen and phosphorus, are necessary for plant and animal growth. High levels of nutrients can cause algal blooms or epiphytic growth that block sunlight and lower oxygen levels in the water. This can result in the loss of underwater vegetation and fish kills. Nutrients are sourced from decaying plant and animal material, eroded soil, sewage, industrial discharges, stormwater run-off, fertilisers, garden waste and agricultural run-off.
- Sedimentation—infilling as a result of the contribution of fine grained sediments from the catchment and near-shore marine sands is particularly significant for wave-dominated systems.

  Excess sediment can cause problems as many nutrients, toxicants and pathogens are transported with the sediment. Vegetation clearing and land use in the catchment can cause an increase in catchment erosion and sediment inputs to the estuary. For tide-dominated systems particularly, where sediments are transported through the estuary, plumes of sediment extend offshore, particularly after floods and heavy rains.
- Habitat loss—estuarine habitats provide food, cover, migratory corridors and breeding/nursery areas. These habitats perform other important functions (e.g. improving water quality and reducing flooding). Important habitats (e.g. shallow sandy flats, seagrass beds, saltmarshes, mangroves and floodplain wetlands) have been affected by drainage, clearing for commercial and recreational developments and dredging.

- Changes to natural flows and tidal flushing—freshwater is an increasingly valuable resource in a continent as dry as Australia. The construction of dams and weirs and the extraction of freshwater has altered the amount and flow regime of freshwater entering estuaries. Natural drought cycles increase the adverse effects of these changes, including increased sedimentation and impacts on fish reproduction and shellfish survival. Many structures restrict freshwater and tidal flows (e.g. bridges, causeways, floodgates and levees).
- Pathogens and toxicants—pathogens are disease-causing organisms such as viruses, bacteria and parasites. Toxicants such as heavy metals, pesticides and polychlorinated biphenyls accumulate in the tissues of plants and animals. Pathogens and toxicants can lead to closures of shellfish areas, fisheries, and swimming and surfing beaches. Sources of pathogens include human and animal waste from boats and marinas, sewage, and stormwater. Toxicants enter estuaries via industrial discharges, stormwater, agricultural run-off and shipping.
- Introduced pests—intentional or accidental introductions of biota from other environments can result in unexpected ecological and economic impacts to estuaries. Introduced organisms can destroy native populations, introduce pathogens, degrade habitats and interfere with fishing, boating and swimming. Examples include rice grass and the black striped mussel. Sources of introduced pests include ship ballast waters, aquaculture and the aquarium trade.
- Modifications to ocean entrances. Training walls and artificial entrance opening regimes can have significant impacts on estuarine ecology such as larval recruitment to the estuary.

CASE STUDY: Gippsland Lakes

Illustrating the complex nature of estuary management

Introduction

In 1995 the funding and responsibility for 12 local ports in Victoria was transferred from the Port of Melbourne Authority to the Department of Natural Resources Environment. In 1996 the Department of Natural Resources and Environment outsourced the management of these ports and appointed local port managers. In the case of the five Gippsland Regional Ports the manager is the Gippsland Ports Committee of Management.

The Port of Gippsland Lakes encompasses one of Australia's largest estuaries stretching from Sale in the west to Lakes Entrance in the east. The port is the largest of the Gippsland Ports and covers the lower reaches of the Latrobe, Nicholson, Mitchell and Tambo rivers as well as Lakes Wellington, Victoria and King.

The Gippsland Lakes are home to one of Victoria's largest fishing fleets (in terms of vessel numbers [about 65] and landed catch value) and an increasingly popular tourist and recreational boating destination due to its sheltered waters.

Access to the ocean is via Lakes Entrance. This man-made entrance was opened in 1899 and has provided an important contribution to the region's history and economy since that time.

Two of the major issues for the Gippsland Lakes are the silting of the channels and entrance (which requires ongoing dredging to maintain ocean access and navigable internal channels) and the increased demand for land based recreation and tourism facilities (which are sometimes incompatible with, and are placing pressure on the port areas).

Estuary use and value

The Port of Gippsland Lakes is used by both commercial fishermen, who use the entrance to access the ocean, and recreational boaters, who take advantage of the sheltered waters within the lake system for fishing and cruising.

The main commercial fishing port is located at Lakes Entrance and provides catch discharge and processing facilities as well as maintenance facilities (e.g. slipways) and moorings. There are also boating facilities located at Paynesville, including marinas, a boat yard and associated services.

To meet the needs of the port users the estuary primarily has to provide a safe, navigable entrance to the open sea and navigable internal channels.

Benefits and estimates of monetary value

The commercial fishing industry is the major user of the Lakes Entrance channel with approximately 13 000 crossings annually.

The Lakes Entrance Fisherman's Co-operative supplies 35–40% of Melbourne's fish product and is a key employer in the region.

Overall Lakes Entrance channel users, including commercial fishermen and recreational boaters account for:

- 32% of regional employment (67% contributed by the commercial fishing sector alone);
- 29% of household income;
- 35% of total regional economic activity (with commercial fishing accounting for 70%); and
- 0.5% of Victoria's entire employment, income and output.

Management issues

The major management issue at Lakes Entrance is the siltation of the entrance and immediate internal channels. The action of normal coastal processes is to form a sand bar across the entrance to the lakes. The water flows within the estuary caused by having an opening to the sea leads to siltation of the internal channels. To maintain safe navigability ongoing dredging of both the entrance and internal channels is required. To alleviate the problem and maximise the efficiency of dredging the internal channels a new sand transfer system has been installed at a cost of approximately $1.5 m. This system pumps the dredge spoil through a series of pumps and pipes back to the open ocean environment. The system has resulted in a reduction of the net inflow of sand into the estuary.

Other management issues include dealing with the sewage discharged from boats (both commercial and recreational) and containing the contaminants (both airborne and water-borne) that are generated during boat servicing/repair.

One final issue facing the Port Manager is that of balancing the requirements of an industrial port with those of a burgeoning tourist industry. The increasing demand for shore based tourism and recreational facilities places pressure on the areas in which port activities have traditionally taken place.

Conclusion

The issues in the Gippsland Lakes are similar though on a different scale to those experienced in all estuaries that contain port facilities. They highlight the need for a balanced approach between natural resource management and development.

CASE STUDY: South-east Queensland regional water quality management strategy

Illustrating the complex nature of estuary management

South-east Queensland's coastal regions and waterways, including Moreton Bay, are complex ecosystems that support healthy populations of dugongs and turtles, migratory wading birds and major recreational and commercial fisheries. Population increases in south-east Queensland have the potential to seriously impact on the ecological and economic health of its waterways and catchments. Nutrients (particularly nitrogen), fine sediments and, to a lesser extent, pesticides and heavy metals have already been identified as causes of significant environmental problems within these systems.

In response to these threats, government, industry and community stakeholders are working to implement a regional water quality management strategy.

The strategy forms part of the South East Queensland Regional Framework for Growth Management 1998 and is a joint Commonwealth, State and local Government initiative covering the south-east Queensland region, including coastal waters, estuaries and freshwater streams from Noosa to the Gold Coast and west to the Great Dividing Range. It covers 15 major catchments with a combined catchment area of approximately 22 352 km^2 and includes 19 local government areas.

- Stage 1 (1993–1995) reviewed available information and delivered a model for strategy development.
- Stage 2 (1996–1998) focused on urban areas in the lower catchment, marine and estuarine areas of the Moreton Region and was developed by six local councils, the Environmental Protection Authority and other State agencies, industry and community.
- Stage 3 (1999–2001) of the strategy is focusing on the freshwater catchment areas of the Moreton region and incorporates the north (Noosa, Maroochy and Mooloolah) and south (Logan, Albert and Gold Coast) regions.

This collaborative approach has been a key characteristic of the strategy. Based on strong local political leadership and advocacy, it has allowed the development of an effective, 'whole of community' organisational approach to action plans that protect and enhance water quality and ecological/economic sustainability.

The vision

> *South-east Queensland's catchments and waterways will, by 2020, be healthy living ecosystems supporting the livelihoods and lifestyles of people in south-east Queensland and will be managed through collaboration between community, government and industry.*

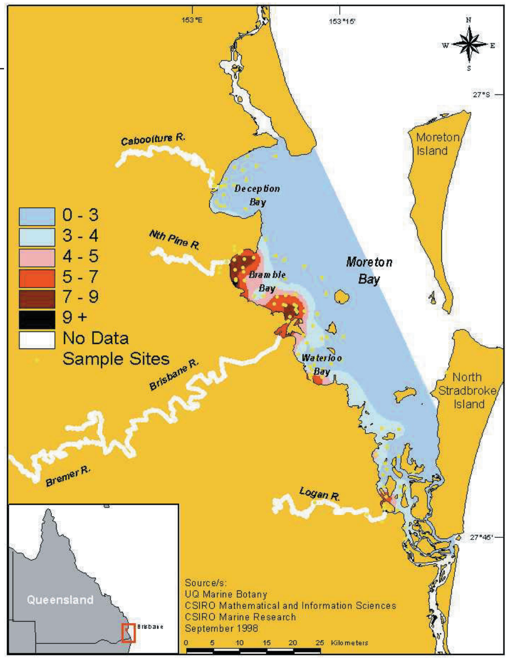
Strengths of the strategy

The major strengths of the strategy are:

- effective collaboration between government, industry and community in decision making;
- a collaborative and coordinated approach to the scoping, gathering and communication of scientific information;
- providing stakeholders with information as it comes to hand;
- consideration of social, cultural and economic impacts of environmental choices;
- unified Healthy Waterways campaign;
- integration with regional planning and statutory processes; and
- whole-of-community monitoring and feedback.

Figure 61. Extent of the South East Queensland Regional Water Quality Management Strategy.

Figure 62. Sewage plume mapping using d15N signatures indicates two distinct sewage plumes in Bramble Bay.



Major achievements to date

Important achievements of the strategy to date include:

- a much better understanding of ecosystem processes and effects of pollutants;
- agreed ecological health indicators, such as seagrass depth range, sediment nutrient fluxes, denitrification efficiency, and phytoplankton productivity and abundance;
- environmental values, goals and water quality objectives defined for marine and estuarine waterways;
- sustainable point source nitrogen loads determined for different waterways;
- technology to track sewage;
- a framework for sewage management for the next 20 years; and
- continuing determination of sustainable stormwater loads and a framework for stormwater management.

Key lessons

- Large scale planning process can often take time, including an initial gestation period, during which few tangible results appear. This period often involves getting the scope of the project right and building the community involvement processes necessary for later success (which often then come with a rush). Patience during these early stages is important, as is rapidly exploiting consequent opportunities for delivery.
- It is necessary to develop an effective process for inter-agency interaction. It is important to never give up on this issue.
- Local political leadership can play a key role in obtaining and maintaining support and funding and in dealing with the bureaucratic issues.
- The Commonwealth Government can play a key role in providing seed funding and political/ social imprimatur to get parties together.
- It is crucial to get scientists, industry and community representatives on decision-making committees where they can interact directly with politicians and State government officers.
- The project must be grounded within the established regional planning framework, ideally through a catchment-based approach.
- A common vision must be developed early in the process to maintain focus and momentum.
- There is no substitute for the delivery of good information by scientists speaking effectively with one voice and the community confidence that results from getting this process and the information right.

Conclusion

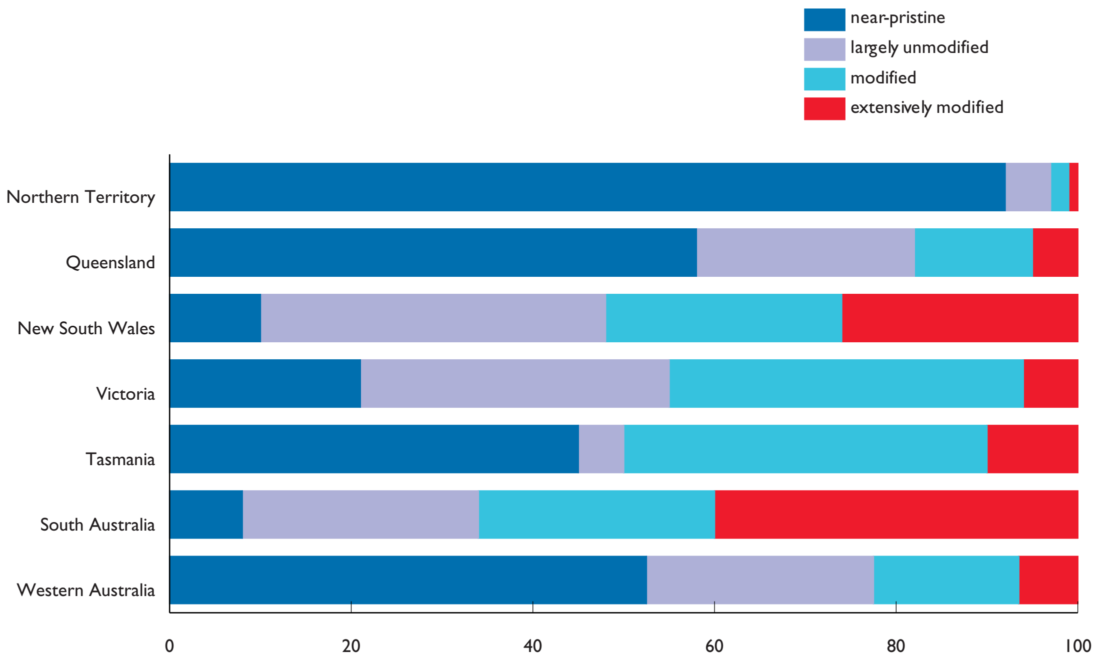
The strategy is an example of a successful regional planning process. Its success is due to:

- effective collaboration between government, industry and community;
- providing consistent information directly to all participants, including scientific findings, computer modelling predictions, impacts and costs of various management actions and impacts and costs of doing nothing;
- developing healthy waterways as a unified identity and vision that can be used by all participants; and
- all participants agreeing to own and implement on-ground management actions to achieve the vision.

This section has been compiled with the assistance of State agency staff involved in the project. It provides an overview of the types of estuaries, their condition and management arrangements in each of the States and the Northern Territory.

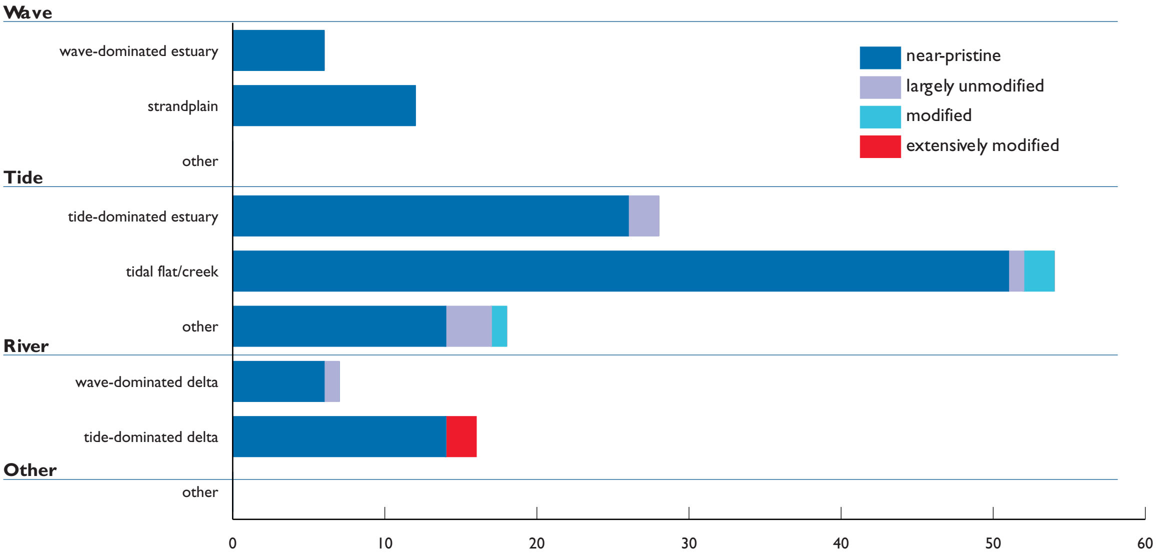
This information is based on discussions and interaction within State agencies and demonstrates the increasing commitment for integrated estuarine management across agencies, industry and the community.

Figure 63. Condition of Australian estuaries by State and Territory (%).



Key findings

Process-based classification and condition assessment.



Key messages

- The majority of estuaries in the Northern Territory are in near-pristine condition, primarily a result of low population pressure and reflecting minimal catchment and estuarine shoreline development. As a result, the focus of estuarine management in the Northern Territory is to maintain and protect estuarine condition, rather than remediation.

Key needs

- Information on the physical, chemical and biotic processes, as well as the habitat requirements of estuarine flora and fauna.
- Understanding and management of the links between catchment activities and estuarine ecological health.
- Management tools that predict the impact of catchment, shoreline and other activities on estuarine health would assist planning and management.
- Research and management activities (including monitoring) for priority estuaries.

Management arrangements

Two Northern Territory government agencies share the responsibility for various aspects of estuarine management. These are the:

- Department of Infrastructure, Planning and Environment (responsible for planning developments, planning approvals, natural resource management, water quality, water resource planning, waste water discharge licensing, waste management and pollution control, habitat mapping, management of coastal reserves, and shoreline infrastructure); and
- Department of Business, Industry and Resource Development (responsible for fisheries, and in partnership with the Australian Quarantine Inspection Service, marine pest management).

The management of estuaries is affected by 22 Northern Territory Acts that deal with issues such as heritage, conservation, biodiversity, public health, fisheries and ports and chemicals.

Of these, the *Water Act 1992* (NT), has the most direct involvement on water quality issues in fresh and marine waters, while the *Planning Act 1993* (NT) and *Waste Management and Pollution Control Act 1994* (NT) are important Acts that affect land use and waste management, respectively. The Department of Infrastructure, Planning and Environment administers all three Acts and is involved in the monitoring of waters and the catchment. The *Water Act 1992* (NT) encompasses the management of estuarine waters as well as all freshwater discharges to estuaries. The Act regulates the discharge of pollutants to waters through the issue of waste discharge licenses and the use of fresh and marine waters for commercial activities through the issue of extraction permits. Relevant Commonwealth legislation, specific to the Northern Territory, includes the *Aboriginal Land Rights (Northern Territory) Act 1976* (Cwlth) the legislative basis for freehold title to land, including estuaries, being granted to Indigenous occupants.

Policies

The declaration of beneficial uses (environmental values) for estuarine and catchment waters is a key policy instrument. Beneficial uses have been declared for Darwin Harbour and its major waterways (Darwin, Blackmore, Elizabeth, Howard Rivers), Fogg Bay, Gove Harbour, the McArthur River, Shoal Bay, Vernon Islands and Groote Eylandt. The uses include aquatic ecosystem protection, recreational water quality and aesthetics.

The Darwin Harbour Strategic Plan for beneficial uses is being developed, in consultation with the community. The plan will provide a management framework that identifies key environmental objectives that ensure the declared beneficial uses are maintained.

A *Mangrove Management Report* for the Northern Territory is in preparation. This report will outline the state of knowledge of mangrove ecosystems in the Northern Territory and will include a summary of the current and future directions for mangrove research.

The Department of Business, Industry and Resource Development implements exclusion zones for the protection of coastal habitat and commercial fisheries. In collaboration with Queensland Department of Primary Industries, it is undertaking extensive mapping of coastal mud crab habitat.

Arnhem Land estuary

Community initiatives

Community-based mangrove monitoring activities are in place for areas around Darwin Harbour. Waterwatch, Bushcare, Landcare and Coastcare are raising awareness of catchment activities that affect estuarine health.

State priorities

- Support and facilitate the establishment of a sustainable aquaculture industry in the Northern Territory. The near-pristine condition of the Northern Territory's estuaries and their warm water temperatures are advantageous to aquaculture.
- Maintenance of sustainable commercial and recreational fisheries, building on the near-pristine condition of the estuaries.
- Estuarine and catchment management to maintain their ecological integrity, as evidenced by the work under way to manage Darwin Harbour.

Around the Territory

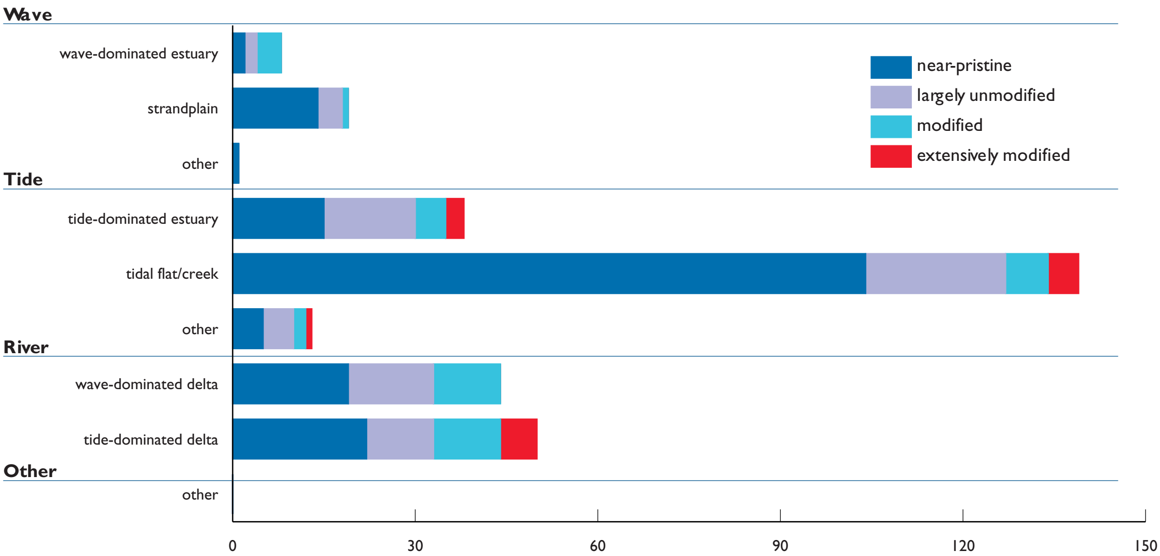
Northern Territory estuaries are all located in the wet/dry tropics of Northern Australia, which experience wet season rainfall during the summer months. Coastal catchments discharge to the Gulf of Carpentaria to the east, the Arafura Sea to the north and the Timor Sea to the west. In the north, monsoonal activity during the wet season is responsible for high rainfall. In the eastern and western regions a combination of weaker monsoonal effects and cyclonic activity influences annual rainfall. Flows in rivers discharging to estuaries are highly variable. Depending on the extent of the monsoon fronts and cyclonic activity the magnitude of annual floods varies between years. During the dry season freshwater discharge from rivers to estuaries often ceases.

A feature of Northern Territory estuaries is the extensive mangrove habitats and macro-tidal regime along the northern and western coastlines. The estuaries provide significant habitat for some of the densest populations of estuarine crocodiles in the world, roosting areas for sea and water birds, and habitat for tropical marine organisms. These estuaries also provide research opportunities as reference sites to better understand natural estuarine processes as a framework for improving management of modified estuaries.

With the exception of the Darwin region and Nhulunbuy in the northeast, the Northern Territory coastline is sparsely populated, with a large proportion of estuaries remote and inaccessible by land. The population in these areas consists of Indigenous communities and the homesteads of pastoral properties. Approximately half the Northern Territory coastline is Indigenous land, with the remainder of the coastline either freehold or pastoral lease. The dominant and often only land use in the catchments is grazing. Northern Territory estuaries are valuable for traditional harvesting, eco-tourism, and pearling as well as commercial and recreational fisheries. The estuaries in the Gulf of Carpentaria support the nationally important Gulf prawn and finfish fisheries.

Key findings

Process-based classification and condition assessment.



Key messages

- Queensland has unique near-shore, marine environments such as the Great Barrier Reef, Hervey Bay and Moreton Bay. These systems are at risk of ecological damage from the sediments and nutrients delivered from catchments through their adjoining estuaries.
- Queensland estuaries are diverse. They vary markedly as a result of catchment size, land use and climatic influences.
- Estuarine values need to be better recognised in State and local government planning instruments. Regional planning should seek to minimize the number and extent of estuaries impacted by coastal development.
- The links between catchment and estuarine health need to be understood and their management integrated, especially within water resource allocation and catchment management processes.

Key needs

- The information base on estuaries established through the Audit partnership needs to be maintained, updated and enhanced.
- There is a need for further research to understand processes in Queensland estuaries, the needs of estuarine fauna and flora and the impacts of sediments and nutrients, building on the Audit's assessment of sediment and nutrient loads to estuaries.
- A baseline understanding of the variability of natural estuary systems and the impacts of episodic, annual, cyclonic events and extreme weather is required. Baseline data for near-pristine estuaries and a long-term monitoring program could provide such information.

- Building on the Audit partnership's categorisation of estuary types, studies of estuaries that are representative of particular categories would enhance management for all Queensland estuaries.
- Recognising that systems such as Moreton Bay, Hervey Bay and the Great Barrier Reef lagoon are downstream of estuaries and are important ecological resources, further work is required to understand and demonstrate links between catchment, estuarine and near-shore processes, and from that basis set priorities for management.
- Further development of an 'index of estuary condition' building on the Audit's assessment process together with long term monitoring of changes in this index would be a useful management tool.
- Coordinated development of public and commercial coastal facilities (e.g. ports and tourist resorts) is essential to avoid duplication and unwanted reclamation of tidal and other estuarine wetlands.

Management arrangements

Although there is no formal coordination of estuarine management in Queensland, the State Coastal Management Plan provides direction to State agencies and local government through principles and policies, for the coordinated management of the coastal zone including estuaries.

Responsibility for different aspects of estuarine management reside with the following agencies:

- Department of Primary Industries (responsible for fisheries resources and fish habitat management, including fish habitat areas, and aquaculture).
- Environmental Protection Agency (responsible for coastal planning, coastal processes, water quality and marine parks).
- Department of Natural Resources and Mines (responsible for water resource planning and catchment management).
- Department of Local Government and Planning (responsible for integrated planning).

Policies:

- *Environmental Protection Act 1994* (Qld) and Environmental Protection Policy (Water)
- *Nature Conservation Act 1992* (Qld)
- *Marine Parks Act 1982* (Qld)
- *Integrated Planning Act 1997* (Qld)
- *Fisheries Act 1994* (Qld)
- Draft Rivers Policy 2001
- State Planning Policy on Acid Sulfate Soil Management 2000
- *Coastal Protection and Management Act 1995* (Qld)

The Queensland Environmental Protection Agency has responsibilities for coastal planning under the *Coastal Protection and Management Act 1995* (Qld). Under this legislation, a State Coastal Plan has been developed and came into force in February 2002. The plan contains principles and policies by which the coastal zone will be managed and which must be taken into account in all planning at State and local government level. More detailed regional coastal management plans are being prepared.

Under the *Environmental Protection Act 1994* (Qld), the Queensland Environmental Protection Authority is responsible for maintaining water quality in estuaries and licenses all discharges to estuaries. Linked to this, the agency carries out routine water quality monitoring in estuaries as far north as Townsville and is involved, along with the Coastal Cooperative Research Centre, in intensive monitoring of estuaries in south-east Queensland.

The Department of Primary Industries, Queensland Fisheries Service is responsible under the *Fisheries Act 1994* (Qld) for the management, monitoring and assessment of fisheries resources, including marine plants and other fish habitats. The Queensland Fisheries Service plays the key role in investigating and gazetting areas of key fish habitats in estuarine and coastal areas as declared fish habitat areas. More than 700 000 ha of fish habitats have been declared to ensure habitat protection and to underpin long-term coastal and estuarine fisheries production. By 2005, the majority of the estuarine and inshore areas along the Queensland coast will have been investigated for possible fisher habitat area status. Separately Queensland Fisheries Service plays a major role in assessment of proposed coastal developments in terms of the potential and real impacts of these on fisheries and habitat resources and mitigation of these impacts should development go ahead. Through the Queensland Fisheries Service's activities, key elements of fish habitat management are incorporated within local government planning schemes. Any approvals issued under the *Fisheries Act 1994* (Qld) are conditional on minimising impact on estuarine fish habitats.

As part of State-wide fish habitat management within estuaries and inshore waters, the Queensland Fisheries Service has developed policies, codes of practice and specific guidelines for key stakeholders (including cane growers, local government officers and public infrastructure developers) with interests and responsibilities in coastal areas. Assessment of the condition and long-term monitoring of change in estuarine fisheries and key aquatic habitats continues to be an important management requirement.

Under the *Fisheries Act 1994* (Qld), Queensland Fisheries Service manages aquaculture activity and contributes to the development of strategic policies to ensure the development of sustainable coastal aquaculture.

Community initiatives

Waterwatch Queensland is working with the Department of Primary Industries, the Department of Natural Resources and Mines, the Environmental Protection Agency (with support from the Natural Heritage Trust Coasts and Clean Seas Program and Coastal Cooperative Research Centre) to develop methods for community monitoring initiatives in the marine environment with a focus on estuarine and coastal areas. This project complements existing community-based monitoring activities such as the Seagrass-Watch program operating in Hervey Bay and the Whitsunday Islands.

Other community initiatives include: Waterwatch, Coastcare, Wader Birds, Sunfish and Surfrider Foundation groups and activities.

State priorities

- Aquaculture is an emerging priority use for Queensland's coastal areas and will need to be well-planned and managed. Appropriate siting of aquaculture proposals above the tidal influence will limit the exposure of acid sulfate soils and minimise impacts on estuarine wetlands.
- Coastal development and pressures are increasing in relatively intact undeveloped areas. Coordination, particularly of marina and port developments and general disturbance of acid sulfate soils is a key issue.
- River and catchment impacts on estuarine health and values need to be better understood and managed to reduce downstream impacts.
- Habitat loss was historically a big issue, particularly with land use expansion in the 1960s and 1970s. Legislation has limited further removal of mangroves and other marine plants. However this may be placing increased pressure on other habitats, particularly brackish wetlands (e.g. the already much reduced melaleuca wetlands) – important for fisheries and estuarine condition and while recognised under the *Fisheries Act 1994* (Qld), processes to protect these habitats are not yet in place.

Around the State

Gulf estuaries

Estuaries from the Northern Territory border to the tip of Cape York are characterised by extreme wet/dry seasonality and large floodplains. Grazing is the main land use in the catchments, with indigenous, recreational and commercial fishing occurring in many estuaries. These estuaries are predominantly in near-pristine condition.

There is great diversity in the way that these estuaries function with tidal and river energy significant for most estuaries. In addition to their importance as habitats for commercial and recreational fish species, the estuaries are important habitat for crocodiles and estuarine elasmobranchs (including sawfish and some rare shark species). The Jardine River near the top of the western side of Cape York is a perennial river. Further south, rainfall is lower and freshwater input more intermittent.

Prawn aquaculture: often located in estuaries

Cape York and the Wet Tropics

Estuaries from the tip of Cape York to Ingham at the southern end of the Wet Tropics experience considerable variation in annual rainfall. There is great diversity in the way that these estuaries function with tidal and river energy significant for most estuaries. Northern Cape York experiences moderate though highly seasonal rainfall. Further south, a broad, low lying dry belt stretches across the bottom of the Cape York Peninsula, towards Cape Melville and Princess Charlotte Bay. South of Cooktown rainfall becomes much higher with steep catchments, fast flowing rivers, floodplains and short estuaries. In the Wet Tropics there is usually year round freshwater flow despite a strong wet-dry seasonality in rainfall.

Sugar cane farming and horticulture (e.g. pawpaws, bananas) are the main floodplain land uses south of the Daintree. Grazing and dairying with cropping on the better soils are the main land use in Tableland areas, above the steep gorge sections that are World Heritage Area listed rainforest/wet sclerophyll forest.

The estuaries north of Mossman are predominantly in near-pristine to largely unmodified condition. The estuaries within the Wet Tropics and their floodplains have been significantly modified for agriculture and urban development. Wetland habitat losses and changes to the ecological function of wetlands and riparian areas are major issues. Land use together with the high intensity monsoonal rainfall patterns leads to major sediment and nutrient loads instream and to significant change to fish habitat, including loss of deeper channels, seagrass beds and changes to algal communities in the estuaries.

Central coast

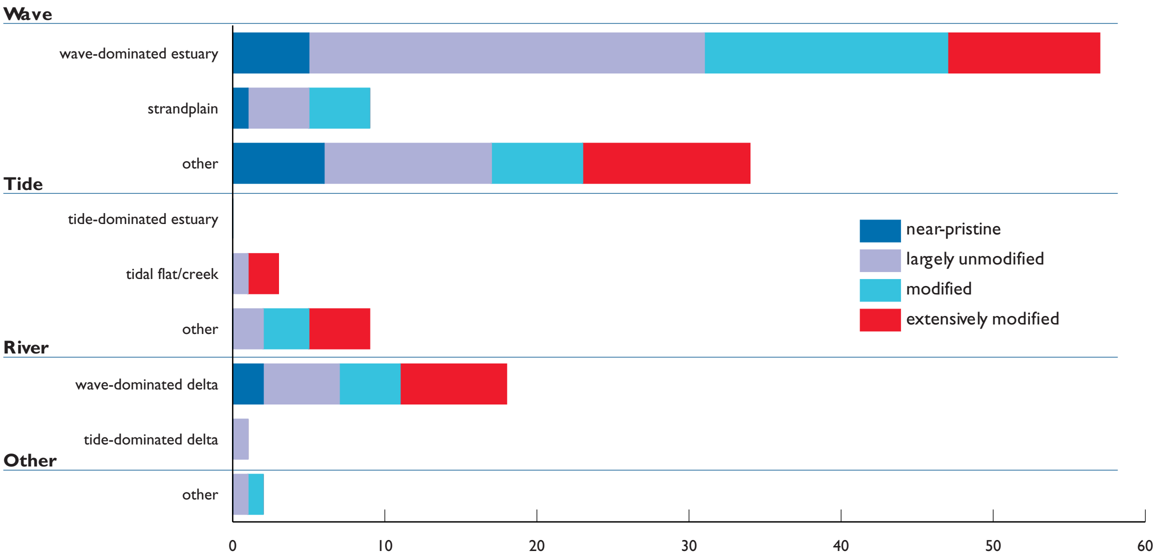
Catchments south of Ingham to Port Curtis are characterised by strongly seasonal rainfall but are much drier than those further north. Agriculture (e.g. grazing, sugar cane, cropping) is the main land use. These estuaries are predominantly in either largely unmodified condition (the smaller coastal catchments) or modified condition (the larger catchments with developed floodplains and land use). There is great diversity in the way that these estuaries function with tidal and river energy being significant for most estuaries. The floodplains of these systems are larger than in the tropics and there are several very large catchments in the region (e.g. the Fitzroy River catchment).

South-east coast

Estuaries from Port Curtis to the New South Wales border receive more consistent rainfall than the dry tropics and are characterised by less obvious rainfall seasonality than elsewhere in Queensland. From Noosa Heads south the estuary hinterland is generally highly urbanised and developed, and the estuaries experience the problems associated with intensive use where appropriate planning measures have not been implemented. These estuaries are predominantly in modified to extensively modified condition.

Key findings

Process based classification and condition assessment.



Key messages

- Most of the estuaries in New South Wales are under intense urban development pressure with approximately 80% of the State's population living near an estuary.
- Some 60% of the State's estuaries are intermittently closed and open lakes and lagoons with ecosystems that are sensitive to catchment land use activities and competing estuary uses.
- The NSW Estuary Management Program and *Estuary Management Manual* were introduced in 1992 to help resolve conflict within local communities over use of estuaries and provide technical and financial assistance to local governments. Under the program, local councils can prepare and implement sustainable estuarine management plans for the protection and where necessary the rehabilitation of degraded estuaries.

Key needs

- Significant gaps in estuarine data have meant that complex natural biophysical processes are poorly understood, making the selection of the optimal management solution difficult. A higher level of investment in estuaries to fill key estuary data gaps, provide coordinated long-term monitoring and research focused on high priority management issues is required to address these problems.
- Statutory planning processes in catchments have historically focused on land capability without adequately addressing aquatic and estuarine effects. A high level of strategic integrated planning is required in coastal catchments to ensure that estuarine environments are protected in the future. The health of an estuary provides a good indicator of catchment health.

Port Kembla harbour: a deep water industrial shipping port

- Filling estuary data gaps and refinement of key estuary health indicators for estuary types as well as improved data accessibility would enhance estuary management outcomes. Important estuary information is generally not available to decision makers.
- Guidelines for considering integrated environment and socioeconomic issues in the management of estuaries are important to assist with investment decisions by local communities.

Management arrangements

The NSW Coastal Council coordinates and reports on the implementation of the NSW Coastal Policy to State Cabinet. The management of the State's estuaries is an important component in the implementation of the policy. In New South Wales, estuaries are managed by a number of key agencies and local government. Key State agencies include:

- Department of Land and Water Conservation (responsible for land, water and vegetation natural resource management);
- Environment Protection Authority (responsible for environmental pollution control);
- Department of Fisheries (responsible for the management of State fisheries resources);
- Department of Urban Affairs and Planning (responsible for State planning development policies);
- National Parks and Wildlife Service (responsible for the management of national parks and reserves); and
- Waterways Authority (responsible for managing boating and navigation).

Local councils develop and implement sustainable estuarine management plans with technical and financial assistance from the State Government:

- over 25 estuarine management plans in place.;
- 75 community-based steering committees are preparing and implementing the plans.

The State Government provides some $1.4 m (matching council contribution) annually to assist councils to prepare and implement the plans.

Policies

NSW Coastal Policy

- provides the key strategic direction for the sustainable management of the New South Wales coastal zone
- policy implementation and achievement of policy outcomes are assessed by the Coastal Council of New South Wales
- key deliverable is the implementation of the NSW Estuary Management Program

NSW Estuary Management Program

Under the policy the New South Wales Government's Estuary Management Program will continue to be implemented by providing technical and financial assistance to local government and agencies for the purposes of preparing and implementing estuary management plans, undertaking activities to rehabilitate the estuarine environment, and improving the recreational amenity of estuarine foreshores.

The policy is implemented through the preparation and implementation of sustainable estuary management plans involving significant community consultation through local councils.

Estuaries management in New South Wales has recently been strengthened with the introduction of coastal management; and water, vegetation and catchment management reforms.

- The new *Water Management Act 2000* (NSW) protects of water quality and quantity, including estuaries, by preparing water management plans and stressed rivers classification.
- The *Native Vegetation Conservation Act 1997* (NSW) affords greater protection of native vegetation in rural areas.
- Amendment of the *Catchment Management Act 1989* (NSW) has provided for catchment management boards, and a greater level of integration and efficiency in management of natural resources.
- Sensitive estuarine wetlands are protected through the New South Wales Wetlands Policy and the declaration of State Environment Protection Policy 14 wetland protection through planning legislation.
- Canal estate developments have been prohibited to protect remaining wetlands.
- Amendments to the *Fisheries Management Act 1994* (NSW) provide greater protection for marine flora and fauna in estuaries affected by development proposals.
- The introduction of recreation fishing areas and reduction of some commercial fishing in threatened estuaries is under discussion in local communities.

Community initiatives

Community initiatives include Coastcare, Streamwatch, Landcare and Rivercare. Community representation is provided for on a number of natural resource management committees that are supported by the State Government and include catchment management boards; and estuary, vegetation, water management and groundwater management committees.

State priorities

- Improve understanding of estuary processes affecting coastal lakes and lagoons (ICOLLs), the management of which is of significant concern to the New South Wales Coastal Council and New South Wales Healthy Rivers Commission.
- Fill key data gaps; and refine estuary health indicators, process models, management and monitoring tools for estuary types and condition to improve state of the environment reporting, assess estuary management strategies and to facilitate informed planning decisions by local communities.
- Improve understanding and quantification of catchment nutrient loads and environmental flows to estuaries to better understand catchment influences on estuary condition.
- Strategies and incentives to promote community participation in the adoption and implementation of best estuary management practices.

Around the State

Far North Coast

Estuaries from the Tweed River at the Queensland border, south to the Sandon River near Grafton are facing increasing pressures from urbanisation and development that is contributing to the degradation of estuarine ecosystems.

Characteristics of this area include coastal strip development, competition for the use of limited estuarine natural resource, decline in seagrass beds, acidification from acid sulfate soils, sand and gravel extraction, and eutrophication of coastal lakes. The New South Wales sugar cane industry and a growing tea-tree industry are based in this area. Other key characteristics include the cultivation of a large proportion of the floodplains (including improved pastures) and associated constructed drainage channels, floodgates and levees.

These estuaries are important for tourism. There remain extensive areas of wetland habitat for aquatic and terrestrial fauna, and significant national park reserves have been established.

Many of these estuaries support commercial fishing, prawn and oyster production. Boating and recreational fishing are popular. Many estuary entrances have been trained with breakwaters and limited dredging occurs to provide navigation channels for commercial fishing vessels.

Mid North Coast

Estuaries from Wooli Wooli River (near Grafton) south to the Hastings River at Port Macquarie support important tourist industries based on their high scenic and recreational values. There are significant national parks and nature reserves including the Solitary Isle Marine Park.

These estuaries are important for oyster production particularly spat catching, and

Nelson Lagoon

provide good amateur and commercial fishing as well as prawning. There are increasing pressures from the tourism and aquaculture industry as well as urban and rural residential developments.

The Macleay and Hastings estuaries are significantly impacted by acidic discharge from high risk acid sulfate soil areas on their coastal floodplains. Flood mitigation structures, bank protection works, drains, floodgates and levees have had a profound impact on the Macleay estuary.

There is considerable local debate over entrances management options for coastal lakes and lagoons (e.g. Arrawarra, Deep and Saltwater Creeks). Numerous floodgate management, wetland restoration and acid soil remediation projects have been initiated on the larger coastal floodplains.

North Coast

Estuaries from Lake Cathie/Lake Innes near Port Macquarie south to the Hunter River near Maitland are characterised by pressures from tourism, intense urban and industrial development (e.g. Newcastle).

These estuaries have significant areas of estuarine wetlands renowned for aquatic bird habitat. Kooragang Island (Hunter River) is a significant international Ramsar wetland site providing key migratory bird habitat. Other unique areas include Lake Innes that is fully surrounded by a national park.

These estuaries are popular for recreational swimming and fishing and support a commercial fishing and prawn industry. There is considerable local debate over the management of entrances of small coastal lakes such as Lake Cathie.

Newcastle is a major commercial port incorporating coal exporting with port facilities capable of loading very large vessels.

Sydney Region

Estuaries from Lake Macquarie extending south to the Minnamurra River near Wollongong are affected by intense urban and industrial development at Gosford/Wyong, Sydney and Wollongong. Estuaries in these areas are characterised by large waterways; intense urban development; and competing natural resource use, commercial ports and related infrastructure.

Rapid population growth has resulted in the degradation of many estuaries from declining water quality, eutrophication of coastal lakes, sewage overflows (especially Sydney), and the poor state of swimming beaches and tidal baths particularly after storms (pollution and litter). Stormwater run-off containing high nutrient loads contributes to toxic algal blooms in poorly flushed estuaries. Many small coastal lagoon ecosystems are threatened as a result of elevated nutrient loads from urban run-off (e.g. Curl Curl Lagoon).

Localised pollution from vessel sewage and industrial discharges (heavy metal, tributyl tin, organochlorine, petroleum, and microorganisms) are causing problems in some areas.

There are a number of large coastal lakes in this area including Lake Macquarie, Tuggerah Lakes and Lake Illawarra. There is continuing community concern over the deterioration of these valuable estuarine ecosystems that has resulted in the implementation of significant estuary restoration projects combining local government, State and Commonwealth resources to provide integrated management solutions.

Botany Bay, Sydney Harbour and Port Kembla are commercial ports. Significant areas of coastal wetlands have been lost in the past to provide land for expanding urban and industrial development.

Sydney Harbour is internationally acclaimed as one of the most beautiful harbours in the world. This area and adjacent large estuaries are an important holidaying area and recreational centre for the population of Sydney, and interstate and international tourists. It is popular for amenity values, recreational fishing, boating, waterskiing and swimming.

Estuaries in this region support a large estuarine fishing industry, and commercial catches of crustacea and molluscs. Large and competing recreational and commercial fisheries have caused some concern in local estuarine communities. The oyster industry has been adversely affected by a virus infection decimating stocks (e.g. Georges River). Exotic aquatic weed infestation (*Caulerpa taxifolia*) is threatening a number of estuaries in this region.

South Coast

The estuaries from Werri Lagoon south of Wollongong to Tuross Lake near Narooma are characterised by coastal strip development, competing natural resource uses, ports, marinas and tourist development, eutrophication of coastal lakes, and Indigenous fishing rights.

The area is a popular tourist destination for residents from Canberra and Victoria. Increasing development pressure on the catchments of small vulnerable coastal lagoons has generated intense local debate and a call for improved planning practices.

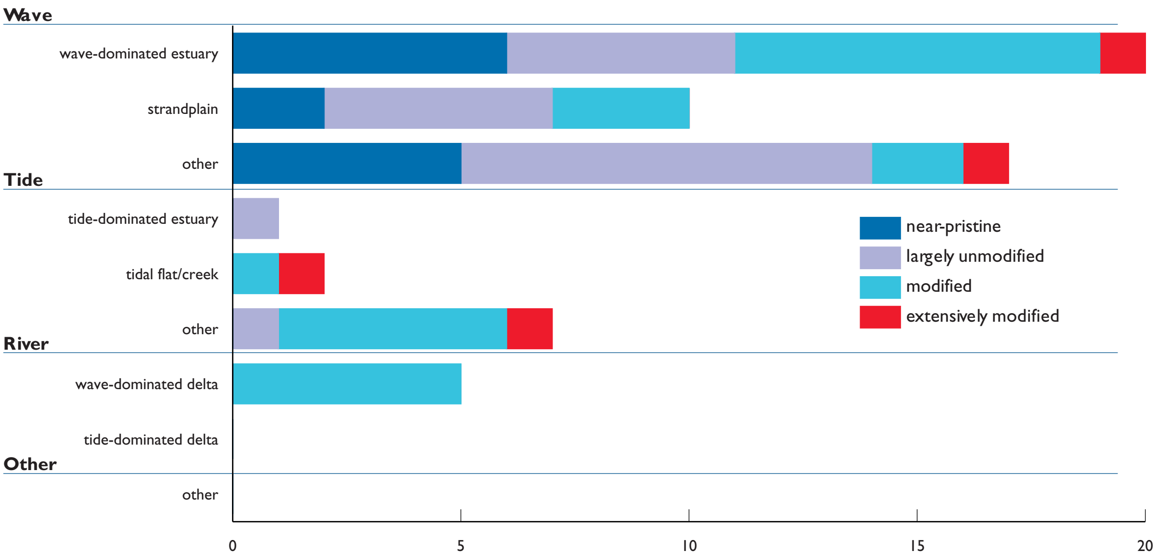
Far South Coast

Estuaries from Lake Brunderee (near Potato Point) south to the Merrica River near the Victorian border are characterised by limited development compared to other areas of the State. Large expanses of national parks surround many estuaries in this area with limited public access.

The large fishing ports of Bermagui and Eden are popular holiday destinations.

Key findings

Process-based classification and condition assessment.



Key messages

- Victorian estuaries (approximately 60) vary from small wave- and river-dominated estuaries in the west, to several large embayments such as Port Phillip Bay and Western Port in central Victoria, to a network of small wave-dominated estuaries in the east.
- The condition of these estuaries also varies regionally, primarily because of the differences in the size and morphology of the surrounding catchment, and the dominant land use practices. Many of the estuaries in eastern Victoria are located within National Parks and are in near-pristine condition. These are valuable conservation and wilderness areas.
- The small wave-dominated estuaries common in West Victoria are at risk from inappropriate land use practices and are in need of targeted management. As many of these estuaries have ephemeral openings to the coast, and the adjacent catchment is often steep and predominantly agricultural, nutrients, sediment and toxicants can accumulate in these estuaries.
- Urbanisation, industry, agriculture, forestry and water diversions and extractions have resulted in major modifications to many Victorian estuaries.
- Pressures on estuaries will increase with a trend to increasing coastal development.

- The importance of estuaries is now well recognised in Victoria, both at government and community levels. Environmental objectives for estuaries are now explicitly recognised in a number of key policies and management plans and are undergoing further development.
- Efforts are under way to streamline and integrate catchment and coastal management strategies, research and monitoring.
- Greater access to information and resources for community groups to monitor and care for estuaries is being implemented. While there is a good understanding and monitoring of large estuarine systems in Victoria, collecting more information to improve our understanding of small estuaries is essential.

Key needs

- Risk-based frameworks for prioritising areas for management action.
- Greater focus on the management of Western Victorian estuaries as these estuaries are most susceptible to impact from land use.
- A decision-support system for making informed decisions about entrance openings.
- Streamlining of management structures particularly in the Gippsland Lakes.
- Greater public access to estuary information and education.
- Improved linkages between indicators of catchment and estuarine health as a basis for setting works priorities.
- Identification of particular estuaries as a representative of western estuaries and to complete comprehensive comparative studies on these estuaries for the development of reference estuaries.
- Greater data collection and process studies to understand small wave-dominated estuaries common throughout Victoria. Specific knowledge and data gaps include primary productivity, turbidity and water depth.
- Explicit methods and data for valuing intrinsic features of estuaries and the industries that rely on them as part of the basis for developing investment priorities.
- The ongoing development of environmental objectives for estuaries in Victoria.

Queenscliffe and Port Phillip Bay

Management arrangements

In Victoria the responsibility for estuaries is spread throughout several agencies with no formal coordination across agencies. A number of peak bodies are responsible for coordination of State or regional coastal and catchment issues.

- Environment Protection Authority (responsible for controlling the discharge of wastes to the environment, preventing pollution and assessing water quality).
- Department of Natural Resources and Environment (responsible for overseeing the management of the land and resources of Victoria's coastal public land and marine resources for conservation and recreational uses).
- Parks Victoria (manages Victoria's national, State, marine, regional and metropolitan parks and conservation reserves; responsible for estuaries within these parks).
- Victorian Coastal Council and Regional Coastal Boards (implements strategic planning for Victoria's coastal resources, including estuaries).
- Victorian Catchment Management Council (advises the State government on issues relating to catchment management; a key role is to promote awareness of integrated catchment management and associated issues in the community).
- Catchment management authorities and catchment land protection boards (ensure the sustainable development of natural resources and maintain and improve land and water resources in their region through development and implementation of catchment strategies; responsible for monitoring and reporting on the condition and management of land and water resources, and promoting cooperation for management of land and water resources in their region).
- Fisheries Co-management Council (State Government's peak advisory body on fisheries management, facilitating co-management of fisheries across all stakeholders and assisted in its efforts through input from eight Fisheries Committees).
- Environment Conservation Council (make recommendations to the State Government on the use of public land and water, taking into account resource use, social issues and environmental needs). The council has recently prepared recommendations on a system of marine protected areas in Victoria. These recommendations included three small estuaries in eastern Victoria within the Croajingolong National Park, Mallacoota Inlet, some areas in Port Phillip Bay and Western Port Bay.

Policies

- The *Environment Protection Act 1970* (Vic) provides an over-arching legislative framework for environment protection in Victoria.
- The State Environment Protection Policies (Waters of Victoria) 1988 apply throughout the State and set out a framework for protection of fresh, marine and estuarine environments defined by beneficial uses. The policy identifies protected beneficial uses and environmental quality objectives for estuarine and coastal segments. The policy is being revised and will include water quality objectives specifically for estuaries and inlets.
- Schedules to waters of Victoria for Port Phillip Bay and Western Port set region specific attainment programs.

- The *Coastal Management Act 1995* (Vic) underpins the Victorian Coastal Strategy, first released in 1997 and ensures protection of significant environmental features, provides clear direction for future use of the coast, identifies suitable development areas and ensures sustainable use of natural resources. The strategy is being revised to specifically recognise the protection of estuaries as a key action.
- Coastal action plans identify strategic directions and objectives for the use and development in the region. This detailed planning facilitates recreational use and tourism and provides for protection and enhancement of the environment. Nine actions plans are in place.
- Environment management plans have been prepared from initiatives such as the Port Phillip Bay Study. Plans for port facilities at Port of Melbourne, Hastings and Portland are also being prepared.
- Ramsar-listed sites falls under the responsibility of Parks Victoria's Strategic Management Plan for Ramsar-listed water bodies and overrides other Gippsland Lakes management plans.
- The *Crown Land (Reserves) Act 1978* (Vic).
- Municipal planning schemes developed by coastal municipalities.
- Regional catchment strategies to address the impacts of catchment based activities that affect the coastal and marine environment.
- Neighbourhood environment improvement plans.
- Regional catchment strategies.
- Fisheries and Park plans and strategies.
- Melbourne's Metro Strategy.
- Biosphere and Watermark Program.

Community initiatives

Community initiatives include several regional Waterwatch programs and the Western Port Seagrass Partnership established in Western Port. Coastcare/Coast Action, Land for Wildlife, Fishcare and Landcare are recognised in the Victorian Coastal Strategy as key initiatives in raising public awareness of marine and coastal issues. The Marine and Coastal Community Network brings together Natural Heritage Trust funded on-ground action programs and integrated management plans but there is little focus on preventative management and research. Habitat assessment groups have been an effective method of capturing fishermen's knowledge of Victoria's estuaries.

State priorities

- Coastal boards and catchment management authorities working together to provide integrated and coordinated management from catchment to coast.
- Monitoring of major estuaries and embayments is being integrated with the State Monitoring Network for freshwater quality and quantity.
- Greater coordination of environment portfolio research programs.
- As part of the revision of State of Environment Protection Policy Waters of Victoria, estuary-specific, environmental objectives are being developed and estuaries are being specifically listed.
- Ongoing monitoring of small estuaries.
- Studies to develop a better understanding of primary productivity and sediment processes in estuaries to gain a better understanding of the processes of algal bloom development and the potential for early warning systems for harmful algal blooms.

Gippsland Lakes

Around the State

Eastern Victoria

The 21 estuaries from Andersons Inlet to the Mallacoota in the far east of Victoria are characterised by being wave-dominated with the greatest proportion being near-pristine estuaries. One tide-dominated estuary is present in this region (Corner Inlet). These estuaries are generally within steep catchments and are influenced by winter-dominated rainfall. In the far east, estuaries in the Croajingolong National Park include 12 near-pristine estuaries. Significant beds of seagrass occur in many of the region's inlets.

The Gippsland Lakes are a focus for tourism, commercial and recreational fishing. Gippsland Lakes has been extensively degraded as a result of extensive catchment-derived inputs of sediment and nutrients and coastal infrastructure development.

Reduced flows to several estuaries have resulted from water extraction upstream (e.g. the Snowy River). The many wave-dominated estuaries in this region with developed catchments receive increased nutrient loads resulting from extensive agricultural activity and urban use.

Comprehensive data exists for the Gippsland Lakes, one of the most studied estuaries in Australia. Little data exists for other estuaries, particularly water quantity and quality information. Gippsland Lakes is the focus for a Victorian Government rescue package and has a well-organised coastal board and two catchment management authorities. A number of management plans have been developed including the *Gippsland Lakes Coastal Action Plan 1999* and the *Gippsland Coastal Waters Coastal Action Plan 2001*. An important priority for management in the lakes is integrating management processes.

Central Victoria

Central Victoria has 13 estuaries from Barwon River to Powlett River including the significant embayments of Port Phillip Bay and Western Port. Many of the other estuaries are 'child' estuaries draining into these embayments. The catchments are heavily urbanised with 4 million people in Melbourne and Geelong. Many rivers and creeks run through urban and industrial developments and have been modified into drains. Rural parts of catchments are mostly used for pasture, cropping and market gardens.

Port Phillip Bay and Western Port are major shipping ports and support a wide range of recreational pursuits. They also support commercial fishing, recreational fishing and aquaculture. Eutrophication, sedimentation, oil spills and the introduction of marine pests are key threats to the integrity of Port Phillip Bay and Western Port. Catchment erosion, resuspension of unconsolidated bay sediments and potential impacts from oil spills are key threats to Western Port and have contributed to large-scale seagrass declines in the bay. All the estuaries are classified as modified except Kororoit Creek flowing through industrial use that is classified as extensively modified.

As many of the smaller estuaries discharge into larger embayments they are tide-dominated (nine) or river-dominated (two). There are comprehensive data on the ecology, condition and function of Port Phillip Bay and Western Port. Western Port, Port Phillip Bay and the Yarra catchment have specific State environment protection policies with defined environmental quality objectives. There is an active Central Coastal Board and Catchment Management Authority and environment management plans are in place for Port Phillip Bay and for port facilities including the Waterfront Geelong Coastal Action Plan 1998. There are several current and proposed marine protected areas and designated aquaculture areas.

Western Victoria

The 25 estuaries from the Glenelg to the Thompson are mostly small (21 are wave-dominated). There is only sparse seagrass coverage and mangroves are absent from these estuaries. The catchments are mostly steep and experience summer rainfall and high erosion rates.

Grazing is the main land use in the catchments. Significant wilderness areas (e.g. the Otways) with high recreational use also exist. Several of the estuaries are important for port and shipping activities. The region has the greatest number of estuaries that are modified. Many western Victorian estuaries are at risk from inappropriate land and extractive uses. As many of these estuaries have only ephemeral openings to the coast, and the adjacent catchment is often steep and predominantly agricultural, nutrients, sediment and toxicants can accumulate in these estuaries. Water quality and quantity information is only available for some estuaries.

Estuary entrances are sometimes opened by local groups with permits to prevent flooding of farms and residences, improve water quality and to promote recruitment of fish. The artificial opening of these estuaries can cause environmental problems (e.g. fish kills and loss of waterfowl breeding). Wetlands also rely on periods of flooding and opening the estuaries can prevent their full ecological functioning. Decision support systems to articulate and allow evaluation of trade-offs in the opening of estuary entrances is needed.

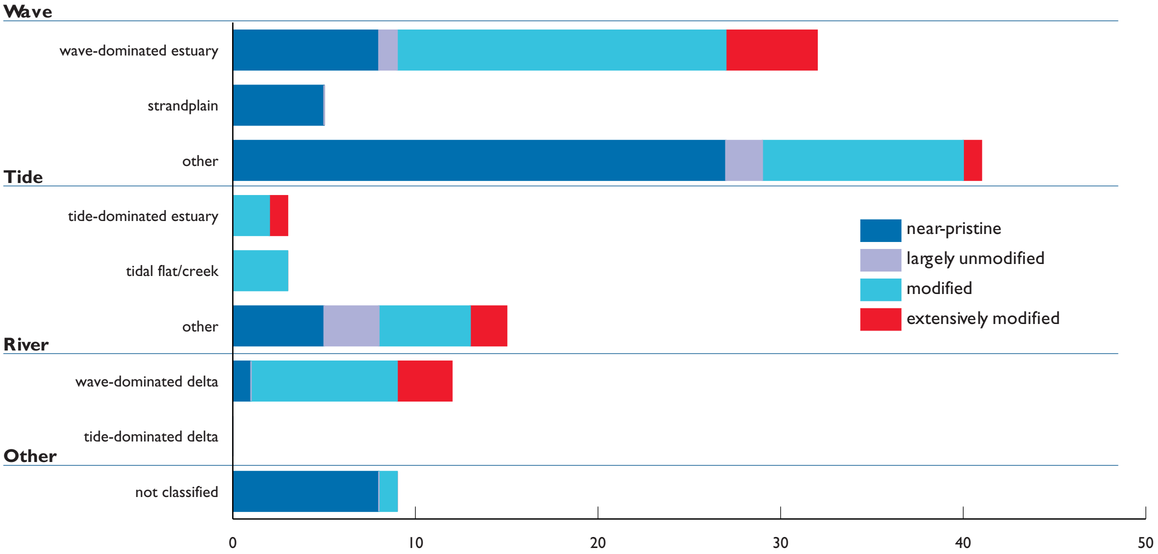
Five coastal action plans have been developed, including:

- Southwest (Aire to Glenelg) Estuaries Coastal Action Plan 2000
- Warrnambool Coastal Action Plan 1999
- Moyne Coastal Action Plan 2001
- Skenes Creek to Marengo Coastal Action Plan 2001
- Anglesea Coastal Action Plan 1999
- Lorne Coastal Action Plan 1998

Pressures on estuaries will increase as an aging population retires and moves to the coast.

Key findings

Process-based classification and condition assessment.



Key messages

- Some of the most pristine estuaries in the Australia are found in southern Tasmania (e.g. Bathurst Harbour and New River Lagoon within the south-west World Heritage Area).
- Tasmanian estuaries are diverse, mainly due to extreme differences in wave energy and rainfall between the west and east coasts, a greater tidal range on the north coast and variation in local geomorphology.
- The main cities of Hobart and Launceston are situated on the shores of the Derwent and Tamar estuaries, respectively. Both estuaries have been severely modified by urban, industrial and agricultural developments yet have high levels of biodiversity and endemism.
- As an island State, many larger estuaries are important for shipping. Many mainland visitors arrive by ship in the Mersey estuary.
- Estuaries, such as the Huon estuary and D'Entrecasteaux Channel are economically important as marine farming areas and for recreational activities.

Key needs

- There is a need for management coordination. This could be achieved based on a synthesis of current legislation and development of an estuarine habitat management plan.
- A range of factors affect estuarine health in Tasmania; management needs to recognise that these factors will impact differently on the different physical types of estuaries.
- We need to provide communities with the tools to monitor estuaries and, given the diversity of estuarine types, directions as to what to monitor.
- We need better mechanisms to provide environmental information about estuaries through to a local level, building understanding and better management.
- Management decisions need greater emphasis in on-ground action.

Management arrangements

The management of Tasmanian estuaries is primarily the responsibility of the Department of Primary Industries, Water and Environment, which provides leadership in the sustainable development and conservation of Tasmania's resources by playing a central role in resource management, industry development, environment protection and conservation of natural and cultural heritage. Various agencies within the Department are responsible for the planning and management of the aquatic and terrestrial estuarine environment.

Policies

State legislation relating to estuaries management:

- *Living Marine Resources Management Act 1995* (Tas)
- *National Parks and Wildlife Act 1970* (Tas)
- *Environmental Management and Pollution Control Act 1994* (Tas)
- *Land Use Planning and Approvals Act 1993* (Tas)
- *Water Management Act 1999* (Tas)

The State Coastal Policy 1996 has a central objective of sustainable development of the coastal zone. All activities, uses and developments which may impact on the coast, are required to meet the objectives of the State Coastal Policy. The three main guiding principles of the policy are:

- protection of natural and cultural values of the coast;
- use and development of the coast in a sustainable manner; and
- integrated management and protection of the coastal zone is a shared responsibility.

Under the State Policy on Water Quality Management 1997, protected environmental values must be set for all Tasmanian surface waters, including estuarine and coastal waters. Protected environmental values (the current uses and values of the waterways) are being documented in a consultative process involving all interested industry and community groups. Water quality objectives, to achieve all protected environmental values nominated for an estuary will then be set.

Cockle Creek, Tasmania

Community initiatives

There are a number of community conservation and rehabilitation initiatives in and around Tasmanian estuaries. Many of these community initiatives have been established under Tasmanian Landcare Association programs (e.g. Coastcare, Waterwatch, Rivercare, Bushcare). The activities undertaken by these groups include water quality monitoring, weed eradication, re-establishment of native flora and fauna, catchment and foreshore management, and the preparation of educational materials. Over 30 community groups provide input to and are linked through the Derwent Estuary Program (a joint Commonwealth, State and Local Government initiative to restore and protect the Derwent Estuary). The Huon Healthy Rivers Project is an integrated catchment management program involving school and community groups, plus local forestry and aquaculture industries, in water quality monitoring and Landcare activities. On the north coast, Five Rivers Waterwatch is a community based water quality monitoring group covering the Rubicon (Port Sorell), Mersey, Don, Forth and Leven Rivers.

State priorities

Management priorities for Tasmanian estuaries are to ensure that all activities meet the sustainable development objectives of the Resources Management and Planning System. The State Policy on Water Quality Management and the State Coastal Policy aim to meet these objectives through the establishment of protected environmental values and water quality objectives, and by defining core principles that guide all activities affecting the coastal zone.

Around the State

Of Tasmania's non-pristine estuaries, many are degraded due to agriculture, forestry and urban development. Sewage, run-off and industrial pollution contribute to reduced water quality in many urban estuaries (e.g. Derwent and Tamar Rivers). Nutrient and sediment loads have increased through agriculture and land clearing, particularly in estuaries in the north-east and north-west of the State. Mining has had a significant impact on some estuaries (e.g. Macquarie Harbour—heavy metals—and in the Boobyalla and Ringarooma estuaries—siltation). In estuaries with upstream hydroelectric dams or irrigation, maintenance of environmental flows is an issue.

The presence of introduced marine pests is a significant issue in many Tasmanian estuaries. Introduced pests (e.g. toxic dinoflagellates (*Gymnodinium catenatum*), Northern Pacific seastars (*Asterias amurensis*) and New Zealand screwshells (*Maoricolpus roseus*) in the D'Entrecasteaux Channel, Derwent and Huon Rivers; rice grass (*Spartina anglica*) in many estuaries, particularly the Tamar River and Port Sorell) can threaten the ecological integrity of estuaries by altering habitat, outcompeting and preying on local species, or causing shellfish closures.

Resource allocation is a major issue in some Tasmanian estuaries. Commercial and recreational fisheries, marine farms and other coastal developments all compete for resources. Some estuaries provide a cultural and historical centre for coastal communities and support non-extractive uses such as boating, swimming and aesthetic values. Balancing these uses with conservation of estuarine habitat is a significant challenge for estuary managers.

North coast

North coast estuaries, from Cape Grim to Cape Portland are characterised by seasonal rainfall with land uses that include agriculture, forestry, urban and industrial developments. These estuaries are generally modified and mostly wave- or tide-dominated. The Tamar estuary has extremely high plant, invertebrate and fish diversity.

East coast

The estuaries on the east coast from Cape Portland to Maria Island are subject to low rainfall. Land use includes agriculture and forestry. Modified estuaries are largely wave-dominated. The region also contains a large number of coastal lagoons.

South east

The estuaries from Maria Island to Southport are influenced by seasonal rainfall, often with very dry summers. This region has a convoluted coastline with many protected embayments. The estuaries have high levels of animal and plant endemism. Land use includes agriculture, forestry, urban and industrial developments. The estuaries are generally modified, and include both wave- and tide-dominated systems.

South and west coast

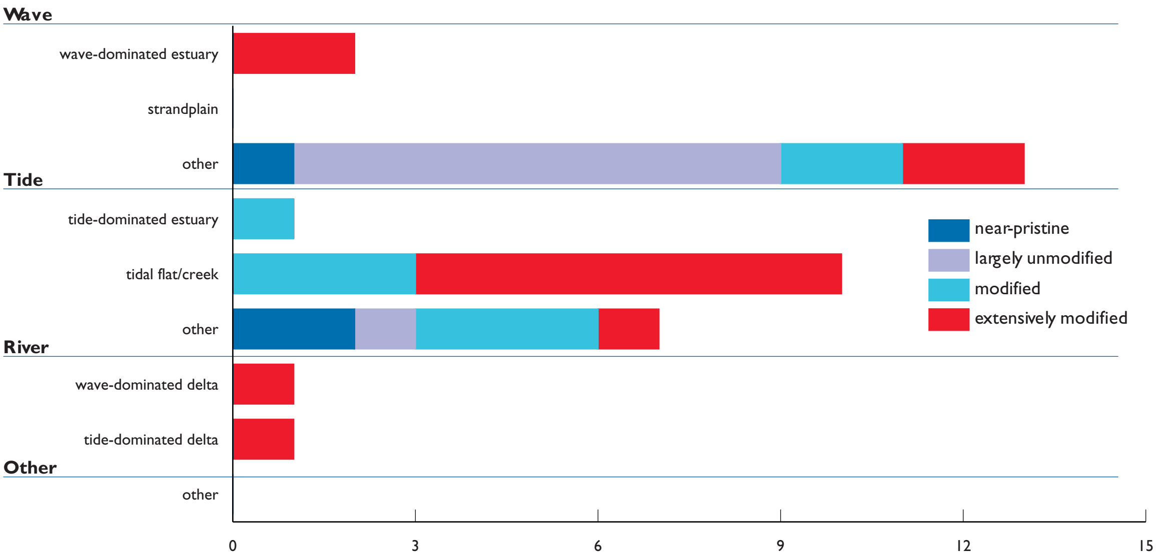
The south and west coast from Southport to Cape Grim has high rainfall. Much of the coastline is exposed to extremely high wave energy. All of the south-west coast is in national parks with grazing occurring in catchments further north on the west coast. These estuaries are predominantly near-pristine with tannin-rich waters. Unique biotic communities occur in Bathurst Harbour.

Bass Strait islands

The predominantly wave-dominated estuaries of King Island, Flinders Island and Cape Barren Island are mostly in near-pristine condition. Rainfall is seasonal and the land is primarily used for grazing.

Key findings

Process-based classification and condition assessment.



Key messages

- South Australia has a predominantly arid climate leading to several inverse estuaries, with salinity increasing to the upper reaches. Spencer Gulf and Gulf St Vincent are two of the world's largest inverse estuaries.
- Many of South Australia's estuaries are either coastal lagoons with little freshwater input or have small catchments with only periodic river inflow.
- The Coorong and Lower Lakes estuary is the downstream end-point of the Murray–Darling system. Catchment and river influences from Queensland, New South Wales, Victoria and South Australia affect the estuary, and its management requires extensive collaboration.
- A State management plan is required to integrate State and local government planning as well as developments within estuaries and their catchments.

Key needs

- A lead agency to coordinate estuarine management linking marine and coastal initiatives as well as integrated natural resources management and catchment management.
- Resources for monitoring and research in South Australia's estuaries to broaden our knowledge of the State's estuarine systems particularly inverse or arid-region estuaries.
- A central geographic information system database/data management system—including marine, coastal, estuarine and waterways information—linked to data sets of commercial and recreational activities as a basis for planning and decision making.
- A focus on regional estuarine management and capacity building in regional National Parks and Wildlife offices to enable inclusion of estuarine issues in nature conservation management.

- Aquaculture development within a framework of coastal and estuarine management plans, and integrated coastal management to foster aquaculture development.
- Promotion of an overall duty of care for estuaries through collaborative government, industry and community initiatives, as a basis for improved management activities.
- Restoration programs for estuaries that have been classified as extensively modified based on an assessment of return on investment.
- Baseline monitoring of selected estuaries classified as near-pristine to largely unmodified.
- Assessment of the economic value of key estuaries and their importance to South Australia as input to investment and management strategies such as aquaculture development.
- Encouragement and facilitation of combined and multi-disciplinary research projects on priority estuaries and management issues linking South Australian tertiary and research institutes including South Australia Research and Development Institute, the University of Adelaide, Flinders University, Port Lincoln Marine Science Centre, the University of South Australia and CSIRO.

Management arrangements

Estuarine management and data collection is within the scope of several State departments, catchment water management boards and local government councils. No one central organisation coordinates an estuaries program State wide.

The Department for Environment and Heritage is the lead agency undertaking research on South Australia's estuaries. Within this department, the Environment Protection Agency has developed the Environment Protection Policy on Water Quality involving marine, estuarine and freshwater resources. The agency also undertakes ambient water quality monitoring in two of the State's estuaries (the Port River estuary and Lakes Alexandrina and Albert near the mouth of the River Murray). The Department released the Coorong, and Lakes Alexandrina and Albert Ramsar Management Plan in September 2000.

The Office for Coast and Marine is in National Parks and Wildlife South Australia, Department of Environment and Heritage. One of the office's main roles is the implementation of the Marine and Estuarine Strategy for South Australia - Our Seas & Coasts (1998). The office has also managed South Australia's contribution to the Audit estuary assessment.

The Department of Water Resources has lead jurisdiction for water quantity allocations as well as for the management of the River Murray. Through this department, the Murray Mouth Advisory Committee provides advice to the Murray-Darling Basin Commission and the South Australian Government on strategies to prevent closure of the Murray mouth. Estuarine management is covered within the *State Water Plan 2000* (Section 4.4.6).

Bunda Cliffs, eastern Great Australian Bight

Primary Industries and Resources including South Australia Research and Development Institute, and South Australia Water including the Australian Water Quality Centre are involved in estuarine monitoring (fish surveys, water quality, eutrophication and algal blooms).

Many of the seaside local councils as well as the Catchment Water Management Boards deal with day-to-day issues confronting estuaries including planning regulations.

Associated with the Catchment Water Management Boards are several Waterwatch groups that monitor some State rivers and their mouths. The Barker Inlet Port Estuary Committee is a community and local government initiative established since 1999 to promote integrated estuarine management of that region.

Policies

- The Marine and Estuarine Strategy – Our Seas & Coasts 1998
- State Water Plan 2000—Water Resources Management Policy for Estuaries (section 4.4.6)
- Environment Protection (Water Quality) Policy (covers all waters in the State including marine and inland surface and underground waters).
- State Acts relating to estuarine management administered by the Department for Environment and Heritage: *Coast Protection Act 1972* (SA), *Native Vegetation Act 1991* (SA), *Environment Protection Act 1993* (SA), *National Parks and Wildlife Act 1997* (SA).
- Other relevant Acts: *Water Resources Act 1997* (SA), *Local Government Act 1999* (SA), *Development Act 1993* (SA), *Fisheries Act 1982* (SA), *Soil Conservation and Landcare Act 1989* (SA).

Community initiatives

A number of community groups are active in estuarine initiatives. These include regional Coastcare and Waterwatch groups, Our Patch, the Port Adelaide Environment Forum, Community Action for Port and Peninsula, the Middle Beach Education Centre and the Southern Fluerieu Catchment Resource Centre Marine Education Program.

State priorities

- Development of a State-wide Estuaries Management Implementation Plan through the Marine Managers Forum and in conjunction with local government, Catchment Water Management Boards and other stakeholders as included in the State Water Plan.
- Formation of an Estuaries Advisory Committee to advise the Marine Managers Forum on estuarine issues.
- An integrated management framework for the Barker Inlet Port Estuary as outlined in their management strategy.
- Establishment of coastal and estuarine protected areas.
- Development of a Coastal Habitat Policy.

Around the State

Local issues of State significance

- The formation of the Barker Inlet and Port River Estuary Integrated Management and Protection Strategy and Barker Inlet Port Estuary Committee;
- Lower lakes and Murray mouth initiatives, including the Murray Mouth Committee;
- Key projects include: Sediment Transport Modelling, Encounter 2002 Program, Natural History of Nuyts Archipelago, Gulf St Vincent ten-year study, Regional Bio-icons and the Acid Sulfate Soils Project.

South east coast

Estuaries from the Victorian border to the tip of the Fluerieu Peninsula are characterised by a semi-arid to temperate climate and predominantly winter rainfall. The main land uses in the Millicent Coast and Lower Murray River basins are grazing, agriculture (e.g. vines) and some timber plantations in the south east. These estuaries are modified to extensively modified. The estuaries are mostly wave-dominated, particularly the Coorong and Lower Lakes where wave energy has resulted in the formation of the Young Husband and Sir Richard Peninsulas. The coast is exposed to some of the highest wave energies in Australia and includes extensive carbonate sediments.

Kangaroo Island

Kangaroo Island estuaries are characterised by a temperate climate and predominantly winter rainfall. The western third of the island is Flinders Chase National Park. Grazing and cropping are the main land uses elsewhere. The estuaries are 'largely unmodified' to modified. Near-pristine estuaries occur in the National Park. Most of the estuaries are small with small catchments, apart from the American River estuary that is part of an extensive coastal lagoon. There is diversity in the way these estuaries function with tidal and wave energy being significant. The southern part of the island is exposed to high wave energy from the Southern Ocean.

Gulf St Vincent and Spencer Gulf

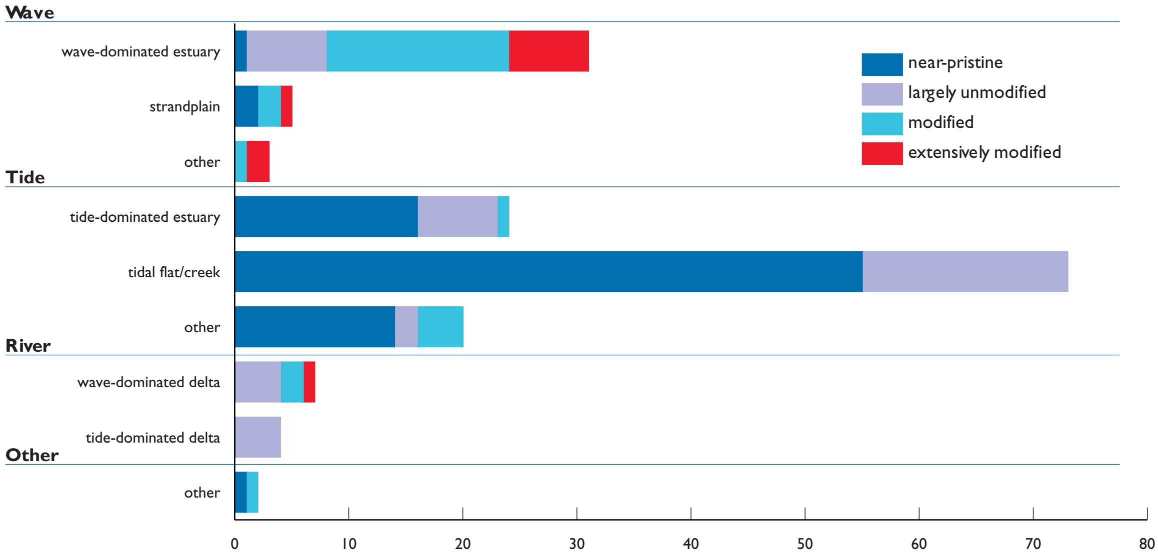
Estuaries in the gulfs from the tip of the Fluerieu Peninsula to the west coast of Spencer Gulf (eastern Eyre Peninsula) are characterised by a semi-arid to arid climate with predominantly winter rainfall. Grazing and agriculture are the main land uses; industrial and urban land uses also occur along eastern Gulf St Vincent and in upper Spencer Gulf. All these estuaries are modified to extensively modified. There is significant variation in the functioning of the Gulf estuaries with wave energy influencing southern estuaries and tidal energy predominating in the northern reaches of the Gulfs where extensive tidal flats have formed. Few South Australian estuaries have significant river energy (e.g. Onkaparinga River estuary).

Eastern Great Australian Bight

Estuaries from the southern tip of Eyre Peninsula and westward are characterised by an arid climate with some winter rainfall. Only minor surface flows occur, although groundwater seepage may be significant. Grazing and cropping (sheep–wheat belt) are the main land uses. These estuaries/coastal lagoons range from near-pristine to modified depending on the extent of oyster aquaculture and catchment clearance. The way these estuaries function is diverse; tidal and wave energy are significant for most of them.

Key findings

Process-based classification and condition assessment.



Key messages

- Western Australia has highly variable systems ranging from monsoonal wet tropics through arid tropics to Mediterranean climates of the south. Rainfall and discharge are variable from year to year.
- Rising groundwater has created more hydraulic forcing on estuaries for catchments affected by dryland salinity in the southern parts of the State. There is a high potential for floods. There is no 'average' condition for these systems throughout the year.
- Many south-west estuaries open and close at different times of the year making it difficult to predict seasonality and estuary behaviour.
- In many cases catchment impacts have not manifested in estuary decline as yet. This incongruity between catchment condition and estuarine condition is a result of long response times. Time lags reflect the fact that groundwater is a significant input to estuaries.
- Whereas some problems have taken time to manifest themselves, improved catchment condition may similarly not result in immediately improved estuarine condition.
- Over-allocation of groundwater is affecting estuaries and has resulted in significant losses of melaleuca, riparian vegetation and critical habitat (e.g. in the Peel–Harvey estuary).
- Drainage has seriously compromised habitat values.

Key needs

- A well-informed, involved and active community.
- Prevention of further development in near-pristine environments with development activities to focus on already modified estuaries.
- Better ways of managing human interactions with estuarine environments—we are presently 'loving our estuaries to death'.
- Increasing pressures from emerging industries (e.g. viticulture at Margaret River and tourism) need to be better understood and managed.
- Better integration of estuarine management issues with coastal and catchment planning.

Management arrangements

Responsibility for the management of estuaries currently lies with the Water and Rivers Commission under the *Waterways Conservation Act 1976* (WA). The commission is being merged with the former Department of Environmental Protection to form the Department of Environment Water and Catchment Protection incorporating powers of the *Environmental Protection Act 1986* (WA). Estuarine and catchment water quality data is maintained in the Water and Rivers Commission and fisheries data resides with Fisheries Western Australia. The Water and Rivers Commission collects, manages and uses data from estuaries and rivers. The commission has developed rigorous quality assurance and data management procedures specifically for estuarine and water quality data. Much of the commission's work is related to eutrophication, algal blooms and local estuarine management issues.

Until very recently key estuaries under risk were managed through community-based waterways management authorities. These were the Albany Harbours, Wilson Inlet, Leschenault Inlet and the Peel–Harvey Inlet. The Swan Canning estuary is managed separately under the Swan River Trust a statutory authority operating under the *Swan River Trust Act 1972* (WA). The Swan River Trust is unique in that it has planning and development powers within the trust area.

Building on the experience gained from the management authorities, estuarine management is now considered an integral component of catchment management which in the Western Australian model is regional and community based. Community-based advisory committees will provide a focus for local initiatives in partnership with State agencies and local government under the umbrella of regional catchment management strategies. For example on the south coast the umbrella regional grouping is the South Coast Regional Initiative Planning Team or SCRIPT covers the region from Broke Inlet to the areas east of Esperance under which the Albany Hinterland Catchment Group works on natural resource management initiatives in the Albany, Wilson Inlet and Torbay Inlet catchments. Local estuary-specific issues are addressed by the Wilson Inlet Management Group under this regional strategy.

Community initiatives

Western Australian communities generally are highly aware of the values and management needs of estuaries. Waterwatch and Ribbons of Blue link in with agency activities in improving awareness of natural resources issues. As noted above, estuaries are managed with community-based regional strategies. Geocatch, for example, is a community-based agency partnership sponsored by the Water and Rivers Commission that is implementing extensive restoration activities on the Vasse River and Vasse Wonnerup Estuary centred on the town of Bussleton.

Perth and the Swan River

Around the State

South coast (east of Albany)

From Albany east to Esperance rainfall drops off markedly and becomes much less predictable. All the estuaries along this coast are classified as wave-dominated and have seasonal bar openings. These estuaries typically open infrequently and for a short period in response to specific rainfall events that may be in summer as often as winter. Rising water tables in the over-cleared catchments have resulted in more rapid run-off. This is starting to change the frequency of bar openings (e.g. Culham Inlet which reputedly opened once in the last century has opened three times in the last ten years; the changed hydrology is having a great effect on the estuary).

Most of the catchments are heavily cleared (85%) and salt-affected and the associated estuaries are showing signs of stress, especially the Beaufort, Gordon and Wellstead estuaries. Sedimentation is a major issue in all of the estuaries along this coast.

In the central part of this coastline the Fitzgerald National Park and World Biosphere Reserve has outstanding natural values and includes Fitzgerald and St Mary's inlet entirely within the park. Oldfield estuary is still largely pristine and despite a heavily cleared catchment much of the riparian vegetation remains. Oldfield is the darkest of these tannin-coloured estuaries.

In general the estuaries along this coast are poorly studied and understood. They have high tourism and recreational potential and associated development pressure. A new pressure in the form of large-scale mining for nickel, tantalite, and silver/lead/zinc in the floristically rich Ravensthorpe Range has also emerged. The South Coast Regional Initiative Project Team groups catchment communities and agencies mainly concerned with agricultural catchments and their associated estuaries. Not all catchments have active community groups and interest in estuarine and coastal issues varies along the coast.

South coast (west of Albany)

The area west of Albany to the south-west corner of Western Australia encompasses a high rainfall (falling mostly in the winter) and highly forested band of catchments. Some catchments are semi-protected state forest and others are being actively logged. The upper catchments are geologically distinct and in general are heavily cleared for agriculture. Salinity is a major problem on the wheatbelt portion of these catchments.

The estuaries along this coast facing the Southern Ocean are wave-dominated and tidal ranges are very low. In the western portion as far as Walpole/Nornalup the estuaries are only slightly modified. Broke Inlet is near-pristine with an almost completely forested catchment; half of the Walpole/Nornalup catchment is forested and good riparian vegetation remains on the lower stretches of the rivers. Many have seasonally open bars although Walpole/Nornalup is permanently open to the sea.

The catchments of the smaller estuaries between Walpole and Albany range from natural to cleared but in general are still in good condition. Even Wilson Inlet, which has been the subject of considerable attention due to the increase in macrophyte and phytoplankton growth, is still in good condition. Here the bar is artificially opened and then closes naturally on an annual basis. The eastern portion of Wilson Inlet and the neighbouring Torbay catchment are extensively drained to prevent waterlogging. Sandy soils and high nutrient loading in the shallow water in these systems has produced cyanobacteria blooms during the summer months. Torbay Inlet, which is artificially opened for brief periods in the summer, is now subject to Nodularia blooms. There is limited commercial fishing along this coast with Wilson Inlet recording the highest catches.

The Albany Harbours, Princess Royal and Oyster Harbour, permanently open to the sea, have had increased management activity since the loss of seagrasses from both harbours. Extensive macroalgae growths were harvested over a number of years without mitigating the problems of enrichment. Reduction of point sources in Princess Royal has greatly reduced the nutrient loading but little progress has been made in reducing nutrient loading from the extensively cleared Oyster Harbour catchment. Gillnet fishing for mullet, King George whiting, flathead, herring, cobbler and garfish is common in these estuaries. These estuaries are highly productive (due to anthropogenic nutrient loading and increased marine exchange).

The coastline around Albany is highly scenic with high aesthetic, tourism and biodiversity values. Community awareness and concern about estuarine issues varies along the coast. In some cases communities in the upper catchments have little connection with the coast partly because dryland salinity is the major natural resource concern.

Broke Inlet at the mouth of the Shannon River is the only estuary in near-pristine condition in this region. It is a large lagoon and is connected to the sea by a long, narrow channel through coastal dunes. The estuary is located entirely within the D'Entrecasteaux National Park, which extends along the coast. Broke Inlet has many conservation values and is also important for recreational and commercial fishing. The inlet is geologically similar to many estuaries on the south coast, making it useful as a benchmark to compare with problems of nutrient enrichment and sedimentation within other inlets and estuaries.

South west

The south-west coast of Western Australia has tidal ranges of 0.5–1.0 m and estuaries in the region are wave-dominated. Many of the estuaries are now permanently open using training walls although a few are still seasonally closed. The Mediterranean climate and rainfall pattern in this region results in a floristically rich vegetation pattern, coastal heath and extensive forests in the wetter areas of the south-west corner. This region of the coast is intensively used by dairy, beef and piggery operations, and horticulture, all of which contribute nutrients to the estuaries. Bauxite and coal mining in the hinterland and sand mining along the coastal plain are the major extractive industries. Acid waters from mine dewatering is an issue in the catchment of the Leschenault estuary.

Further to the south on the Scott coastal plain that runs into Hardy estuary, intensive horticulture (e.g. potato growing) contributes high nutrient loads to the estuary. The Swan coastal plain from the Peel–Harvey catchment through to the Vasse-Wonnerup catchment near Busselton is extensively drained to prevent waterlogging on the over-cleared catchments. This has resulted in highly modified flows to estuaries and in combination with high nutrient loading land practices and low nutrient retention on the predominantly sandy soils has led to blue–green algae blooms, fish kills, and modified flows to the estuaries. Many of the estuaries in this area are extensively modified.

The Peel–Harvey is well known for the Dawesville Cut, an opening to the ocean to relieve the estuary from extensive *Nodularia spumigena* and macroalgae blooms. Although this has been effective, cyanobacteria blooms still occur in the tidal regions of the incoming streams. Since nutrient losses from the catchment are unabated, there is concern that the Peel–Harvey will again experience macroalgal growth. The potentially toxic

Lyngbya masucla has been detected in the region. The Leschenault estuary now has a permanent opening and the southern portion has been developed for the Port of Bunbury. The estuary faces increasing development pressure. The Vasse River has been diverted to the ocean bypassing the Vasse Wonnerup estuary and at the mouth of the estuary a barrage restricts tidal inflow into this Ramsar wetland. Algal blooms and fish deaths are common in the estuary during summer and intensive agriculture and canal developments are threats to the estuarine ecology. The very small Margaret River estuary has suffered reduced flows from water abstraction, mainly for viticulture.

The south west is the fastest growing residential area in Western Australia (e.g. towns of Dunsborough and Bussleton). There is some community awareness of the issues in their estuaries and a number of catchment groups are active. Many developments are not compatible with the maintenance of estuarine values and many residents adjacent to the estuaries do not appreciate these values (e.g. complaints are often received about natural levels of plant growth and the associated smell).

Swan–Canning estuary

This estuary contains Perth and is extensively modified. The bar at Fremantle was removed in the 1890s and the Port of Fremantle has been dredged and expanded a number of times. As a result 85% of the tidal prism at Fremantle makes its way to the upper Swan resulting in a salt wedge estuary that is highly stratified in summer. Agricultural and urban catchments contribute a range of contaminants including nutrients, which lead to macroalgal blooms. Reduction of point source pollution and sewage from the estuary has led to an improvement although algal blooms during the summer period remain a problem. Urban drainage and groundwater are major contributors of nutrients to the estuary during the summer. The Swan-Canning Cleanup Program has been instituted to improve estuarine condition and to minimise likelihood of algal blooms. The Avon catchment is very extensive (the size of Tasmania) and contributes the bulk of the water flow to the Swan–Canning estuary. Flood events in this catchment can move large quantities of nutrient in to the estuary with potentially dramatic effect as evidenced by the *Microcystis* bloom of February 2000.

Mid-coast

This area is the stretch of coastline from Perth to Shark Bay. Shark Bay (13 000 km^2) is a declared World Heritage Area and marine park due to its world-renowned stromatolite deposits. A salt lease covers part of the area and the park is extensively fished both recreationally and commercially. Dugongs graze on the extensive seagrass beds and dolphins are a tourist attraction. The Murchison River drains an extensive agricultural and pastoral catchment entering the sea at the popular tourist town of Kalbarri. Mining in the catchment has led to lead contamination of the estuarine sediments from old mine tailings. The mid-west coast is arid with sandy soils and is characterised by small riverine estuaries that are heavily impacted by agriculture south of Geraldton. Sedimentation and algal blooms are issues of concern.

Relatively little is known about these estuaries and community catchment activity is not well developed except for the Moore River where community activity is strong. The bar separating the Moore river from the ocean is opened for short periods during the winter. The catchment is extensively cleared, highly saline and affected by floods. Riparian vegetation around the estuarine portion is in reasonable condition. Estuarine water levels in the summer are sustained by groundwater inflow (high in nutrient in the lower reaches and lower in nutrients in the upper reaches).

In this region, marine and terrestrial species with tropical affinities mix with species of temperate affinities. Further research is needed to fully understand the ecological communities that are under threat in these estuaries. The estuaries in this area are important for recreational fishing. Commercial fishing is not viable due to eutrophication and habitat loss.

Pilbara

The Pilbara is a region of arid coastline with rivers that only run to the sea during the irregular wet seasons. At this time the rivers empty directly to the coast. In drier periods, the rivers peter out before they enter the ocean creating inland deltas and may seek alternative paths to the ocean in the next substantial wet. Estuaries along this coast are classified as tide-dominated with tide ranges up to 4 m. Catchments are extensively grazed and mining is a significant industry. Port Hedland and Dampier/Cape Lambert have been developed as export ports for the mining and oil industries and salt works. Karratha is a base for the offshore oil industry.

Kimberley

Estuaries from the Dampier Archipelago to the Northern Territory border in Northern Western Australia are characterised by rocky catchments with very high tides of more than 10 m. Estuaries in this region are tide-dominated and include many tidal creeks and strand plains.

Monsoonal rainfall also has a seasonally important influence on the ways these estuaries function. Many are dominated by fluvial inputs for a month or two. Extreme heat and evaporation cause stunted growth in estuary-associated vegetation such as mangroves, but little more is known about the natural processes driving these estuaries. Land tenures for this region are Indigenous and non-Indigenous leasehold, defence, mining tenement and conservation reserve. Potential impacts to estuaries include fishing activity, both commercial and recreational.

In a few areas (e.g. the Ord) aquaculture projects have been proposed or are being developed. Mining on the plateau is a significant industry and an ore loading facility is planned for Londonderry Creek. Fishing charter activity is having some minor impact. Cotton growing impacts are being assessed. Near-pristine estuaries in this area are important for cultural values, pearl aquaculture, commercial and recreational fishing, and eco-tourism.

Major areas of irrigated agriculture have been established in the Ord and will increase with the second stage of the Ord release. There is some concern that the Keep estuary will be affected by agricultural expansion into the catchment. There is evidence that abstraction has led to increased sedimentation of the lower Ord.

The level of estuary management is this region could be described as benign neglect. Management plans have already been formed for safari eco-tourism. Integrated planning agreements are needed to identify potential threats and to make specific recommendations on how to maintain and manage these estuaries in near-pristine condition.

Improved understanding of estuaries will assist in establishing priorities for works and investment

IMPROVING UNDERSTANDING OF ESTUARIES AND ACCESS TO INFORMATION

A key issue for improved estuarine management is to build knowledge and understanding at all scales from community groups to senior management in government. For effective estuarine management we need to understand:

- estuarine processes;
- linkages between catchment land use and estuary condition;
- implications of management decisions within catchments or estuaries;
- priorities for investment; and
- complexities and variation within the Australian landscape.

A series of products were commissioned by the Audit to enhance our collective understanding of the concepts and imperatives for improved estuarine management. These include:

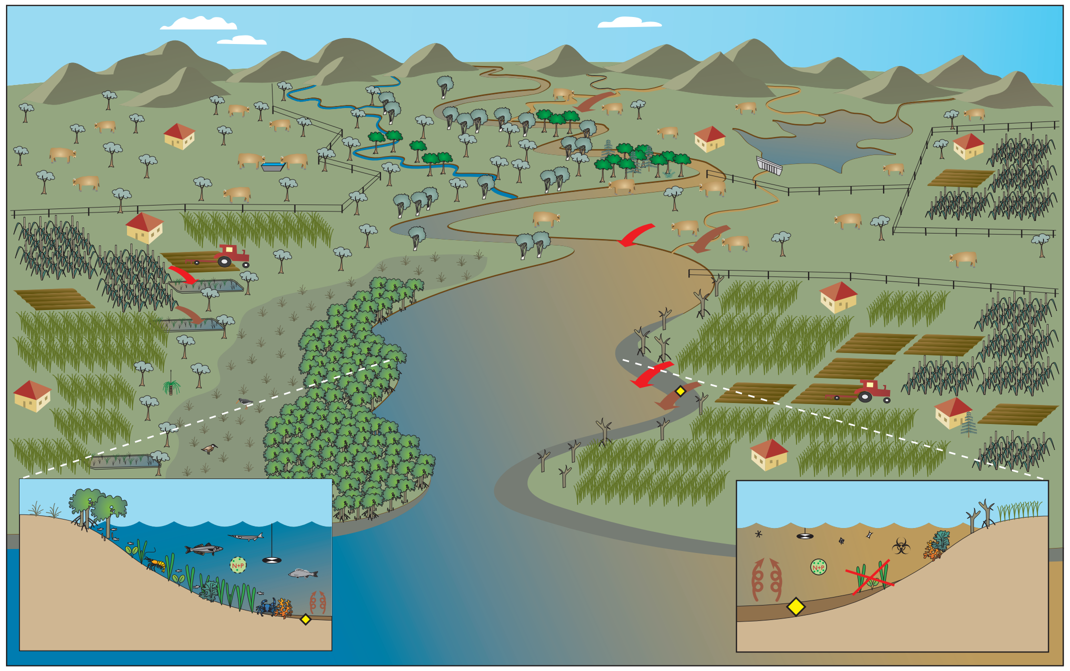
- conceptual models that link catchment and estuarine use and estuary condition;
- conceptual models of the processes that drive estuarine ecology;
- a simple estuarine response model; and
- the OzEstuaries Database.

Combined with local understanding, these tools will assist estuarine managers to identify issues, assess management options, develop monitoring programs and establish priorities for works and investment.

Developing a understanding of the links between estuarine use and condition

The following models illustrate the anthropogenic uses of estuaries (pressures) as they link to and change the condition (state) of an estuary. They summarise the management considerations for a variety of catchment, recreational, fisheries, urban and industrial uses. The University of Queensland and the Coastal Cooperative Research Centre are refining these models in the development of an *Australian Estuary Management Handbook,* supported by the Fisheries Research and Development Corporation.

Figure 64. Best management practices—catchment pressures.



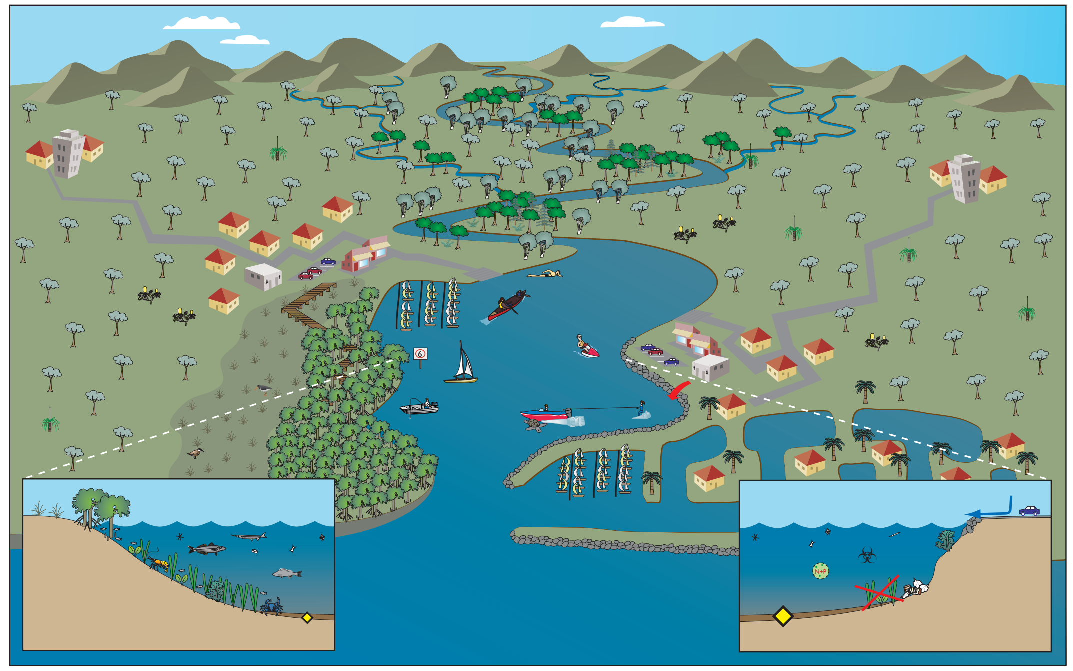
Good management practice

- Better farm practices reduce erosion and nutrient run-off
- Stock fenced off from creeks and remote watering points provided
- Riparian buffer strips preserved along creeks
- Wetland areas protected
- Filter strips and artificial wetlands reduce silt/nutrients in run-off
- Riparian vegetation promotes infiltration of run-off
- Efficient irrigation practice reduces water use
- Base flow from groundwater to streams maintained
- Appropriate use of pesticides

Poor management practice

- High levels of sediments and nutrients in agricultural run-off
- Sediments and adsorbed nutrients flow to estuary
- Nutrients in groundwater enter catchment streams
- Stock in creeks cause erosion of stream banks
- Riparian vegetation cleared or badly degraded
- Compaction and sealing of cleared soil surfaces
- Wetland areas reclaimed for agriculture
- Impoundment and extraction reduces base flow in streams
- Faecal bacteria from stock in waterways
- Overuse of pesticides and poor application practices

Figure 65. Best management practices—recreational pressures.



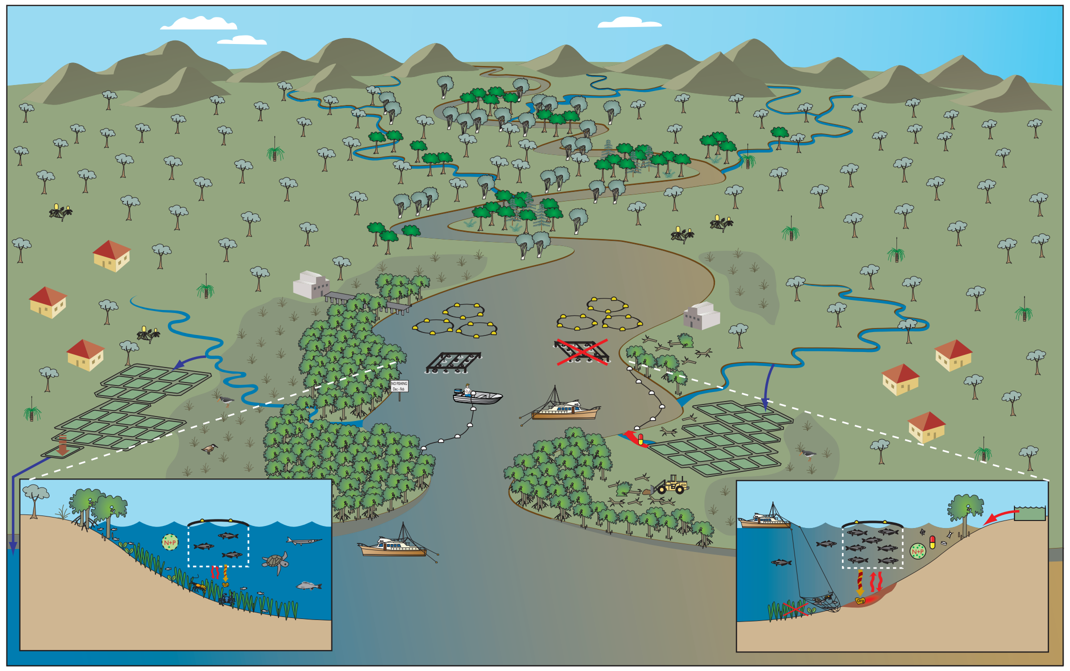
Good management practice

- Less invasive activities favoured
- High aesthetic value
- Large areas of original wetland preserved
- Presentation of wetland areas (e.g. boardwalk access, information)
- Ecological integrity of estuary intact
- Careful design and positioning of public amenities
- No litter
- Fish stocks attract recreational fishers
- Speed limits protect foreshore and other estuary users
- Good water quality encourages recreation (e.g. swimming)

Poor management practice

- Focus is on more invasive activities
- Infrastructure developed along foreshore
- Extensive habitat destruction for canal development
- Poorly positioned public amenities pollute estuary
- Chemicals from boat antifouling paint in sediment
- Litter threatens estuarine biota and aesthetic values
- Destruction of fish habitat threatens recreational fish stocks
- High speed water craft threaten animals and disturb other users
- Wash from high speed water craft erodes foreshore
- Poor water quality (e.g. presence of pathogens) can threaten recreation

Figure 66. Best management practices—commercial fishing and aquaculture pressures.



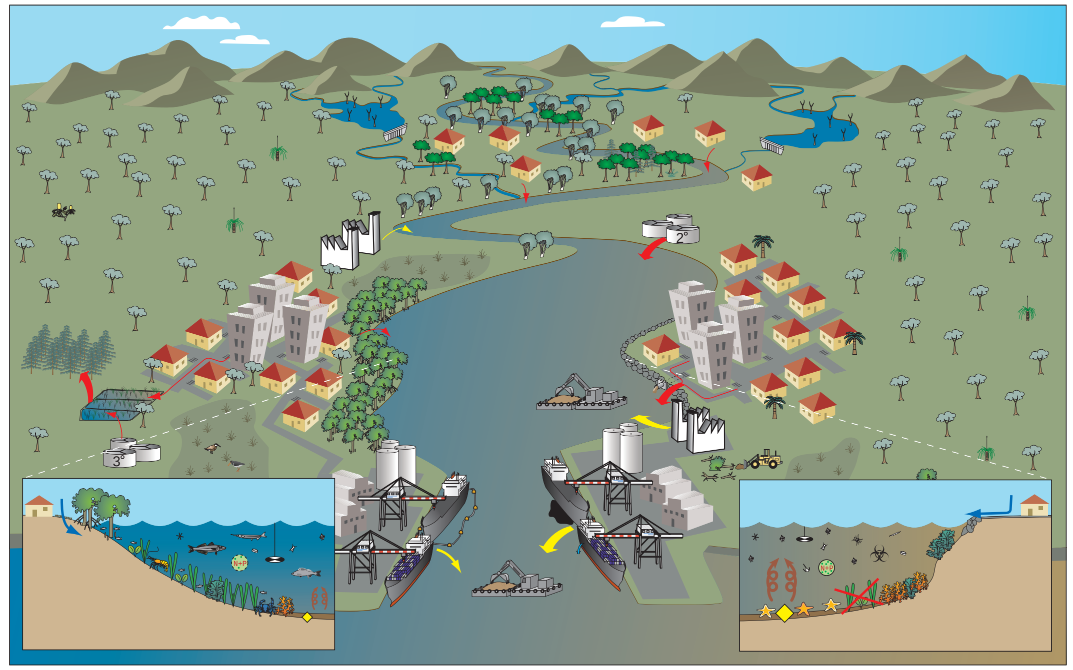
Good management practice

- No trawling in sensitive estuarine habitats
- Use of alternative, more selective fishing methods
- Seasonal closures for protection of spawning stock
- Responsible capture and release of bycatch
- Prawn farms developed outside wetland areas
- Prawn farm tailwater discharged to site with good tidal flushing
- High quality feed used and regular fallowing of cage sites
- Sustainable use of wild larval stock
- Medicated feed a response to specific diagnosis of disease
- Overstocking of ponds and fish cages avoided

Poor management practice

- Indiscriminate trawling in estuary and netting of entire creek mouths
- Fishing during spawning season reducing fish stocks
- Indiscriminate netting of juvenile and non-target species
- Wetlands destroyed for pond and infrastructure construction
- Overfeeding leads to high nutrient levels in pond effluent
- Organic deposition leads to anoxic areas near fish cages
- Unnecessary use of antibiotics in feed
- Unregulated harvest of wild larve may impact adult stocks
- Exotic fish species escape from cages
- Poor water quality precludes development of shellfish farms

Figure 67. Best management practices—urban and industrial pressures.



Good management practice

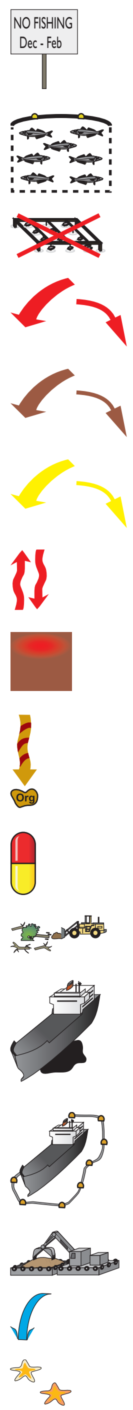
- Nutrients and pathogens removed from sewage
- Sewage nutrients used (e.g. for irrigation of plantation forestry)
- Constructed wetlands treat stormwater and sewage discharges
- Impermeable surfaces minimised to maximise infiltration
- Surviving wetland areas protected
- Areas of natural foreshore retained
- Strict controls on industrial discharges
- Measures taken to minimise pollution risk from port
- Ship ballast water treated to remove pest organisms
- Dredge spoil dumped outside tidal areas

Poor management practice

- Low levels of sewage treatment
- Sewage nutrients and pathogens discharged into estuary
- High proportion of impermeable surfaces leads to high run-off
- Stormwater flows directly to estuary
- Surviving wetlands destroyed
- Heavily modified foreshore
- High levels of industrial discharges
- Toxicants enter estuary from port (e.g. Tributylin, oil spills)
- Pest organisms enter estuary from ballast and hull fouling
- Dredging occurs with estuary

Legend

fish
crustaceans
wetlands birds
mangroves
salt marsh
seagrass
riparian vegetation
macroalgae
phytoplankton
boat speed limit
pathogens
seagrass loss
low to moderate nutrient levels
moderate nutrient levels
high to very high nutrient levels
tri-butylin from marina
low/high pesticide levels
sediment resuspension
water clarity



seasonal closure
overstocked fish cage
unsuitable for oysters
nutrients
sediments
toxicants
nutrient fluxes
anoxia
organic carbon release
antibiotics
destruction of wetlands
oil spill
oil containment measure
dredging
ballast water
invasive species

Simple Estuarine Response Model— a tool for decision makers (www.marine.csiro.au/serm/)

Building on the developed conceptual understanding of estuary processes and the multi-dimensional ecological interactions that then drive estuary condition, the Simple Estuarine Response Model was developed as part of the CSIRO contribution to the partnership initiative.

Model description

The Simple Estuarine Response Model consists of two parts:

- a simple circulation model which predicts physical exchanges in different estuary types, based on specification of a coarse box geometry to broadly represent estuary slope, and forcing variables (e.g. river flow and tidal amplitude); and
- a complex biogeochemical/ecological model, developed through previous coastal studies, and extended and improved for the Audit's Estuary Assessment. It is implemented on the same coarse box model geometry, and uses the exchanges predicted by the hydrodynamic model.

Modelling approach

Estuaries were divided into three hydrodynamic estuarine types, and simple coarse resolution circulation models were developed for each type.

The models are designed to investigate the response of Australian estuaries to changes in external forcings such as nutrient loads and flushing times. Models have been developed to represent each of the major estuary process types. They have been designed to allow users (scientists and managers) to examine a number of common management options (e.g. alterations to freshwater flows, nutrient loads, or oceanic exchange).

The Simple Estuarine Response Model:

- provides an indication of likely status, for estuaries where we have information on catchment modifications and loads, or on point source loads, and little or no direct measurements of water quality;
- helps to interpolate or interpret sparse data (e.g. putting scattered observations of water quality into context); and
- provides an interpretation of environmental status in terms of cause and effect.

In supporting management recommendations, the model can be used to describe the effects of a number of typical management actions for each estuary type, by performing simulations over a range of estuarine parameters and forcing scenarios. From these descriptions the user will be able to recommend the general types of management actions that are likely to be most effective for each estuarine type.

A relatively small number of estuarine parameters, that characterise the shape and physical and chemical forcing on an estuary, were identified for each. Simulations for a small but representative set of values of each parameter were run. This required some tens of thousands of model simulations.

The model was run for the equivalent of ten years for each parameter combination, by which time the model state variables had reached a repeating seasonal cycle. The initial conditions, which were the same for every simulation, represented ecology with a viable benthic community. The tenth year of the simulations represents the ecological system that the model predicts will have emerged after ten years of forcing as determined by the estuarine parameters. Model results were recorded every five days over the last year of simulation, and condensed into a standard set of indicator statistics, which can be viewed at the Simple Estuarine Response Model interface.

The Simple Estuarine Response Model interface has four main components:

1. Specification: requires the user to specify the range of estuarine parameters (which determine the estuary and the natural and human pressures on it) for which model results will be displayed. The user can choose any number of combinations of estuarine parameters, from one estuary (a single range for each parameter), to over 5000 combinations.
2. Explorer: graphs the results for the estuaries on the specification page using a coloured scatter plot. The user may choose to plot an indicator (which quantifies the response of the estuary) against another indicator or estuarine parameters. Explorer is ideal for looking at large combinations of estuarine parameters.
3. Assessment: depicts the indicators that are commonly used in assessments of estuarine conditions for the estuaries on the specification page. Assessment is ideal for looking at a single estuary while varying only one or two estuarine parameters.
4. Case studies: depicts the results of simulations for five different estuaries against data collected from those estuaries.

Case studies

Case study estuaries have been used to provide an assessment of Simple Estuarine Response Model performance in five different estuaries. The estuaries chosen include lagoons, tidal and salt-wedge estuaries from a variety of climate zones. The case study estuaries provide an example of the working of the model, and how the results can be interpreted.

The case study estuaries are:

- Brunswick River, New South Wales
- Huon River, Tasmania
- Maroochy River, Queensland
- Port Phillip Bay, Victoria
- Wilson Inlet, Western Australia

Limitations

The Simple Estuarine Response Model represents a first attempt to develop broad-brush, generic models of Australian estuaries, and the user should treat the results cautiously. In particular, it is not intended, and should not be used, to replace detailed local modelling studies or hydrodynamic modelling in developing and assessing management strategies for individual estuaries.

The models have largely been developed and calibrated in temperate and subtropical estuaries. There have been very few studies of Australia's tropical macrotidal estuaries, and model predictions for those estuaries may be less reliable. While this first attempt involves considerable extrapolation from our current knowledge base, the Audit's estuary assessment itself will provide data to assess model performance. The project will provide the first step in an ongoing cycle of model prediction, observation and refinement.

General management recommendations can be linked to the process-based classification of estuaries. It is not possible to recommend specific management actions for each individual estuary because:

- there is no detailed data for most estuaries to allow specific investigations;
- any examination of specific estuaries would have to be carried out in close collaboration with responsible State managers; and
- the time and cost to run models for a large number of specific cases would be prohibitive.

The model focuses particularly on the impacts of diffuse and point source loads of sediments and nutrients on estuaries as these represent the most significant and widespread anthropogenic stresses on Australian estuaries. The model also represents the effects of changes in freshwater run-off on circulation and flushing. The model is able to represent the effects of engineering works or dredging on tidal exchange and flushing, but only in a broad empirical sense (i.e. as changes in exchange coefficients).

The model used is an integrated physical – biogeochemical – ecological model. It represents the cycling of nutrients (nitrogen and phosphorus) through the water column and sediments, and ecological impacts on primary producers (phytoplankton, benthic micro-algae, macroalgae and seagrasses). Higher trophic levels, including fish, are not represented explicitly in models, although links between fisheries and model outputs such as primary productivity and seagrass habitat are well known.

Example of assessment of model performance—Maroochy River

General description

The Maroochy River is a tide-dominated estuary north of Brisbane.

Estuarine parameters

Estuary type: wide tidal

Depth: 2.5 m (Simple Estuarine Response Model range: shallow [1–3 m])

Fresh water replacement time: The annual mean river flow is about 1.8 m^3/s. This flow would deliver a volume equal to the estuary volume in about 74 days (Simple Estuarine Response Model range: medium [days])

Tidal range: 1.5 m at mouth (Simple Estuarine Response Model range: low [1–3 m])

Climate zone: dominant summer rainfall

Point source loads: sewage treatment plants contribute about 110 tonnes nitrogen per year. This is equivalent to an areal load of about 64 mg $N/m^2/d$. It should be noted that in reality most of the sewage load enters the estuary nearer to the mouth, whereas the model puts all loads into the head of the estuary (Simple Estuarine Response Model range: high [20–100 mg $N/m^2/d$])

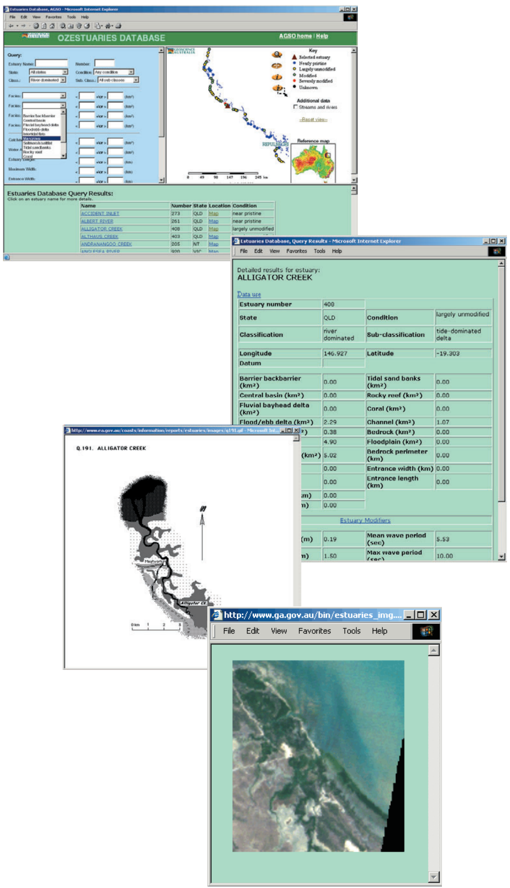
Inflow colour (CDOM): 1.0/m (Simple Estuarine Response Model range: medium (0.5–2.0/m)]

Catchment clearance: 50% cleared (Simple Estuarine Response Model range: high [20–100%])

Model performance

The model predicts almost continuous algal blooms through the year, and a very high annual mean chlorophyll-a. While algal blooms do appear to periodically be a problem, they are certainly not continuous. The Simple Estuarine Response Model may fail to capture important physical and chemical processes which limit phytoplankton growth. In particular, the model does not adequately capture the resuspension of sediment, which reduces light availability to phytoplankton, and therefore growth rates. The loss terms for phytoplankton, such as sinking and grazing may also be underestimated.

Figure 68. OzEstuaries—online information about Australia's estuaries.



OzEstuaries database—information collation on Australia's estuaries (http://www.agso.gov.au/ozestuaries)

The estuary assessment collated information on 979 estuaries. This information makes up the OzEstuaries Database. The starting point of the OzEstuaries Database was the Australian Estuarine Database (Digby et al. 1999), containing data on 780 estuaries with a catchment size greater than 15 km^2 and visible on a 1:100 000 topographic map.

The States and the Northern Territory nominated smaller estuaries to add to the database. Many of the smaller estuaries are locally significant such as Dee Why, Curl Curl and Manly Lagoons on Sydney's northern beaches.

Estuarine attributes include:

- name, identification number and location;
- estuary condition;
- geomorphic classification;
- geometry;
- sedimentary environment; and
- oceanographic information such as tidal range and wave data.

Linking natural resources—the Australian Natural Resource Atlas (www.environment.gov.au/atlas)

The interactive web-based Australian Natural Resources Atlas (Atlas) presents Audit products at scales from local to regional to Australia-wide. The OzEstuaries Database and Simple Estuarine Response Model are part of the Atlas.

Figure 69. Australian Natural Resources Atlas is a source for estuary information and reports.

Figure 70. Report for a modified estuary as available on the Australian Natural Resources Atlas.

ESTUARY ASSESSMENT FRAMEWORK FOR NON-PRISTINE ESTUARIES
Estuary 509 (MORETON BAY)

Estuary ID 509

Name MORETON BAY

Location

Latitude / Longitude -27.071 153.284 **Datum** GDA94

Condition Assessment This estuary is in modified condition under high to very high pressure

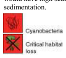
Initial Classification In the first stage of this condition assessment this estuary was classified as being modified.

Basis of Initial Classification This was based on the changes to catchment natural cover: minor clearing.

Processed-Based Classification

The way Moreton Bay functions is primarily a result of wave energy. It is a wave-dominated estuary. This means that the estuary would have high sediment trapping efficiency; naturally low turbidity, salt wedge/partially mixed circulation and there is high risk of sedimentation.

Issues:



General Comments / Notes: Nice on eastern side. Some parts bad some good - averaged classification. Contrast - very intact diverse systems and severley degraded impacted systems.

	Notes, Data and Supporting Qualitative Text	Rating (1-4)	Data Confidence	References
STATE COMPONENT (OVERALL)				
ECOSYSTEM INTEGRITY INDEX		3	A	
Eutrophication				

ESTUARY ASSESSMENT FRAMEWORK FOR NON-PRISTINE ESTUARIES
Estuary 509 (MORETON BAY)

	Notes, Data and Supporting Qualitative Text	Rating (1-4)	Data Confidence	References
Chlorophyll a (µg/L) [median(80th)] HEAD				
Chlorophyll a (µg/L) [median(80th)] MIDDLE				
Chlorophyll a (µg/L) [median(80th)] MOUTH				
Chlorophyll a (µg/L) [median(80th)] AVERAGE	1.5 (5.0)	2	A	1
Harmful algal blooms	Blooms of the toxic marine cyanobacterium, Lyngbya majuscula, in Deception Bay and eastern banks	4	B	6
Turbidity [median(80th)]	Turbidity gradient from high in western embayments to very low in eastern Moreton Bay			
Turbidity (NTU or secchi depth) HEAD				
Turbidity (NTU or secchi depth) MIDDLE				
Turbidity (NTU or secchi depth) MOUTH				
Turbidity (NTU or secchi depth) AVERAGE	Turbidity 8 (12) NTU; Secchi depth 0.7 (0.5) m	2	A	1
Shellfish closures				
Fish/bird kills				
Pathogens	Faecal coliforms flushed into bay after storm events	3	B	6
Faecal coliforms (no/100mL) [median(80th)] HEAD				
Faecal coliforms (no/100mL) [median(80th)] MIDDLE				
Faecal coliforms (no/100mL) [median(80th)] MOUTH				
Faecal coliforms (no/100mL) [median(80th)] AVERAGE				
Critical habitat loss	Seagrass decline in western and southern bay. Mangrove loss.	4	B	6
Anoxic and hypoxic events				

ESTUARY ASSESSMENT FRAMEWORK FOR NON-PRISTINE ESTUARIES
Estuary 509 (MORETON BAY)

	Notes, Data and Supporting Qualitative Text	Rating (1-4)	Data Confidence	References
Invasive species				
HABITAT CONDITION INDEX	Moreton Bay was mapped in 2000 and the following facies areas were calculated: Barrier/back Barrier 436.6 sq.km; Central Basin 1057.0 sq.km; Fluvial-bayhead delta 35.9 sq.km; Flood and ebb tidal delta 149.0 sq.km; Intertidal flats 75.7 sq.km; Mangroves 80.3 sq.km; Saltmarsh/Saltflats 22.8 sq.km; Tidal sand banks 422.8 sq.km; Total facies area 2280.0 sq.km. The following habitat deviations from expected were identified +1; contains tidal sand banks.		D	2
Seagrass species present	Zostera capricorni, Halophila ovalis, Halophila spinulosa, Halophila decipiens, Halodule uninervis, Cymodocea serrulata, Syringodium isoetifolium			
Seagrass coverage				
Mangrove species present				
Mangrove coverage	0.035			2
Saltmarsh coverage	0.01			2
Wetland coverage				

	Notes, Data and Supporting Qualitative Text	Rating (1-4)	Data Confidence	References
FISH CONDITION INDEX	Fisheries values include: Australian bass, bream, blue salmon, estuary cod, flathead, garfish, jewfish, luderick, mangrove jack, sea mullet, tailor, whiting, mud crabs, sand crabs, banana prawns, eastern king prawns, school prawns, greasyback prawns, bay prawns		D	4
Diversity				
Abundance				

ESTUARY ASSESSMENT FRAMEWORK FOR NON-PRISTINE ESTUARIES
Estuary 509 (MORETON BAY)

	Notes, Data and Supporting Qualitative Text	Rating (1-4)	Data Confidence	References
Health				
Recruitment				

	Notes, Data and Supporting Qualitative Text	Rating (1-4)	Data Confidence	References
WATER QUALITY INDEX		3	A	
Nutrients [median(80th)]				
Dissolved oxygen [median(20th)]				
Dissolved oxygen [surface] (%sat or mg/L) HEAD				
Dissolved oxygen [surface] (%sat or mg/L) MIDDLE				
Dissolved oxygen [surface] (%sat or mg/L) MOUTH				
Dissolved oxygen [surface] (%sat or mg/L) AVERAGE	99 (90)	1	A	1
Dissolved oxygen [bottom] (%sat or mg/L) HEAD				
Dissolved oxygen [bottom] (%sat or mg/L) MIDDLE				
Dissolved oxygen [bottom] (%sat or mg/L) MOUTH				
Dissolved oxygen [bottom] (%sat or mg/L) AVERAGE				
pH				
Heavy metals				
Are heavy metals a problem in this estuary (Y/N)?				
Other toxicants (including pesticides)				
Salinity				
Temperature				
Depth				
Ammonia (µg/L) AVERAGE	11 (30)	2	A	1
Oxidised nitrogen (µg/L) AVERAGE	3 (74)	3	A	1

ESTUARY ASSESSMENT FRAMEWORK FOR NON-PRISTINE ESTUARIES
Estuary 509 (MORETON BAY)

	Notes, Data and Supporting Qualitative Text	Rating (1-4)	Data Confidence	References
Phosphate (µg/L) AVERAGE	29 (46)	4	A	1

	Notes, Data and Supporting Qualitative Text	Rating (1-4)	Data Confidence	References
SEDIMENT QUALITY INDEX			D	
Sediment toxicants				
Sediment load TN				
Sediment load TP				
Invertebrate diversity				
Invertebrate abundance				

	Notes, Data and Supporting Qualitative Text	Rating (1-4)	Data Confidence	References
PRESSURE COMPONENT (OVERALL)		4	B	
UTILISATION INDEX	1995 BRS data: Crop/pasture & Plantations comprise 37.0733 % of the catchment. Native woody vegetation comprises 47.1433 % of the catchment.	4	B	5
Recreation Pressure				
Aesthetic & Amenity				
Yachting & Boating	Present			
Shellfish				
Swimming				
Recreational Fishing	Present			
Infrastructure Pressure				
Sewage Treatment Plants	2 Present; TN load 111 t/yr, TP load 37 t/yr (1994-1997)			1
Urbanisation and urban runoff	Urban centres on most rivers/creeks discharing into Moreton Bay; Brisbane population 1,520,600 (1996 Census)			

ESTUARY ASSESSMENT FRAMEWORK FOR NON-PRISTINE ESTUARIES
Estuary 509 (MORETON BAY)

Dredging	Dredging of shipping channels; potential future gravel and sand extraction			
Commercial Pressure				
Industry	Various industrial areas present			
Aquaculture	Prawn farms at mouth of Logan River; present historically at Cleveland; oysters in eastern bay			
Reclamation / Declamation	Reclamation for Port of Brisbane; various canal estates in river estuaries			
Commercial fishing	Present			
Tourism	Present			
Agriculture	Extensive grazing and agriculture in river catchments			
Habitat clearing				
Ports & Port Works	Port of Brisbane			
Shipping Activity	Total GRT (gross registered tonnage): 45227649; Average GRT: 20595; Avg Length: 165; # of arrivals: 2196			

	Notes, Data and Supporting Qualitative Text	Rating (1-4)	Data Confidence	References
SUSCEPTIBILITY INDEX	Susceptibility varies considerably west to east		D	
Flow-modifying structures				
Catchment loads				
Flows and flushing	Eastern bay well flushed, western embayments have long residence times (2 months for Bramble Bay)			6
Acid sulphate soils				

ESTUARY ASSESSMENT FRAMEWORK FOR NON-PRISTINE ESTUARIES
Estuary 509 (MORETON BAY)

RESPONSE COMPONENT (OVERALL)	
Institutional Arrangements	Various Fish Habitat Areas
Management Actions	
Community Initiatives	
Details of References	1. QLD state data, 2. AGSO, 3. Expert opinion through state workshop, 4. Beumer J et al. 1997. Declared Fish Habitat Areas in Queensland, 5. Derived from BRS landcover data, 6. Dennison & Abal, 1999
Key Contacts	

Data confidence tags were used to account for the differences in the reliability of the data and information available for the condition assessment.

Data confidence tags

A Confident result—supported by data and sound information

B Fairly confident result—general consensus based on expert opinion

C Not confident—best guess

D No data or information available—not assessed

Lake Arragon, New South Wales within Yuraygir National Park

State, Territory and Commonwealth agencies, researchers and community groups have agreed on a series of priorities for improved estuarine management.

Protective management arrangements

Estuary restoration is expensive and often not possible. Protective management arrangements are recognised to be more cost-effective in the long term. The concentration of near-pristine estuaries in northern tropical Australia and western temperate Tasmania, indicates that the different types of estuaries that occur in populated parts of Australia are not well represented in the near-pristine list. The protection of a representative group of near-pristine estuaries from around Australia selected on the basis of estuary type, size, and location would provide a framework for improved nature conservation as well as useful benchmarks for improved understanding and management of Australia's estuaries. This could be achieved through a greater emphasis on estuarine protection as part of the Commonwealth's National Representative System of Marine Protected Areas program.

A part of this initiative might include a National Estuarine Research Reserve System, similar to that established in the United States of America in 1972. The estuary reserves within this category would be chosen to represent the wide range of different estuary types and coastal and estuarine habitats around Australia. Commonwealth, State and local authorities could work together to establish, manage, monitor and maintain the reserves, and to provide for their long-term protection. Research and education are crucial to meeting this goal. The estuary reserves could serve as laboratories and classrooms where the effects of both natural and human activity can be monitored and studied.

Monitoring and assessment

Estuaries are dynamic systems with variable response times. Managers need to be provided with feedback on progress to help understand the time frames required to deliver improvements in estuarine condition. The estuary assessment has highlighted information that is available for Australian estuaries. Significant gaps exist and needs to improve the information include:

- enhanced assessment and monitoring activity and improved integration and reporting of existing activities undertaken by all levels of government and the community;
- agreed reporting frameworks that make information collected at the local level readily available to be rolled up to contribute to initiatives such as State of the Environment reporting;
- increased use of online data warehousing to improve access to and value adding of local, State and Commonwealth data and information;
- use of new technology to capture nationally comprehensive data and information (e.g. the use of remotely sensed imagery to monitor turbidity);
- detailed studies of representative estuaries chosen by type, location, size, condition and process type, with outcomes applied to similar systems;
- involvement of communities (e.g. Waterwatch, Coastcare, Fisheries Action Program) to gain information on physical parameters (such as depth), habitat type and status, make up and status of fisheries, opening and closing frequency and for the ground-truthing of remotely sensed information;
- assessment and management frameworks to better account for spatial and temporal variation within an estuary;
- assessing and monitoring fish communities to gain a better appreciation of populations, changes, and priorities for estuary protection and rehabilitation to sustain fisheries;
- data presented within appropriate natural resource management frameworks (e.g. population census data by catchment boundaries);
- ongoing attention to selection, evaluation and refinement of attributes for assessing the condition of Australian estuaries and collection of minimum data sets; and
- monitoring and assessment activities need to proceed as a close partnership between land and waterway managers, policy-makers, the interested community and scientific specialists.

Approximately 50 estuaries have been studied in any detail. These have generally been studied because of their proximity to population centres, particular problems or a decline in their condition which has sparked interest in them. A more integrated monitoring program would be of benefit if based on considerations of estuary type, location, condition, beneficial uses and size.

It is unlikely that there will ever be sufficient resources available to monitor all of Australia's estuaries in detail. Even if estuaries were to receive this level of monitoring, better value for money would be investment in intervention strategies to improve and protect estuarine condition. A more cost-effective approach may be to select a small number of representative estuaries from around Australia and investigate their behaviour and management needs in detail and adapt this understanding for other similar systems.

Community groups—key to estuary management

Institutional arrangements

Commonwealth and State initiatives are essential to address the institutional failings that have resulted from the absence of lead agency responsibilities for estuarine management.

- Lead agency responsibilities need to be clearly defined at a State and Australia level.

An Australia-wide initiative in estuarine protection and management would provide a much needed policy framework for States to implement protective management arrangements through their various agencies and existing legislation.

At a state and regional level catchment management processes need to formally recognise and incorporate estuarine management targets.

Case studies that showcase good estuarine management could be used as a basis for similar programs elsewhere.

Education and awareness

Estuaries are important to, and valued by, Australians. The project has successfully engaged Australians in a national discussion on the condition of our estuaries and their management. Community groups, such as Waterwatch and educational institutions are seeking resources and information on Australia's estuaries and their management. Continued effort in communication will build understanding. From understanding will follow improved management and healthier estuaries.

Management needs for Australian estuaries

Australians are interested in the health of their estuaries. We need to build on this interest with improved management. Key management needs to improve the condition of Australian estuaries based on analysis of the key causes of decline in condition include:

- Undertaking habitat restoration to rehabilitate damaged estuaries.
- Maximising habitat and catchment protection to prevent the degradation of less modified estuaries.
- Minimising nutrient enriched and polluted run-off from urban areas and agricultural catchments. This can be achieved by improving land use management practices, with tertiary treatment and preferably land application of sewage effluent, stormwater retention basins, and with the re-establishment of filter strips, riparian forests and wetlands to trap overland flow of pollutants.

- Implementing catchment management strategies to specifically target and intercept increased sediment loads being delivered to estuaries.
- Control and reduce the likelihood of infestation by invasive species.
- Recognition of the economic and non-market values of estuaries, factoring their net worth for aquaculture, recreation, nature conservation and commercial fisheries into planning decisions such as urban development and infrastructure.
- Development of multiple objective strategies for the management of estuary entrances.
- Restoration of tidal flushing, particularly to tidally-dominated systems, by minimising interference to tidal flows by causeways, bund walls, culverts, floodgates and bridge approaches coupled with strategic dredging to re-establish tidal channels.

Research needs

The Cooperative Research Centre Coastal Zone, Estuary and Waterway Management (Coastal Cooperative Research Centre) with State and Territory agencies and other research providers will continue to build on the work of the Audit's estuary partnership, through a national estuary management network.

Activities include:

- enhancements to the Simple Estuarine Response Model increasing specificity for each of the six subclasses of the process-based classification and re-testing performance against observations from a large number of estuaries;
- linking the Simple Estuarine Response Model to the OzEstuaries database, allowing the model to be run for each estuary in the database, using variables such as depth, length, shape and tidal energy specific to that estuary;
- incorporating the estimates of catchment loads and run-off available for many estuaries from other Audit projects to provide more realistic input into the model. Model predictions will then be compared with observations collated through the estuarine assessment process;
- development of the *Australian Estuary Management Handbook*;
- reviewing indicators of estuarine health and trialling new indicators; and
- application of remote sensing technologies to gather nationally comprehensive data sets on Australian estuaries.

Cobourg Peninsula, Northern Territory

Strategic research priorities vary for differing estuary types. Certainly there is a need to develop better understanding of:

- advantages and disadvantages of artificially opening coastal lakes and lagoons to provide better advice for entrance opening strategies;
- the importance of the timing and quantities of freshwater flows and effects of change in environmental flows on estuarine ecology;
- the role of fringing mangroves and saltflats in macrotidal, tropical estuaries;
- mechanisms for prevention and control of invasive species;
- impacts of harmful algal blooms and eutrophication in coastal waters (including associated anoxic and hypoxic events);
- the role of extreme climatic events in estuarine condition and predictions on the likely influence of climate change;
- the combined implications of multi-stressors, especially on fish populations;
- effective protective management and rehabilitation strategies;
- links between floodplain and estuary ecology particularly water quality and loss of fishery habitat; and
- the impact of modified fish communities on estuary condition and ecological functioning.

ACKNOWLEDGMENTS

We would like to acknowledge the contribution of those involved in completing the catchment, river and estuary assessment projects. To the real unsung heroes of these projects, the project teams, we extend our sincere thanks.

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NATIONAL LAND AND WATER RESOURCES AUDIT

Who is the Audit responsible to?

The Minister for Agriculture, Fisheries and Forestry – Australia has overall responsibility for the Audit as a program of the Natural Heritage Trust. The Audit reports through the Minister for Agriculture, Fisheries and Forestry to the Natural Heritage Board which also includes the Minister for the Environment and Heritage.

How is the Audit managed?

An Advisory Council manages the implementation of the Audit. Dr Roy Green, with a background in research, science policy and management chairs the Advisory Council. Members of the Advisory Council and the organisations they represent in February 2002 are: Warwick Watkins (L&WA), Bernie Wonder (AFFA), Stephen Hunter (EA), John Radcliffe (CSIRO), Peter Sutherland (SCARM), Jon Womersley (SCC), Roger Wickes (SCARM) and Colin Creighton (Audit).

What is the role of the Audit Management Unit?

The Audit Management Unit's role has evolved over its five-year life. Phases of activity include:

Phase 1. Strategic planning and work plan formulation—specifying (in partnership with Commonwealth, States and Territories, industry and community) the activities and outputs of the Audit—completed in 1998–1999.

Phase 2. Project management—letting contracts, negotiating partnerships and then managing all the component projects and consultancies that will deliver Audit outputs—a major component of Unit activities from 1998–1999 onwards.

Phase 3. Reporting—combining outputs from projects in each theme to detail Audit findings and formulate recommendations—an increasingly important task in 2000–2001 and the early part of 2001–2002.

Phase 4. Integration and implementation—combining theme outputs in a final report, working towards the implementation of recommendations across government, industry and community, and the application of information products as tools to improve natural resource management—the major focus for 2001–2002.

Phase 5. Developing long term arrangements for continuing Audit-type activities—developing and advocating a strategic approach for the continuation of Audit-type activities—complete in 2001–2002.

The Audit Management Unit has been maintained over the Audit's period of operations as a small multidisciplinary team. This team as at February 2002 comprises Colin Creighton, Warwick McDonald, Maria Cofinas, Jim Tait, Rochelle Lawson, Sylvia Graham and Drusilla Patkin.

How are Audit activities undertaken?

As work plans were agreed by clients and approved by the Advisory Council, component projects in these work plans were contracted out. Contracting involves negotiation by the Audit to develop partnerships with key clients or a competitive tender process.

Facts and figures

• Total Audit worth, including all partnerships	in excess of $52 m
• Audit allocation from Natural Heritage Trust	$34.19 m
• % funds allocated to contracts	~ 92%
• Total number of contracts	149