National Climate Change Adaptation Research Plan: Freshwater Biodiversity

Consultation Draft

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Some of the text in section 2 of this document has been adopted from the National Climate Change Adaptation Research Plan for Terrestrial Biodiversity.

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Executive Summary

Climate change will affect the basic physical and chemical environment underpinning all life. Species will be affected differentially by these changes, with flow on effects for the structure and composition of present-day freshwater ecological communities, and potentially to changes in how these ecosystems function and the services they provide. Species and ecosystems will also be affected indirectly, as climatic change affects important processes such as water flows and rainfall patterns. Some of these changes are already evident.

The role of the National Climate Change Adaptation Research Facility (NCCARF) is to generate the biophysical, social and economic information needed by policy- and decision-makers in government, and in vulnerable sectors and communities, to manage the risks of climate change impacts, by leading the research community in a national interdisciplinary effort. Development of National Climate Change Adaptation Research Plans (NARPs) for each major sector is a key activity in this role. As national research plans, NARPs focus on identifying research required for national policy purposes and national industry development and management, but they also provide a key sectoral research investment framework and prioritisation for all stakeholders at regional and local scales.

The Freshwater Biodiversity NARP is concerned with climate adaptation research priorities for freshwater species and ecosystems. This research aims to support ongoing protection of freshwater species and ecosystems by enabling governments, conservation agencies, landowners, community organizations and individuals to implement effective climate change adaptation initiatives for freshwater species and ecosystems. These initiatives will take advantage of opportunities for freshwater biodiversity that result from climate change and reduce unavoidable detrimental climate change impacts.

Climate change will affect Australia’s freshwater biodiversity in highly variable ways depending on the type and location of climate impacts and freshwater species and ecosystems. Adaptation responses to climate change impacts will be taken in response to the specific impacts, opportunities and detrimental impacts in each location.

The Freshwater Biodiversity NARP identifies a research program for a 5-7 year time-frame.

Adaptation research for freshwater biodiversity is fundamentally about generating information, knowledge and tools concerned with determining:

- Why and to what extent freshwater species and ecosystems are vulnerable to or might benefit from climate change?
- What is their adaptive capacity?
- How their adaptive capacity can be increased?
- How the management of freshwater biodiversity integrates climate change information, knowledge and tools?
- What implications this integration has for policies, plans and on-ground management of freshwater biodiversity?

Adaptation research is therefore interdisciplinary. It needs to address stakeholder understanding, institutional factors, management practices and end-users needs as well as the biophysical and technical aspects of climate change adaptation.

This NARP identifies four broad areas of research:

- Incorporating climate change adaptation into the management of freshwater species and ecosystems;
- Identifying climate change adaptation options for Australia’s freshwater biodiversity refugia;
- Managing climate change adaptation interactions between freshwater biodiversity and other sectors; and
- Supporting national environmental goals and policies to protect freshwater biodiversity under changing climate conditions.

Climate change adaptation research will build on past and current research, particularly research concerned with responses to climate variability or to other external changes. Research outlined in this NARP will further contribute to a considerable body of knowledge about adaptation responses available to freshwater biodiversity managers and other stakeholders.

This NARP has very close links with the *National Water Knowledge and Research Strategy* being developed by the Commonwealth Department of Sustainability, Environment, Water, Population and Communities (previously the Department of Environment, Water, Heritage and the Arts (DEWHA)) and climate research being undertaken under Australia's Climate Change Science Program. This NARP also relates strongly to the NARPs developed for the other priority thematic areas and will guide researchers to generate the information that Australia needs to develop an effective portfolio of adaptive strategies.

Research will gain greatest stakeholder acceptance and use where the people and organisations who will use the research (that is, the end-users of the research products) are involved in the research process. Stakeholder involvement is also likely to enhance the relevance of research projects and the capacity of stakeholders to understand how research outputs can best be applied to their concerns, and thus increase their capacity to adapt successfully.

This NARP proposes three principles to guide climate change adaptation research for freshwater biodiversity:

- Emphasis on local and regional scales;
- Participatory research and adaptive learning; and
- Building on national and international research.

The NARP identifies a set of priority research questions. As with all NARPs, these research questions are prioritised according to:

- The severity of the potential impact to be addressed;
- The immediacy of the response required;
- The degree to which research will lead to practicable interventions or responses;
- The potential for the research to produce benefits beyond informing climate adaptation strategies;
- The extent to which the research addresses more than one issue or sector; and
- The extent to which the research addresses the needs of the most vulnerable groups.

The following research questions were identified as high priority through applying these criteria.

Table 1. High priority research goals and questions.

Goal 1: Incorporate climate change adaptation into management of freshwater species and ecosystems.
1.1 How will climate change affect the effectiveness of freshwater biodiversity management?
1.2 How can climate change adaptation initiatives be developed for a wide range of poorly understood species and communities?
1.3 What climate change adaptation initiatives are necessary to maintain freshwater ecosystem services?
1.4 What monitoring systems are needed to evaluate the effectiveness of climate change adaptation initiatives for freshwater biodiversity?
1.5 How can flow-on effects from climate change impacts on other environmental conditions such as soil acidification and sea level rise be managed.
Goal 2: Identify climate change adaptation options for Australia's freshwater biodiversity refugia.
2.1 How can the climate resilience of freshwater biodiversity refugia be increased?
2.2 What changes to Australia's conservation reserve system would improve protection of current and projected climate refugia and support connectivity for freshwater biodiversity?
Goal 3: Understand climate change adaptation interactions between freshwater biodiversity and other sectors.
3.1 How will climate change affect existing stressors to freshwater biodiversity, such as invasive species and pollution?
3.2 How will climate change adaptation and mitigation actions by other sectors affect freshwater biodiversity, such as increased use of surface or groundwater, introduction of new species or new agricultural areas?
3.3 How can integrated climate change adaptation response plans be developed at the local, landscape and regional scales to improve the protection of freshwater biodiversity and other sectors to climate change impacts?
Goal 4: Understand the role of national environmental policies in protecting freshwater biodiversity under changed climate conditions.
4.1 How will climate change affect existing national conservation goals, policies and programs for freshwater biodiversity?
4.2 What management initiatives are required to address the social and economic consequences of climate change impacts on freshwater biodiversity?

Implementation

A detailed implementation plan will be prepared upon completion of the Freshwater Biodiversity NARP, outlining budget, research capacity and funding opportunities. The National Adaptation Research Network for Water Resources and Freshwater Biodiversity will play an essential role in implementing the NARP, and will contribute greatly to building collaboration, information sharing and research capacity across the Australian research community.

1 Introduction

1.1 Background

There is now widespread acceptance that human activities are contributing significantly to climate change, and that this change is producing significant physical effects. It is also generally acknowledged that these impacts will become more severe if substantial changes in human behaviour and resource use do not occur.

There are two main themes to such modification.

- *Mitigation* strategies involve actions that are intended to reduce the magnitude of our contribution to climate change (primarily by reducing greenhouse gas emissions) or offset or even reverse its effects (for example, by establishing and maintaining forest areas to sequester carbon).
- *Adaptation* strategies involve actions in response to changes that are inevitable, or at least likely. Adaptation seeks to take advantage of new opportunities resulting from climate change and to reduce vulnerability to detrimental climate change impacts.

The National Climate Change Adaptation Research Facility (NCCARF), established by the Australian Government and hosted by Griffith University, aims to lead the Australian research community to generate the biophysical, social and economic information needed by policy- and decision-makers in government, and in vulnerable sectors and communities, to manage the risks of climate change impacts, by leading the research community in a national interdisciplinary effort.

A key role of NCCARF is to coordinate the development of National Climate Change Adaptation Research Plans (NARPs). These NARPs identify critical gaps in the information needed by policy and decision makers, set national research priorities and are developed in partnership with governments, stakeholders and researchers. The focus of this NARP is adaptation in relation to climate change impacts on Australia's freshwater biodiversity.

1.2 National climate change policy context for this National Climate Change Adaptation Research Plan

The National Climate Change Adaptation Framework (the Framework) was endorsed by the Council of Australian Governments (COAG) in April 2007 as the basis for government action on adaptation over the following five to seven years. The Framework includes possible actions to assist vulnerable sectors and regions, such as biodiversity, fisheries and coasts, to adapt to the unavoidable impacts of climate change. It also includes actions to enhance the knowledge base and scientific capacity underpinning climate change adaptation.

In 2007, the Australian Government provided $126 million over five years towards implementing the Framework, of which up to $50 million is being invested in priority research for key sectors as identified in National Climate Change Adaptation Research Plans (NARPs). This gives effect to Action 1.1 of the Framework, which aims to improve national coordination of climate change adaptation research.

In November 2008, the Council of Australian Governments endorsed the development of a *National Water Knowledge and Research Strategy* (KRS) which will establish priority national research themes, including for climate change adaptation for water resources. The KRS will also ensure coordinated research efforts and ensure the best returns from investment. The KRS is an important component of the *National Water Policy Agenda* that has the objective of achieving national economic, social and environmental benefits through a shared vision across jurisdictions of principles and practices for improving the Australian water industry.

1.3 Development of this National Climate Change Adaptation Research Plan

NARPs are developed by NCCARF in partnership with governments, other stakeholders and researchers.The development of the NARP for Freshwater Biodiversity builds on recent initiatives that identified potential climate change impacts on Australian species and ecosystems, and research strategies needed to minimise future biodiversity loss. These initiatives include:

- *National Action Plan for Biodiversity and Climate Change* (2003-2007) (NRMMC 2004);
- *Biodiversity conservation research in a changing climate* (Hilbert *et al*. 2006); and
- *Implications of climate change for Australia's National Reserve System* (Dunlop and Brown 2008).

In November 2006, the Natural Resource Management Ministerial Council (NRMMC) adopted as a priority action the preparation of a strategic assessment of the vulnerability of Australia's biodiversity (Biodiversity Vulnerability Assessment, BVA) to climate change Steffen *et al.* (2009) (Appendix 1).

The BVA had the following terms of reference:

- To cover terrestrial, freshwater and marine environments;
- To be strategic in nature and provide policy directions for future adaptation planning (i.e. it will not be a systematic, region-by-region, community-by-community assessment);
- To include an assessment of the scientific observations and predictions around impacts/responses to climate change; and
- To provide comments on ways biodiversity management can adapt to enhance the resilience of Australian biodiversity to the impacts of climate change.

The BVA is the first national assessment of the vulnerability to climate change of Australia's biodiversity in its entirety. This NARP, as well as the Terrestrial Biodiversity NARP, draws heavily on the principles and recommendations of the BVA, based on ecological principles that characterise:

- How individual species interact with their environment;
- How species interact with each other in ecological communities and ecosystems;
- How ecosystems and landscapes are structured and function; and
- How environmental change affects species and the structure and functioning of ecosystems.

These principles underpin the analyses of current and projected biodiversity changes as well as the policy and management principles required to deal with these challenges.

This NARP is accordingly developed within this overall Government water and biodiversity research and policy context. It is therefore a contribution to both the development of the KRS and to the development of a comprehensive approach to managing Australia's biodiversity. The specific focus of this NARP, and the contribution it will make to the KRS and other elements of the Commonwealth policy agenda and to other Australian policy, planning and management initiatives, is to identify and prioritise a research agenda relevant to climate change adaptation for the freshwater biodiversity sector.

Funding of up to $10 million has been provided by the Australian Government over five years to support the establishment and operation of Adaptation Research Networks (ARNs), which form an integral part of NCCARF. An inclusive, multi-disciplinary ARN for Water Resources and Freshwater Biodiversity has been established and is convened by Professor Stuart Bunn at the *Australian Rivers Institute* at Griffith University. This ARN currently includes over 150 researchers from more than 30 institutions and is continually expanding. The aim is to include members that represent all Commonwealth, state and territory government freshwater biodiversity and climate change units, major non-governmental organisations (NGOs) and stakeholder groups. Members of the network collectively incorporate knowledge and experience in all major freshwater ecosystems and taxonomic groups relevant to designing and implementing adaptation strategies.

The network will work with NCCARF to advance regional and sectoral knowledge about climate change impacts, vulnerability and adaptation options for the management of freshwater biodiversity, and to foster an inclusive and collaborative research environment across Australia, through:

- Collating and synthesising relevant literature, data and resources;
- Open exchange of information and sharing of resources;
- Contributing to the work of NCCARF in synthesising existing and emerging research and in developing and implementing the NARP; and
- Nurturing the careers of young investigators and research students by promoting a sense of community, collaboration and strong, effective mentoring, and encouraging them to shape the future direction of their research areas.

The development of this NARP has been led by the following writing team:

- Dr Bryson Bates, CSIRO Climate Adaptation Flagship (co-chair);
- Professor Stuart Bunn, Australian Rivers Institute (co-chair);
- Dr Peter Baker, Department of Sustainability, Environment, Water, Population and Communities;
- Associate Professor Malcolm Cox, Queensland University of Technology;
- Mr Angas Hopkins, Department of Climate Change and Energy Efficiency and Energy Efficiency;
- Dr Bill Humphreys, WA Museum;
- Professor Sam Lake, Monash University;
- Professor Garry Willgoose, University of Newcastle; and
- Dr Bill Young, CSIRO Land & Water.

Dr Mark Kennard and Mr Brendan Edgar were contributing authors.

Executive support was provided by Ms Marie Waschka and Dr Ida Fellegara, National Climate Change Adaptation Research Facility.

A number of climate change adaptation workshops have been held at the jurisdictional level across Australia over the past 18 months that have contributed further to the development of the research priorities that underpin this NARP.

1.4 The scope of this National Climate Change Adaptation Research Plan

This Freshwater Biodiversity NARP focuses on research to inform adaptation to climate change impacts on freshwater biodiversity. This NARP identifies:

- Important gaps in the information, knowledge and tools needed to support effective climate change adaptation for freshwater biodiversity;
- Adaptation research priorities based on these gaps; and
- Capacity that can be harnessed or needs to be developed to do priority adaptation research.

Research on the nature of climate change impacts and vulnerability *per se* is not emphasised unless such research is considered essential to fill a void in understanding or implementing adaptation options. Climate research is the responsibility of the Australian Climate Change Science Program and is not the focus of this NARP.

Those responsible for protecting or managing freshwater biodiversity need to understand interactions between climate change risks and adaptation responses and other factors that affect the conservation of Australia's freshwater biodiversity. These factors include land degradation and trends in social factors such as public support for conservation investment.

Future climate impacts on freshwater biodiversity and the required adaptation responses will depend on the future rate of global warming and its interactions with other stressors. While the temporal scale relevant to this NARP is therefore necessarily relatively unconstrained, its focus is a research program for a 5-7 year time frame. However, the research program in this NARP also provides a framework for longer-term climate change adaptation research and response, potentially extending from issues apparent now to those expected to become important in several decades. Potential longer-term impacts are also considered because it may be important to commence research now to inform actions in the near future that will enable us to accommodate or avert negative impacts in the more distant future.

Research will gain greatest acceptance and use where people and organisations involved in managing freshwater biodiversity as individuals, through their community or public sector organisations, are involved in the research process. Stakeholder involvement is also likely to enhance the relevance of the research projects and the capacity of research end-users to understand how the research outputs can best be applied to their concerns and thus increase their capacity to adapt. This NARP therefore sets out several principles to guide the research approach and process.

This NARP focuses on adaptation to the impacts of climate change on freshwater biodiversity. It is closely linked with the *National Water Knowledge and Research Strategy* (see section 1.2) and several other NARPs (see section 1.5).

This NARP touches on some adaptation issues or options for freshwater biodiversity important to Indigenous communities around Australia. We recognise that these issues are critical. They will be considered further as part of a National Climate Change Adaptation Research Plan for the Australian Indigenous Communities.

To enhance the accessibility of this NARP, referencing has been kept to a minimum; except when referring to specific data, most references are not cited in the text. The reference list included at the end of the NARP will enable readers to pursue particular interests and the BVA (Steffen *et al.* 2009) provides a good introduction to key issues.

This NARP, like the others, will be periodically reviewed to ensure research prioritisation takes account of research findings and reflects current information needs.

This NARP is structured as follows:

- *Section 2* describes the context within which adaptation research is set, including the characteristics of Australian's freshwater biota that will affect its response to climate change, and the interaction of climate change with other environmental stresses.
- *Section 3* describes the primary stakeholders to whom this NARP is aimed, and their information needs.
- *Section 4* sets out the priority research questions under four climate change adaptation goals for freshwater biodiversity.
- *Section 5* outlines the criteria used to prioritise the research questions.
- *Section 6* outlines some implementation issues arising from the NARP.

Once this NARP has been completed a separate implementation plan will be prepared that will set out the research budget, research capacity and further research funding opportunities available to implement the NARP.

1.5 Links to and synergies with the other NARPs

There are clear overlaps between this NARP and research priorities in other NARP thematic areas. Of particular importance is the growing body of evidence that adaptation strategies that enhance resilience of natural ecosystems have co-benefits for many other sectors. This is particularly the case for climate change impacts on freshwater biodiversity, terrestrial biodiversity, water resources and primary industry, and their management, but it is also true for other thematic areas, as set out below. Potential synergies between this NARP and the Water Knowledge and Research Strategy, currently being developed by the Department of Sustainability, Environment, Water Population and Communities, could significantly benefit both water resources and the ecological systems with which they are associated. Integrating research activities and findings is a role of NCCARF through its networks, communication program and synthesis activities.

Terrestrial Biodiversity

The Terrestrial Biodiversity NARP has clear links to the Freshwater Biodiversity NARP including:

- Many terrestrial ecosystems share species, nutrients or space with freshwater ecosystems (whole of landscape management issue;
- Management of terrestrial ecosystems can affect the quality and quantity of water resources and affect aquatic ecosystems;
- Climate refugia for many terrestrial taxa and ecosystems are likely to coincide with aquatic areas currently important for freshwater taxa and ecosystems;
- Water availability and allocation will be a key conflict and decision issue in climate change policy and actions; and
- Management of water bodies is integrated with catchment management.

Water is one of the major factors shaping Australia's ecosystems and is therefore particularly relevant to both NARPs. For example, adaptive measures to maintain aquatic ecosystems during dry periods could significantly affect terrestrial biodiversity and vice versa. Well-informed, collaborative and adaptive environmental management at the interface of freshwater and terrestrial ecosystems is therefore critical for both sectors. Adaptation actions that reduce degradation of watersheds, such as reduced deforestation, controlled or excluded grazing, afforestation and soil conservation, can reduce terrestrial and freshwater ecosystem vulnerability to drought.

Marine Biodiversity and Resources

The Marine Biodiversity and Resources NARP also has links to the Freshwater Biodiversity NARP including:

- The Marine NARP is concerned with coastal ecosystems including estuaries; and
- Changes to freshwater ecosystems that result in changes to the seasonality, periodicity, quality or quantity of freshwater outflows could affect coastal and marine ecosystems.

Both sea level rise and increased storm activity will have significant impacts on the marine-freshwater interface and coastal ecosystems, including the condition and distribution of salt marshes, mangroves and coastal wetlands, including subterranean estuaries.

Primary Industries

Primary industries and freshwater ecosystems often compete for land and water. Without careful management, climate change will intensify this conflict, such as where agriculture might seek to capture more water for irrigation or other production purposes, to relocate to regions of reliable water availability or to use wetter parts of the landscape under drier climate conditions. Relocation of agriculture could lead to increased nutrient content or sediment in freshwater systems, the introduction of pests and weeds, or degraded riparian zones. Potential synergies between primary industries and freshwater biodiversity include a common interest in maintaining genetic diversity to protect future adaptation options and increased use of integrated landscape management options.

Disaster Management and Emergency Services

Natural systems are especially vulnerable to the introduction and spread of invasive species following damaging natural events such as floods or cyclones. A key recommendation of the Biodiversity Advisory Committee's 2008 Climate Change and Invasive Species report was that policy frameworks be developed that anticipate the invasive risks posed by cyclones, floods and other extreme events. It suggested that scenario planning be used to predict the outcomes of different events on different regions, and that planning activities consider which actions have the potential to promote invasions after extreme events, and generate plans to mitigate the risks. Emergency plans for cyclones and floods should include protocols for preventing the spread of weed seeds and other invasive organisms during rescue and clean up operations.

Settlements and Infrastructure

Current patterns of population growth and urbanisation will increase demands for development of areas currently used for stormwater management or freshwater habitat. This will exacerbate climate-related pressures on those habitats. Population shifts to less populated parts of Australia in response to a changing climate may lead to freshwater habitat disturbance in new locations.

Demographic shifts will require both significant infrastructure and natural resource management planning. Existing infrastructure such as roads, powerlines and pipelines already affect freshwater habitats directly and may impede the continuity of freshwater habitats and reduce the capacity of aquatic species to disperse in response to changed climate conditions. Conversely, climate change adaptation projects for the built environment could be designed to facilitate the movement of species through establishing or improving dispersal corridors and habitat continuity. There are potential co-benefits or synergies where stormwater harvesting helps restore or create wetlands and freshwater conservation areas, but care will be required to avoid introducing pollutants or other degradation to important habitats.

Social, Economic and Institutional Dimensions

Responding to the potential impacts of climate change on freshwater biodiversity will require changes to freshwater biodiversity management practices, potentially including an expanded role for conservation on private land. Migration of human population induced by climate change and changes to regional socio-economic trends will affect regional conservation challenges and management. The institutional and regulatory arrangements needed and the best mix of economic incentives will be addressed broadly in the Social, Economic and Institutional Dimensions NARP.

Human Health

As freshwater ecosystems change in response to the changing climate, so will the complex interactions between disease-causing organisms, vectors and human hosts. The National Climate Change Adaptation Research Plan for Human Health and Climate Change recognises links with freshwater biodiversity, especially with regard to vector-borne diseases such as Ross River virus, Barmah Forest virus and environmental pathogens such as *Leptospira*.

Loss of freshwater biodiversity may also negatively affect the mental and physical health of all Australian residents, including Indigenous people in remote settlements and those maintaining a close spiritual connection to the land. The loss of important aquatic food sources could detrimentally affect communities that do not have alternatives.

Indigenous communities

Indigenous communities, groups and individuals are significant land holders and managers, have considerable knowledge about freshwater ecosystems and biodiversity and are closely connected culturally to Australia landscapes, regions and species. The Indigenous Communities NARP will identify key cross-cutting issues relevant to climate change adaptation by Indigenous communities.

2 Context of this NARP

2.1 Introduction

Effective management of climate change impacts on freshwater biodiversity requires knowledge about future climate conditions, how changed climate conditions will affect water resources (amount, quality and periodicity), how changed climate conditions and changed water resources and systems will affect freshwater biodiversity and how adaptation responses may reduce detrimental impacts and increase beneficial outcomes. This information is subject to uncertainty at all stages of the evaluation process:

a) The socio-economic, political, demographic and technological assumptions that underpin the number and range of greenhouse gas emissions scenarios;

b) The global climate models (GCMs) used to produce climate change scenarios (different models may be equally good at simulating past climate but respond differently to increasing atmospheric concentrations of greenhouse gases);

c) The methods used to downscale GCM runs to the spatial and temporal scales required for hydrological and ecological studies;

d) The conceptual or mathematical models used to predict the responses of hydrological and ecosystems to changes in climatic forcing;

e) Management options for water resources and freshwater biodiversity;

f) The joint impacts of other sources of anthropogenic stress (e.g. changing land use, pollution, invasion by exotic species); and

g) The effectiveness of and feedbacks from adaptation and mitigation activities.

Future freshwater biodiversity research planning, management and policy-making will need to operate in the context of these uncertainties. The Australian Climate Change Science Program is concerned with improving knowledge in relation to points (a), (b), (c) and parts of (d) and (e). This NARP addresses part of points (d) and (e) and points (f) and (g).

2.2 Australia's Water Resources

Australia is the driest inhabited continent on Earth and has a more variable climate than most, if not all, of the world's major agricultural nations (Croke and Jakeman 2001). In many parts of Australia, runoff and hence streamflow variability are high compared with the rest of the world (e.g. Puckridge *et al.* 1998). This has been a key factor in shaping its unique freshwater ecosystems and also in guiding water resources policy and management.

The geographic distribution of Australian surface water resources is highly variable reflecting the latitudinal variation on climatic zones from the tropics to southern temperate Australia. Much of Australia's freshwater systems occur in the northern parts of the country. In contrast, nearly 75% of irrigated agriculture occurs in southern Australia, in the Murray-Darling Basin, which generates only about 6% of the total runoff in Australia (AWR 2005; Figure 1).

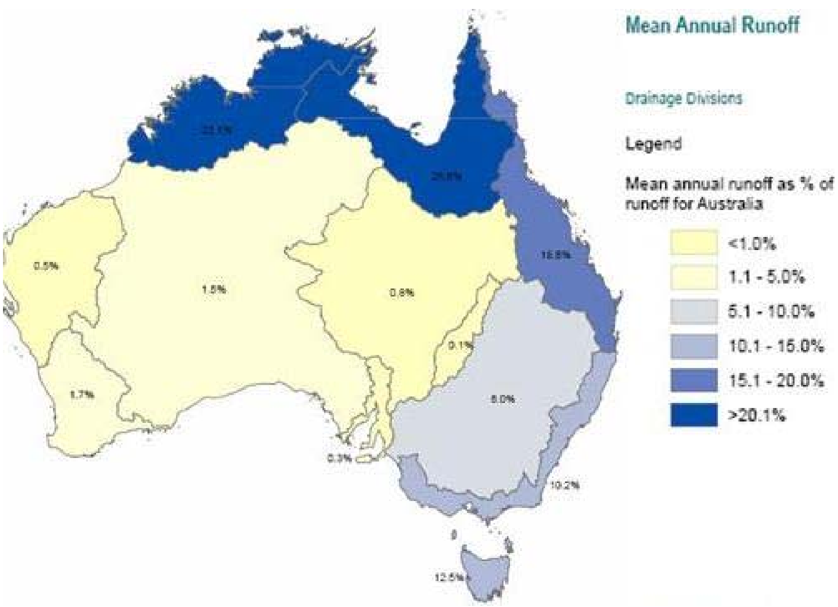

Figure 1: Distribution of surface water runoff (AWR 2005)

There is abundant evidence from the instrumental record and existing impact assessments that the water resources of southern Australia are at least vulnerable to, and have the potential to be strongly impacted by, projected climate change (PMSEIC 2007).

Surface water systems interact considerably with groundwater systems. Water may move directly between groundwater and surface water as through a spring, but interactions are usually through more diffuse flows, such as seepage into or out of drainage channels or from wetlands into surrounding groundwater systems. These flows are primarily controlled by the hydraulic gradient, or the height of the water table, and by ground permeability. Hydraulic gradient is controlled by groundwater recharge, which has significant temporal and spatial factors. It is clear that climatic conditions and trends can therefore have significant flow-on effects and temporal lags. In many cases, land use, in particular groundwater abstraction for irrigation can substantially alter the natural balance.

Hydrogeologically diverse groundwater systems occur across Australia, including the Great Artesian Basin that underlies one fifth of the continent. Groundwater is a critical component of the total water cycle at catchment or regional scales, and contributes to surface water ecosystems as well as supporting diverse subterranean aquatic ecosystems comprising locally endemic species. Groundwater is the major source of water for agricultural irrigation, stock watering, mining operations and community use in many locations in Australia's arid interior and is also the major source of water for Perth Metropolitan Region.

2.2.1 The impact of climate change on Australia's water resources

The impact of climate change on freshwater bodies will vary across the globe, and hydro-morphological changes will influence freshwater habitats. Changes in intensity, distribution and seasonality of rainfall, snow cover and precipitation runoff, increasing acidity and changes in extreme events such as floods, droughts and fire have already occurred that are consistent with climate change (Kundzewicz *et al.* 2007).

Higher water temperatures, and variations in runoff are likely to produce adverse changes in water quality affecting human health, ecosystems, and water use. Higher air temperatures have been associated with increased river and stream temperatures (e.g. Kaushal *et al.* 2010), which is a key factor in the health of a stream ecosystem (Ward 1963). Eutrophication is a major water-quality problem (Davis 1997, SOE 2001). Increased nutrient load and higher surface water temperatures will promote algal blooms and increase the bacteria and fungi content. Lowering of the water levels in rivers and lakes will lead to the re-suspension of bottom sediments and liberating toxic compounds, with negative effects on water supplies and quality. More intense rainfall will lead to an increase in turbidity, and introduction of pollutants and nutrients from adjacent agricultural areas. Acidification in rivers and lakes is also expected to increase because of acidic atmospheric deposition. In estuaries and inland reaches with decreasing streamflow, salinity may increase.

Changes to rainfall will affect water availability. Climate change already affects water resources in southwest Western Australia, where lower mean annual rainfall has been reflected in reduced river flows and dam inflows. Climate models suggest that drought could be as much as 20% more common by 2030 over much of Australia and up to 80% more common in south-western Australia by 2070. However regions such as Northern Australia are not expected to be more drought affected. Increases in extreme rainfall events are projected for many regions across Australia, resulting in more flash flooding, strains on drainage systems, and impacts on groundwater recharge (Hennessy *et al.* 2007).

The Murray-Darling Basin is Australia's largest river basin, accounting for about 75% of irrigated crops and pastures (MDBC 2006). By 2030, average annual runoff across the Basin could reduce by as much as 33% but could also increase by up to 16%; the median estimate is for a 9% reduction (CSIRO, 2008). The median estimate (under a medium global warming scenario) is for 2050 is a 15% reduction, and for 2070, a 23% reduction; under a high global warming scenario much greater reductions are possible (CSIRO, 2008). In Australia, there is a 50% chance by 2020 of the average salinity of the lower Murray River exceeding the 800 EC threshold set for desirable drinking and irrigation water (MDBMC 1999).

While it is well known that climate change will affect groundwater recharge, levels, resources and ecosystems through changed rainfall, flooding and evapo-transpiration patterns, better predictions about these effects are required (Jones *et al.* 2007).

In arid Australia, the groundwater systems are already in a state of net discharge owing to global climatic changes on the order of 10^3–10^5 years (Hatton 2001). Any decrease in groundwater recharge will exacerbate the effect of sea level rise on coastal aquifers and freshwater ecosystems. In inland aquifers, a decrease in groundwater recharge can lead to saltwater intrusion of neighbouring saline aquifers, and increased evapo-transpiration in semi-arid and arid regions may lead to the salinisation of shallow aquifers. A warmer climate, combined with increased climate variability, will increase the risk of both floods and droughts. Excessive water withdrawals can exacerbate the impact of drought.

The demand for groundwater is likely to increase in the future, mainly due to increased water use globally, but also due to the need to offset declining surface water availability due to increasing precipitation variability in general and reduced summer low flows in snow-dominated basins.

Changes to hydrological regime will affect the formation and location of estuaries associated with marine shores and salt lakes, the rich subterranean faunas they host, and the distribution and abundance of potable groundwater, submarine groundwater discharge, the location of saltwater interfaces, and discharge and location of springs.

2.3 Australia's Freshwater Biodiversity

2.3.1 Features of Australia's biota and ecosystems

Several unique features of the Australian biota, of the organisation and structure of Australian ecological communities and of the environment within which they have evolved will affect the effectiveness of management responses to climate change. Research to assist adaptation of freshwater biodiversity in the face of climate change should be responsive to the way that these features affect impacts in Australia, since these are the effects for which we are least able to draw on overseas research.

Key features of the Australian continent and its freshwater species and ecosystems are outlined below.

- *Biogeographic history and degree of endemism*: The Australian continent has been isolated from other land masses for over 45 million years. Today, Australia has 7-10% of all species on Earth and a significant portion of these species occur nowhere else. For example, more than 90% of Australia's reptiles, frogs and vascular plants are endemic. Many endemic species are already considered threatened, and/or have small geographic and climatic ranges, factors which indicate high vulnerability to rapid climate change. Many of Australia's freshwater biota are more diverse and endemic than elsewhere in the world (e.g. galaxiid fish, parastacid crayfish, phreatoicid isopods and candonine seed shrimps and diving beetles in groundwater) and include relicts of Pangaean and Gondwanan origin (e.g. syncarid shrimps, petalurid dragonflies, lungfish, salamander fish and Spelaeogriphacea) and Tethyan origin (e.g. in groundwater Thermosbaenacea, Remipedia). Although fish taxa are relatively depauperate (~200 spp) by world standards, they have a high degree of endemicity. While Australia's freshwater biodiversity has not been fully described, recent studies have highlighted high levels of local endemicity and cryptic species complexes in some regions (e.g. Baker *et al.* 2003 and 2004; Cook *et al.* 2008; Page *et al.* 2008; Bradford *et al.* 2010) and whole new ecosystems (Humphreys 2008).

- *Aridity and rainfall variability:* Australia's climate spans a very wide gradient and is highly variable, with extremes in temperature and precipitation (droughts, floods and storms). These episodic climate events are important in driving the structure and function of Australian freshwater ecosystems. If Australia's climate becomes drier, the pre-adaptation of some species to climate variability could bestow a degree of resilience not found in many other parts of the world suffering similar drying conditions. However, many species may already be operating close to their physiological limits and even small changes could therefore have large impacts.

- *Flat topography*: Australia has limited topographic relief with less than 5% of the land more than 600 m above sea level. Lack of topographic variability can increase the spatial impact of climate extremes, such as heavy rainfall, flooding and droughts.

- *Tectonic stability*: Over several geological periods much of Australia has been free of major orogeny and glaciation, and has been emergent, resulting in deep regolith, mosaic soils and vegetation, with landscape dominated by palaeovalleys. Such edaphically driven community mosaics may pose special challenges to adaptation.

- *Role of fire*: The combination of aridity, high temperatures and abundance of sclerophyllous vegetation means that fire plays an important role in determining ecological community composition, distribution and function. Fire directly affects the boundaries and health of ecosystems sensitive to fire, including wetlands and bogs. Climate-associated change in fire regimes may be one of the most significant drivers of ecosystem change in many regions.

- *Nature of human impacts:* Intensive farming, widespread grazing and trampling by ungulates, and extensive mining are relatively recent phenomena in Australia compared to most other continents. We face a situation of relatively recent land use change to which biodiversity is still responding and possibly adapting.

- *Invasibility of Australian ecosystems:* Nutrient enrichment of Australia's water systems from agricultural and urban development has had negative consequences for many freshwater ecosystems, including the establishment of many alien plant species. Introduction of vertebrates and invertebrates has also had devastating consequences for native biodiversity.

2.3.2 Water resources and freshwater biodiversity

Water quality changes, often related to salinity, sediment, water temperature and nutrients, may demonstrate strong links to aquatic biodiversity because of changes to individual species' habitat requirements and the direct impact on species' lethal tolerance.

Toxic algal blooms are likely to become more frequent and to last longer due to climate change. They can pose a threat to human health, for both recreation and consumptive water use, and can kill fish and livestock (Falconer, 1997). Saltwater intrusion as a result of sea level rise, decreases in river flows and increased drought frequency, are very likely to alter species composition of freshwater habitats, with consequent impacts on estuarine and coastal fisheries (Bunn and Arthington 2002; Hall and Burns 2002; Herron *et al.* 2002; Schallenberg *et al.* 2003). Saltwater intrusion into freshwater swamps has occurred since the 1950s in Northern Territory have been accelerating since the 1980s, possibly associated with sea level and precipitation changes (Winn *et al.* 2006).

Many coastal and estuarine settings host complex hydrological systems with interaction of fresh and saline groundwaters and surface waters, tidal influences, common mixing of waters and often specific localised environments related to a delicate balance of physico-chemical conditions. This complexity results in highly variable habitats. Modifications of groundwater regimes and changes in water resources balances in such areas can result in ecological changes, such as mangrove colonies invading saltmarshes and *Casuarina* stands. Rising sea levels in these settings will also impact on coastal groundwater systems and associated freshwater *Melaleuca* wetlands, with effects being propagated along tidal estuaries.

Rivers and wetlands are the most threatened ecosystems on the planet and face growing pressures from an expanding human population (Malmqvist and Rundle 2002, Postel and Richter 2003). Many of the world's larger river systems are fragmented by dams and flow regulation, with significant consequences for migratory species, coastal and inland fisheries (Nilsson *et al*. 2005; Pringle 2001).

River corridors in Australia have been transformed for urban and agricultural land use to the extent that many floodplains are functionally extinct (Tockner *et al*. 2008), and increases in nitrogen loading from cities and agriculture have resulted in order-of-magnitude increases in riverine fluxes to the coastal zone (Green *et al*. 2004). As a consequence of these cumulative impacts, freshwater systems have the highest rates of extinction of any ecosystem.

2.3.3 Freshwater Biodiversity and Climate Change

Climate, and particularly its influence on surface and groundwater availability, plays a fundamental role in determining freshwater species distribution and abundance, the distribution and structure of vegetation and the rates of most ecosystem processes.

The extent to which a species or ecosystem will be vulnerable to or benefit from climate change impacts is a function of sensitivity and exposure to climate change as mediated by the resilience, evolutionary potential or ecological plasticity of the species, habitat or process (Williams *et al.* 2008).

Responses of species and ecosystems to rapid climate change will vary, with both winners and losers. Adaptation management requires objective prioritisation based on relative vulnerability or benefits to allow the efficient allocation of management resources and to avoid wasting resources on species or ecosystems that can adapt on their own. Assessing the relative vulnerability of species and ecosystems requires consideration of three factors.

(i) *Species traits including life history and geographic range characteristics:* these traits include the ability to disperse, and thus migrate to more suitable locations, and the presence of opportunistic reproductive strategies. Life history traits have an important influence on both resilience and evolutionary potential to adapt.

(ii) *Degree of exposure:* the degree and rate of climate change will vary from region to region. Habitats and regions vary greatly in their degree of climatic buffering. For example, temperature in coastal areas is less variable than inland areas and maxima daily temperatures are lower where there is cloud cover during part of the day. Regions with high topographic relief, such as dissected plateaus with cool, moist gorges, may continue to provide refugia within a landscape as the regional climate warms. The relative influence of variable exposure is an important aspect of adaptation and conservation planning and will need consideration at several spatial scales. Identifying and protecting climatic refugia will be an important component of future adaptation actions. Refugia are areas that provide significant buffering to extreme events or maxima. They can either give rise to a relictual

situation or can provide temporary refugium that, with connectivity, can allow species to move and survive the disturbance coming from climate.

(iii) *Adaptive capacity:* some species may adapt genetically, or have sufficient phenotypic plasticity to tolerate new conditions *in situ* while others may adapt genetically in the longer term. Others may be able to cope, at least in the short- to medium-term, by altering their use of microhabitats, colonising subterranean waters (Humphreys 2008), or by shifting their geographic range. The capacity of mobile species to travel some distance to more suitable areas will depend on the permeability of the landscape matrix between suitable habitats. Some species capable of shifting their range will be prevented from doing so by physical barriers such as dams or unsuitable habitats such as cleared farmland that impede connectivity.

Freshwater biodiversity will be affected by climate change directly (such as effects of changes in temperature, rainfall and atmospheric CO_2 concentration) and indirectly (impacts on ecosystem processes such as fire, or on interactions between species and consequent effects on ecological communities and ecosystems).

Direct impacts

Changes to hydrology, such as riverine flow regimes, and groundwater connectivity sustaining base flow, are widely regarded as a key driver of riverine ecosystem structure and function (Poff *et al.* 1997; Bunn and Arthington 2002, Boulton 2003). Climate change impacts would thus be expected, on the basis of ecological principles, to affect the diversity and function of aquatic habitats.

Dryer conditions in some parts of Australia have already impacted on flow regimes and similar impacts will occur as climate change progresses. Changes in the physical environment affect the physiological processes of plants and animals such as respiration, photosynthesis, metabolic rate, and water use efficiency. Individuals may also respond to environmental change by altering their behaviour or the timing of life cycle events (phenology) such as flowering, dispersal, migration and reproduction.

All organisms are able to cope with some degree of variability in their environment, and to maintain homeostasis and reproduction within the bounds of that variability. Beyond some physiological threshold, however, responses change quite dramatically and death may result. Both physiological tolerances and how close these tolerances are to existing limits, that is, how much safety margin is available, are important. For example, recent research suggests that tropical species which have narrower tolerance ranges than temperate species are also, on average, closer to their upper limits with a smaller safety margin (e.g. Deutsch *et al*. 2008, Colwell *et al*. 2008). Understanding physiological and other thresholds, extreme events and tipping points is important as many biological patterns and processes are more determined by upper or lower climate thresholds rather than by average climate conditions.

Freshwater biota and ecosystems will be affected directly by climate change in several ways:

- By the thermally-induced changes of global warming;
- By changes in hydrologic regime (i.e. changes in the timing, magnitude, and frequency of low and high streamflows, groundwater recharge and discharge, and the magnitude and distribution of hyporheic exchanges);
- By changes in aquatic chemistry both directly and through groundwater and hyporheic exchange (e.g. dissolved oxygen, pH, nutrients, salinity and turbidity); and
- By sea level rise.

Increased air and water temperatures have many direct implications for plant and animal physiology and subsequent changes to ecosystem structure and processes. For example, differential changes in growth rates can change competitive balances between organisms, impacts that will potentially change ecosystem processes and structure in ways that are inherently hard to predict.

Freshwater taxa in some regions of Australia are already close to their thermal tolerance levels and unable to migrate to cooler environments (Davies 2009). Some taxa have restricted distributions (e.g. mountain top species of stream frogs and crayfish in north eastern Australia) and may have little ability to move in response to rising temperatures or changed hydrology.

The response of freshwater plants to rising CO_2 concentrations in the atmosphere and water will also be important, especially coupled with warming and/or altered water availability patterns. Increased CO_2 is also likely to result in differential responses between plant species that could have large secondary impacts on plant community structure, net primary productivity, animals that use plants as habitat or food, and even nutrient cycles in ecosystems.

These direct effects could be compounded in the short term if more surface and ground water is diverted to meet agricultural, industrial and mining needs without sound consideration of ecological water requirements.

The impacts of climate change on freshwater ecosystems systems are yet to be examined carefully in a quantitative framework that captures the linkages between climate, hydrologic regime, water quality, physical habitat and aquatic ecosystem health.

Understanding physiological and other thresholds, extreme events and tipping points is important as many biological patterns and processes are more determined by upper or lower climate thresholds rather than by average climate conditions.

Indirect impacts

Many non-climatic drivers already affect freshwater resources. The quantity and quality of water resources and their associated species and ecosystems are influenced by changes in land use, construction and management of reservoirs, pollutant emissions, and water and wastewater treatment. Water use is driven by changes in population, food consumption, economic policy (including water pricing), technology, lifestyle, and society's views of the value of freshwater ecosystems. Vulnerability of freshwater systems to climate change also depends on water management. Climate change impacts on any of these factors will have indirect impacts on freshwater biodiversity.

Climate change is thus a new stressor that adds to and interacts with a range of existing stressors that have already significantly changed and diminished Australia's freshwater biodiversity. These stressors include loss, degradation and fragmentation of habitat, introduction and spread of invasive species, stormwater diversion and over-harvesting of water resources.

Dispersal

Future changes in climate and the hydrologic cycle will redistribute many of the factors which define the preferred locations for freshwater systems. Individualistic responses of species to climate change will result in changes to both the structure and composition of many ecological communities and ecosystems.

With the current rapid rate of climate change, novel combinations of species will appear in the future, creating ecological communities that have no present day analogue. Flow-on effects to ecosystem services on which humans depend are potentially significant. Such ecosystem services include provision of food, pest control, purification of water, and biogeochemical (nutrient) cycling. The impact of climate change on the provision of ecosystem services is largely unknown.

However, dispersal capacity and geographical and human barriers will limit colonisation of new locations by freshwater biota. Many species or habitats may not be able to move at all due to habitat fragmentation and lack of connectivity, natural barriers or specialisation for specific environmental conditions. For instance, fish, which are highly vulnerable to increased habitat fragmentation and alterations to both temperatures and river flows, could be considered as highly mobile species but their movement may be blocked by a lack of connectivity between their current locations and future suitable habitat e.g. dams. Changes in fish species composition can lead to cascading impacts on other freshwater biota through aquatic food webs (e.g. due to changes in the intensity of biotic interactions such as predation and competition).

Knowledge of how climatic changes in the past have affected freshwater biodiversity will provide useful insights into possible future changes. Many species and ecosystem responses to climate change are expected to be non-linear and there may be thresholds where rates of change to species distribution and ecosystem composition, structure, processes and services alter or jump rapidly to different levels. This behaviour inherently increases uncertainty in predictions.

Understanding species and ecosystem responses to climate change

Current research on predicting impacts and vulnerability is mostly focussed on changes to species or vegetation structure that would result from specified levels of climate change impacts. The framework presented in Figure 2 outlines the factors involved in assessing climate change impacts and vulnerability of a species. It also indicates how the vulnerability of ecosystem composition, structure and processes might be investigated. However, more research effort is required to develop and evaluate methods and appropriate measures to determine the vulnerability to climate change impacts of ecosystem processes and function and effective adaptation responses.

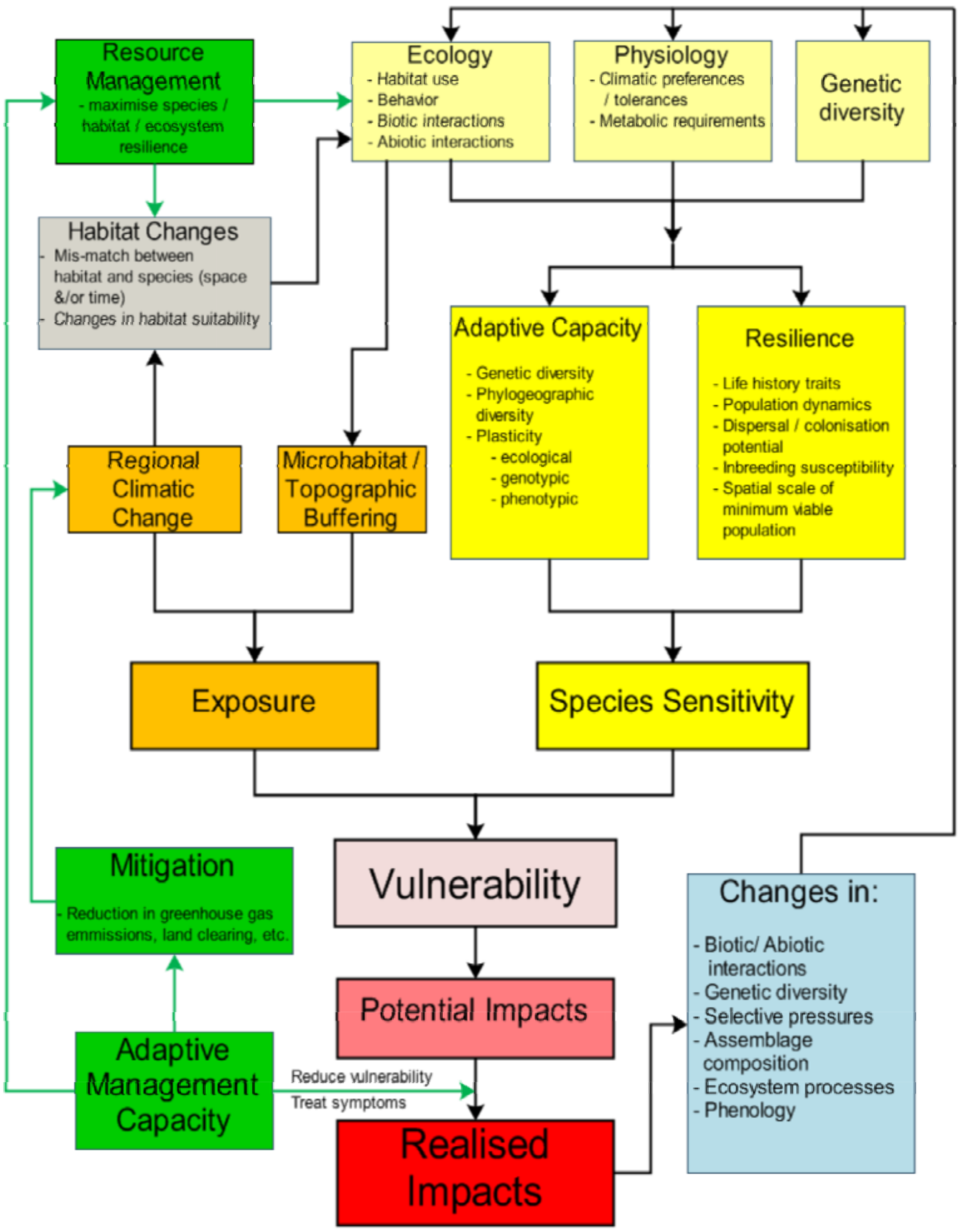

Figure 2) Prioritising species based on relative vulnerability and adaptive potential: a general framework to assess the vulnerability of species to global climate change. See Williams *et al.* (2008) and Steffen *et al.* (2009) for full discussion.

2.3.4 Observed trends: species and ecological communities are already responding to climate change

On other continents, particularly in the northern hemisphere, the availability of long-term biological datasets has enabled comparisons of recent climate and biological trends. The clearest evidence for such changes comes from observations of phenology (life cycle events occurring earlier in the season) and geographic range shifts (mostly polewards and to higher elevations). Expansions at the colder edges of ranges appear to be occurring more rapidly than retractions at warmer edges. It is not yet clear whether this is just a lag effect (colonisations occurring faster than local extinctions), or because minimum temperatures in many regions are increasing faster than maximum temperatures, or simply because instances of colonisation are easier to observe than confident detection of local extinctions.

There is also evidence that some organisms are responding genetically to the strong selective pressures imposed by climate changes.

To the extent that similar organisms respond to climate change in similar ways in Australia, some changes in species' life cycles and distributions recently observed in Australia are also likely to be correlated with climate change, at least in part. For instance, past phases of aridity led to colonisation of caves and groundwater by lineages that, by their adaptations, became trapped *in situ* and so have endured climate change through geological periods and may serve as exemplar models of adaptation.

Many ecological changes are likely to have significant non-climatic causes and the precise role of different factors may continue to be almost impossible to quantify in most cases. Most of the recently observed changes in biodiversity have been at the species level, due partly to the visibility of larger mobile species such as birds, and partly to the nature of biological organisation itself. Relatively faster processes such as dispersal, migration, and population growth in small organisms will be more obvious in many species. For further information about observed trends, please see Chapter 5 of Steffen *et al.* (2009).

What is most noteworthy about the observations, both in Australia and elsewhere, is that in many cases, significant impacts are apparently occurring with *extremely modest increases* in temperature compared with those expected over coming decades. However, as noted above, Australia's highly variable climate and the features that have contributed to the evolution of Australian biota and ecosystems will limit the applicability of overseas research to local circumstances.

2.3.5 Summary

Predicting and managing the impacts of climate change on Australia's freshwater biodiversity is complicated for a number of reasons:

- There is a great deal of uncertainty inherent in all aspects of climate and biodiversity impacts and responses.
- Climate change will interact with other drivers that are currently affecting freshwater biodiversity.
- Responses to physical and chemical changes will occur at the level of the individual organism, and be reflected in population dynamics of individual species. The component species or functional groups within an ecosystem will therefore not respond as a single unit, and interactions among species will have the potential to modify outcomes, sometimes in unpredictable ways.
- Many properties of biological and ecological systems are inherently difficult to track. For example: (a) a change in the average value of a continuous environmental variable (such as temperature) may not be as important biologically as a change in variability or extremes of that variable and (b) responses of biological systems may be non-linear, with thresholds or tipping points not yet identified.
- Basic knowledge about limiting factors, genetics, movement patterns, and interactions among species and ecosystem processes that make up Australian ecological communities and ecosystems is generally lacking.
- Management actions taken to adapt to and/or mitigate the impacts of climate change on human systems could have further adverse impacts on biodiversity.

Current understanding of future climate conditions, species' climate dependencies and thresholds, and climate-ecosystem interactions will only support very general guidance about potential vulnerability and management options. Adaptation decisions made in such circumstances need to incorporate risk management and could include research elements that improve knowledge and understanding over time. Sound experimental approaches, including observation, monitoring and model testing, and effective stakeholder engagement would be required.

2.4 Adaptation Responses

Adaptation responses can reduce vulnerability by treating impacts, reducing regional exposure or increasing system resilience, such as by reducing other threats or stressors. There are four main adaptation responses for freshwater biodiversity currently available to decision-makers. These adaptation responses form the framework for Section 4 (Research priorities).

2.4.1 Incorporate climate change considerations into freshwater biodiversity management

Freshwater biodiversity is already the focus of many Australian conservation and other programs and initiatives. Climate change needs to become a fundamental element of existing programs that seek to protect freshwater biodiversity because it will affect species survival, competitive pressures and species interactions within ecosystems. While some species may be able to adapt to the new environmental conditions and even thrive, other species may already be close to the limit of their physiological capacity, be unable to adapt to climate changes or suffer competitive disadvantage. Existing program managers need to distinguish those species for which current approaches may need to be altered for conservation goals to be achieved and to formulate effective management responses.

So far there has been little research focussed on potential adaptation responses to projected climate change impacts on freshwater biodiversity.

While adaptation options such as assisted colonization have been suggested for aquatic species of conservation significance with restricted geographic distributions (Hoegh-Guldberg *et al*. 2008), these options are expensive and hold risks such as introducing potential weed or pest species. Other options also need to carefully reviewed and configured to meet the needs of freshwater species and ecosystems.

2.4.2 Identify and protect current and future refugia

Refugia are places where biota with appropriate life history strategies reside when disturbances such as droughts or floods occur. They are highly variable in respect to climatic conditions, topography, geology, soil type, vegetations, and the form of the surface water source. Refugia may be temporary or may endure over long periods, or, like aquifer ecosystems, through many millions of years. Refugia are important as repositories of species or genotypes that may repopulate areas after the causative factor is no longer affecting the areas.

Refugia range from the clearly identified pools to an array of smaller sites, such as under stones or in yabby holes in riparian and littoral vegetation. In dry periods refugia will tend to be those locations which remain wet or moist; in wet periods they are locations which are well drained, in rain shadows or sunny. In other words, they tend to be locations which offer alternatives to prevailing climate or other environmental conditions.

Refugia may be located in rugged highland terrains, valleys, coastal plains and along shorelines. They may be found where diffuse groundwater discharge occurs at local topographic lows, or on high slopes where perched groundwater conditions exist.

In southern Australia, refugia in most cases are related to or exist at sites where surface water remains during dry periods. Thus during droughts, fish may survive in pools. When water returns surviving individuals move to potentially repopulate newly wetted habitats. Migrating to and from refugia requires refugia to be connected to other areas that can be repopulated or from which escape is required.

In riverine systems, water holes may be refugia, enabling species to survive dry periods and from which they can repopulate the remainder of the system once flow returns. In wetlands, refugia will tend to be the lowest-lying area, where groundwater expression is most likely to endure through dry periods. Many river systems in Australia are characterised by episodic flows and for much of the time are reduced to a series of disconnected pools and waterholes, which provide important refugia for fish and other aquatic species (Hamilton et al. 2005). Increasing the duration of no-flow events (e.g. because of water abstraction or more frequent or longer droughts) reduces the physical persistence of these important habitats and often leads to local extinctions (Bunn et al. 2006).

Refugia can be damaged or destroyed, by rural or urban land use and development. Grazing, poor channel management, water diversion or harvesting, fertiliser and other pollution, clearing, or ploughing can damage rural refugia. Urban refugia can be damaged by poorly planned development, flood control measures or other water management measures, Changes to vegetation can have a major impact on refugia where they alter evapotranspiration and thus groundwater levels. Establishing forests or plantations is likely to increase evapotranspiration, thus reducing groundwater levels and the extent of damp refugia. Removing deep-rooted vegetation can reduce evapotranspiration resulting in higher groundwater levels and possibly altering water chemistry. Temporal changes in evapotranspiration are usually slow with vegetation growth, but can also be significant in the short-term, such as after fires or forestry plantation are harvested, and an associated watertable rise. Impacts on a groundwater system that contributes to the support of refugia, may be spatially distant, and involve a temporal lag.

Connectivity is vulnerable to infrastructure development and other actions. Weirs and other barriers may prevent aquatic organisms dispersing to otherwise connected aquatic habitats and limit recolonisation when flows return. Climate change will exacerbate these impacts on existing refugia either directly through changes to water regimes or indirectly through changes to water management or abstraction.

Future changes in climate and the hydrologic cycle will redistribute freshwater systems. Colonisation of new locations by freshwater biota may be limited by dispersal difficulties and inabilities due to the species' physiological tolerance, lack of connectivity with existing systems, human barriers and geographical regions. This will constrain both the dispersal of species to areas suitable for them but also affect the composition of new ecosystems and the services they are able to provide.

2.4.3 Reduce threats and impacts arising from climate adaptation initiatives in other sectors

Developing and assessing the potential effectiveness of climate change adaptation responses for freshwater biodiversity is complicated by the need to consider processes which operate across catchments and in upstream drainage networks, the surrounding land, the riparian zone and, in the case of migratory species, downstream reaches of rivers and wetlands (Dudgeon *et al.* 2006). There are two aspects to this complication:

- Actions taken in most other sectors will affect freshwater biodiversity (see section 1.5) and
- Climate change adaptation responses taken in other sectors could affect freshwater biodiversity.

Freshwater biodiversity is detrimentally affected by actions in virtually all other sectors, including terrestrial biodiversity, primary industry, water resource management and urban and infrastructure development. Freshwater biodiversity management already needs to incorporate these impacts and threats, However, management actions taken to adapt to and/or to reduce the impacts of climate change on one sector could have further adverse impacts on other sectors. This is especially a concern for freshwater biodiversity, which is vulnerable to changes in the quality and quantity of water resources as well as to direct physical damage. For instance, land use, including agriculture, forestry or urban development, has considerable impacts on freshwater biodiversity directly through conversion of natural ecosystems and indirectly through affecting water resources and hydrologic patterns. Careful management is thus required to avoid impacts on freshwater biodiversity where primary industry seeks to adapt to climate change impacts by using new techniques or developing new areas or climate-induced migration results in urban development.

2.4.4 Ensure policies, plans and programs enhance the resilience of freshwater biodiversity to climate change

National environmental goals and policies have key roles in protecting Australia's biodiversity at all scales from national to local, landscapes to species or even individual organisms.

The overall goals of conservation in Australia are (i) maintaining well functioning ecosystems; (ii) protecting a representative array of ecosystems; (iii) removing or reducing existing stressors; (iv) building and restoring habitat connectivity; (v) identifying and protecting current refugia; and (vi) minimising the loss of species. Climate change could pose challenges for a 'preservationist' approach to conservation policy, with a move towards approaches that seek to manage change to minimize loss of biodiversity and maintain evolutionary processes and ecosystem function. This would mean, for instance, anticipating or identifying refugia that develop as climate change impacts occur and protecting them through reservation, management agreements or other options.

Climate change is also likely to test the utility of the criteria of comprehensiveness, adequacy and representativeness (CAR) that currently underpin the protected area estate and inform national approaches to conservation. Resolving the meaning and utility of CAR and other criteria for conservation planning and reserve programs will become more pressing under climate change to ensure Australia's protected area system can meet the challenges of climate change.

The role of Australia's protected area system for freshwater biodiversity is further complicated by the relatively limited protection currently afforded freshwater species and ecosystems. While protected areas comprised around 89.5 million hectares (11.5%) of Australia's landmass in 1998, the proportion of certain types of ecosystems in protected areas can vary considerably (*Australia's strategy for the national reserves system – 2009-2030)*. For example, while 80% of Ramsar listed wetlands in Australia are protected, only 3% of wetlands in New South Wales are currently protected in the National Reserve System. This situation is common globally, as 13% of lands, 6% of coastal areas but less than 1 % of the planet's ocean areas are currently protected (Nellemann and Corcoran 2010).

Protection of Australia's freshwater biodiversity will be improved through activities currently under development under the National Water Initiative, including a '*national imperative to ensure the health of river and groundwater systems*' (Clause 5) and an initiative which tasks all States and Territories to '*identify and acknowledge surface and groundwater systems of high conservation value*' (Clause 25x).

The Aquatic Ecosystems Task Group (AETG), a multi-jurisdictional group under the Natural Resource Management Ministerial Council, was formed to develop a framework to identify and classify High Conservation Value Aquatic Ecosystems (HCVAEs). The framework is designed for systematic application at several scales (national, state/territory and regional). Regular reviews of data and HCVAE assessments will enable impacts (due to both climate change and others reasons) to be identified. The AETG is also developing an Australian National Aquatic Ecosystem (ANAE) Classification Scheme to provide a nationally consistent set of aquatic ecosystem classes to identify different aquatic ecosystems across Australia.

The AETG is scoping the development of an Integrated Ecological Condition Assessment Framework for aquatic ecosystems. The Framework is intended to provide the capacity to assess and report at the individual aquatic ecosystem scale or on a number of connected aquatic ecosystem types at a range of scales. It will provide a rapid assessment technique that identifies risk and incorporates a diagnostic capacity to inform adaptive management. It is envisaged that the Framework will establish condition based on the functional processes and ecological characteristics that underpin the aquatic ecosystem's key values. Condition will be evaluated in relation to critical thresholds/tipping points and management triggers (i.e. thresholds of potential concern) identified as essential to maintain critical functions and processes.

3 Key stakeholders and their information needs

NARPs are an important tool for coordinating climate change research across Australia. NARPs identify critical gaps in the information available to decision-makers in key vulnerable sectors and regions, set national research priorities, and identify science capacity that could be harnessed to conduct priority research. The process by which NARPs are developed enables stakeholder groups to contribute to identifying priority research topics that will help meet key end-users information needs.

NARPs have four main stakeholder groups: researchers, research investors, research end-users and the beneficiaries of effective research uptake and application.

It is important that research priorities identified in the NARP address the management needs of key end-users including government, industry and the community (Table 2). However, different stakeholder groups have a range of issues and topics that they consider important, and these help frame the research agenda of the NARP. Moreover, engagement with all stakeholders and the wider community about the intent of the NARP will help build support for implementing the NARP and using the resulting research outputs over the medium and longer terms. In addition, involving stakeholders from the beginning of the research planning process will help ensure that the communication of results will be in user-appropriate forms and methods.

A collaborative research approach, of which this NARP is the first element, will encourage national, state and territory, regional and local partnerships between researchers, policy analysts, managers, interested citizens and others. While all stakeholders need to be involved in co-ordinated responses to climate change adaptation, these stakeholder groups also have distinct roles:

- The Australian research community seeks to provide information, tools and insights the nation requires to address critical issues it faces, including climate change adaptation. This community includes:

    - Professional scientists based in universities, government agencies, the CSIRO and other research organisations, who can apply creative and structured approaches to research programs into complex questions and uncertainties.
    - Commonwealth, state and territory biological collections, such as museums and herbaria, and their researchers, which provide an essential resource to verify past and current species distributions and molecular diversity.
    - Citizens individually and in groups, such as NGOs, private entities, regional bodies, peak organisations, land holders and land managers, are able to provide cross-sectoral insights about national or regional issues or specific issues in particular places. Local knowledge from these stakeholders can help verify model outputs from other research activities.
    - Indigenous groups can provide important knowledge about aquatic ecosystems, particularly in remote areas where limited information may be available.
- The Commonwealth, state and territory governments, research and development corporations and research investment organisations seek to ensure that Australia has the research outputs it requires for effective decision-making, delivered effectively and efficiently.
- A wide group of research end-users have well-defined needs for research outputs:
    - Commonwealth agencies have a key role in ensuring Australia has a comprehensive and effective national response to unavoidable climate change.
    - State and territory biodiversity and water management agencies have a significant role in leading regional collaborations because they have both an extensive on-ground presence and considerable management capacity. The roles of these agencies include managing protected area systems and water resources and administration of a wide range of natural resource management (NRM), biodiversity and water legislation, program and policies.
    - Local government plays a key role in forming and supporting local responses and collaborations and implementing local adaptation initiatives.
    - Citizens and groups such as NGOs, regional bodies and peak organisations need information to support advocacy about issues of concern and to mobilise effort to respond to issues.
    - Landholders and land managers, including Indigenous groups, local environmental groups and activists, school groups and others, need information to support management decisions that result in sustainable use of ecosystems and the protection of biodiversity.
    - Researchers and research investors require access to research outputs to formulate new research priorities.
- Virtually every Australian resident has a personal stake in the sustainable use of ecosystems and the protection of biodiversity and benefits in some way from effective adaptation to climate change.

This NARP engages research investors and research providers to deliver research outputs required by three broad groups of end-user stakeholders.

Government agencies

Commonwealth agencies are responsible for ensuring Australia meets the responsibilities it has adopted under international treaties. State and territory government agencies are responsible for managing climate change impacts and protecting biodiversity values at the sub-national scale. Governments need information that will support sound policies, programs, plans and on-ground initiatives. An overriding policy issue is whether current policies will guide effective responses to climate change impacts and vulnerabilities and, if they will not, how they need to be revised in terms of both adaptation and mitigation benefits. Resolving this matter will require information to project species adaptation and ecosystem resilience thresholds, future reserve system representativeness, adequacy and viability, and instances where enabling dispersal or undertaking translocation would be effective. Information about potential indirect impacts from climate change and effective management responses will be required avoid or reduce changes to ecosystem composition, structure, processes and services.

Local government, individuals and community organisations

These stakeholders will have a hierarchy of information needs. National conservation, industry and community groups will require information that enables them to develop and evaluate policy proposals related to climate change adaptation. Agencies which manage natural resources, such as local government, catchment management authorities, regional or local community groups, businesses, landholders and some Indigenous groups, will require information that is biologically and geographically relevant to their responsibilities and interests. In many instances this information will be similar to that required by their state and territory government colleagues, although it will normally be more heavily focussed on supporting the inclusion of climate change risks in regional, local or site planning and on-ground projects. Local governments will have similar information needs.

Research scientists and research providers

Research providers need to understand the broader context in which their research activities occur, and particularly the potential applications of their research. This is also a critical requirement for research investors seeking to make informed decisions about allocation of research funding.

Table 2. Key stakeholders groups for the Freshwater Biodiversity NARP.

Government agencies	Private organisations, Industries and Community	Research scientists and research providers
• Department of Sustainability, Environment, Water Population and Communities • Department of Climate Change and Energy Efficiency • Bureau of Meteorology • Department of Agriculture, Fisheries & Forestry • Murray-Darling Basin Authority • National Water Commission • R&D Corporations • Now ABARE – BRS Bureau of Rural Sciences • Australian Research Council • State and Territory Government departments of environment, climate change, water resource management and agriculture • Catchment Management Authorities • Local government	• Australian Water Association • Water Boards/Authorities • Water Utilities • Power Utilities • Mining Companies, Mineral Council of Australia • Petroleum and Coal Seam Gas Industry • Catchment Associations • Irrigator Associations, Cotton Australia, Dairy Australia, Rice Growers Association • Building and Industry Development • Australian Conservation Foundation, World Wildlife Fund and regional environmental organisations • Indigenous land councils and water policy groups • National Farmers' Federation and State/Territory equivalents (of which PGA is one)	• State and territory biodiversity, land management and water agencies • CSIRO • Australian Universities • eWater CRC • GeoScience Australia • ERISS • Other research agencies

4 Priority research topics

Four climate change adaptation research goals have been developed for the NARP that focus on immediate priorities for adaptation initiatives. These goals are interrelated such that the outputs of each will in many cases also inform work toward the others.

Goal 1: Climate change adaptation is incorporated into management of freshwater species and ecosystems

Overview

Climate change will affect species survival, competitive pressures and species interactions leading to changes in ecosystem services. Managers of freshwater biodiversity will need to understand the potential implications of these changes for their conservation programs.

Our capacity to project these impacts on freshwater species and ecosystems is limited by several factors:

- There are critical methodological, technical and data challenges (Heikkinen *et al.* 2006, Dormann 2007) including significant gaps in existing datasets about freshwater species and ecosystems (HRSC 2009, Humphreys 2008), and
- There is limited scientific understanding of the complex interactions among environmental and hydrological processes and the responses of aquatic biota to scale-dependent environmental conditions (Ward *et al.* 2002, Allan 2004).

Information about these matters is required to enable climate change to be incorporated to current freshwater biodiversity management programs.

Priority research questions:

- Where are freshwater species and ecosystems currently at their climate limits?
- How will freshwater species adapt and ecosystems change autonomously to climate change?
- How will climate change affect the effectiveness of freshwater biodiversity management?
- How can climate change adaptation initiatives be developed for poorly understood species and communities?
- What climate change adaptation initiatives are necessary to maintain freshwater ecosystem services?
- What monitoring systems are needed to evaluate the effectiveness of climate change adaptation initiatives for freshwater biodiversity?
- How can flow-on effects from climate change impacts on other environmental conditions such as acid sulphate soils and sea level rise be managed?

Goal 2: Climate change adaptation initiatives protect freshwater biodiversity refugia

Overview

A refugium is a location that has remained relatively unaffected by a climatic (or other) change in comparison to surrounding regions and that therefore forms a haven for biota. Refugia thus contain concentrations of plants and animals and sometimes unique ecosystems. They may be relicts of formerly widespread biota that have remained there for thousands of years, or they may be biota that have retracted to the refugium in the face of intermittent or shorter-term adverse environmental conditions such as widespread drought.

Refugia thus provide biota an opportunity to survive within a limited area while hostile environmental conditions occur over a broader area. Identifying and protecting such areas is therefore a key management response to predicted climate change impacts on freshwater biodiversity.

Faced with rapidly changing environmental conditions due to climate change and human population growth, systematic selection of areas for conservation action must be undertaken with future climate change and other environmental changes as an integral selection factor (Hannah *et al.* 2002).

Priority research questions:

- How can the climate resilience of freshwater biodiversity refugia be increased?
- What changes to Australia's conservation reserve system would improve protection of current and projected climate refugia and support connectivity for freshwater biodiversity?

Goal 3: Manage climate change adaptation interactions between freshwater biodiversity and other sectors

Overview

Freshwater biodiversity is affected by agriculture, grazing, forestry, mining and other types of rural development and activities and most types of urban development and many activities. Climate change will affect virtually all of these activities, with flow-on effects on freshwater biodiversity. Climate change adaptation taken in other sectors could also have positive or negative impacts on freshwater biodiversity. These interactions need to be understood to avoid detrimental impacts and to promote adaptation responses that benefit all relevant sectors.

Priority research questions:

- How will climate change affect existing stressors to freshwater biodiversity, such as invasive specie and pollution?
- How will climate change adaptation and mitigation actions by other sectors affect freshwater biodiversity, such as increased use of surface or groundwater, introduction of new species or new agricultural areas?
- How can integrated climate change adaptation response plans be developed at the local, landscape and regional scales to improve the protection of freshwater biodiversity and other sectors to climate change impacts?
- How can climate change vulnerability and adaptation links between terrestrial, marine and freshwater biodiversity be identified and managed?

Goal 4: National environmental goals and policies protect freshwater biodiversity under changing climate conditions

Overview

Conservation goals will need to reflect environmental processes, the public good and private attitudes to conservation. While conservation policies will vary in response to specific circumstances and precise objectives of conservation initiatives will vary from region to region, they must also be informed by an enhanced understanding of what is ecologically desirable and achievable. Conservation managers will need guidance on the most appropriate timing to move to new management goals and interventions while continuing their current initiatives to address existing challenges and opportunities.

Priority research questions:

- How will climate change affect existing national conservation goals, policies and programs for freshwater biodiversity?
- What frameworks will provide guidance for climate change adaptation in different regions of Australia, including the semi-arid zone?
- What management initiatives are required to address the social and economic consequences of climate change impacts on freshwater biodiversity?

5 Research prioritisation

5.1 Criteria and considerations for prioritising research questions

Actions aimed at addressing the likely impacts of climate change span many sectors. The COAG National Climate Change Adaptation Framework 2007 identifies eight sectoral areas, including primary industries, for implementing adaptation actions. The National Climate Change Adaptation Research Facility has developed a set of six criteria for prioritising research topics within each theme area (see Appendix 3 for details). These criteria are used in all the research plans developed by NCCARF.

The criteria are:

- Severity of potential impact or degree of potential benefit (essential)
- Immediacy of required intervention or response (essential)
- Need to change current intervention and practicality of alternative intervention (essential)
- Potential for co-benefit (desirable)
- Potential to address multiple, including cross-sectoral, issues (desirable)
- Equity considerations (desirable).

5.2 Freshwater Biodiversity climate change adaptation research priorities

Ranking research questions into high, medium and low priority is difficult, given that many aspects of research are not directly comparable and timeframes for research vary. Nonetheless, the six prioritisation criteria have been applied to the research questions identified under each of the four sub-themes in Section 4.

Applying the criteria outlined above, priority research questions were ranked from low to high. The full assessment matrix is in Appendix 3. From this, the following research questions identified in this NARP were determined to be high priority (Table 3).

Table 3. Summary of priority research questions.

Goal 1: Incorporate climate change adaptation into management of freshwater species and ecosystems.
1.1 How will climate change affect the effectiveness of freshwater biodiversity management?
1.2 How can climate change adaptation initiatives be developed for a wide range of poorly understood species and communities?
1.3 What climate change adaptation initiatives are necessary to maintain freshwater ecosystem services?
1.4 What monitoring systems are needed to evaluate the effectiveness of climate change adaptation initiatives for freshwater biodiversity?
1.5 How can flow-on effects from climate change impacts on other environmental conditions such as soil acidification and sea level rise be managed.
Goal 2: Identify climate change adaptation options for Australia's freshwater biodiversity refugia.
2.1 How can the climate resilience of freshwater biodiversity refugia be increased?
2.2 What changes to Australia's conservation reserve system would improve protection of current and projected climate refugia and support connectivity for freshwater biodiversity?
Goal 3: Understand climate change adaptation interactions between freshwater biodiversity and other sectors.
3.1 How will climate change affect existing stressors to freshwater biodiversity, such as invasive species and pollution?
3.2 How will climate change adaptation and mitigation actions by other sectors affect freshwater biodiversity, such as increased use of surface or groundwater, introduction of new species or new agricultural areas?
3.3 How can integrated climate change adaptation response plans be developed at the local, landscape and regional scales to improve the protection of freshwater biodiversity and other sectors to climate change impacts?
Goal 4: Understand the role of national environmental policies in protecting freshwater biodiversity under changed climate conditions.
4.1 How will climate change affect existing national conservation goals, policies and programs for freshwater biodiversity?
4.2 What management initiatives are required to address the social and economic consequences of climate change impacts on freshwater biodiversity?

6 Implementation strategy

This section summarises the requirements for effective implementation of this National Climate Change Adaptation Research Plan for Freshwater Biodiversity. These include the principles on which effective adaptation research should be carried out, research funding and research capacity available to undertake the research identified in the NARP

The Freshwater Biodiversity NARP provides a strategic framework for priority research for a five to seven year period. Some of this research will be supported directly by Commonwealth funding allocated for this purpose. However the breadth of research required is so great that significant further resources will be required, not all of which are specifically allocated at the time this NARP was prepared. It is anticipated that further resources will be available from a wide range of sources including natural resource management organisations, State and Territory agencies and programs. For these groups, the NARP provides a conceptual framework and prioritised statement of research requirements that can enable a higher level of coherence and effectiveness in the implementation of adaptation research than would have otherwise been possible. Nevertheless, each research funder will have its own priorities. Similarly, most research projects will focus on a context-specific issue, ensuring that the broad high priority research questions will be explored at scales that will generate information, knowledge and tools that are meaningful at the local and regional scales as well as being relevant to national and sub-national policy development.

Implementation of this NARP will be supported by the NCCARF Adaptation Research Network for Water and Freshwater Biodiversity. The Network brings together people from diverse sectors and disciplines relevant to freshwater biodiversity adaptation. The Network also provides a focus for synthesis, communication and distribution of knowledge, experience, data resources and information.

Given that climate adaptation research raises new and challenging areas of work, this NARP focuses on learning-by-doing, with ongoing assessment of success/failure and a redirection of research based on these assessments. This section also provides a brief overview of the resourcing issues – both financial and human - that are likely to arise in the implementation of this NARP.

6.1 Research principles

6.1.1 Emphasis on local/regional scale 'bottom-up' approaches

Adaptation to climate change is fundamentally different from the underlying physical climate science and to the impact studies derived from that science. Practical adaptation in the field must be driven by the key sector groups, peak bodies, natural resource-based industries, local government, local communities and regions. In this NARP, groups able to contribute to adaptation include those that traditionally have been concerned with freshwater biodiversity conservation, but also an increasing number of groups from other sectors, such as water management, agriculture, forestry, mining and tourism, whose activities affect or depend on freshwater biodiversity.

A bottom-up approach to defining research needs and conducting research, in which end-user engagement is a specific focus of the research process, brings a broad community of both practitioners and scholars to bear on the climate adaptation problem. Some of these stakeholders may not have previously been involved in climate change research or with biodiversity conservation – water engineers, farmers, natural resource managers, regional planners, political scientists, lawyers, economists, sociologists, geographers, national park managers, foresters, conservation biologists, agricultural scientists, and so on. This approach increases both research effort and commitment to the research being performed and to its findings. In addition, it enables research scientists to understand better how to communicate research findings to potential users.

Many of the researchers, communities, and organizations interested in freshwater biodiversity conservation operate at regional or local levels, and would rely on knowledge focused on the species/genetic, ecosystem/community and landscape scales described in the previous sections to implement adaptation actions. Nevertheless, policy development at the larger regional scales (often across state borders) and at the national level is central to dealing with climate adaptation, and research questions aimed at these scales must be addressed. Both an upwards and downwards exchange of information is required to deliver effective adaptation.

6.1.2 Participatory research and adaptive learning

To generate the new knowledge needed to support adaptation action, the various stakeholders concerned with freshwater biodiversity conservation need to be involved in the research itself, from the formulation of the questions to be addressed, to the implementation of the results.

To ensure that research outputs are capable of ready and prompt up-take, it is essential that the needs of end-users be taken into account early in the design of adaptation research. Understanding the context and manner in which research will be used will help determine what modes of dissemination and uptake are most appropriate. Few end-users access research through traditional academic publications, preferring instead toolkits, presentations and workshops, interactive web-based material, CDs and DVDs and so on (although traditional academic publication is still very important).

A critical starting point in deciding how best to disseminate information and promote uptake is to identify relevant primary and secondary end-users for particular research priorities. Some work, for example, may directly inform the operational decisions of biodiversity conservation agencies and organisations. Other research, however, may directly address policy-makers at regional and national levels, informing their choice of policy intervention.

6.1.3 Dealing with uncertainty

The approach to adaptation research described above, with its emphasis on experts in biodiversity conservation, freshwater ecology and institutional design, is in strong contrast to climate impact research, which is often driven by climate scenarios and thus begins with change in the physical climate system. The bottom-up approach thus often demands new and different types of climate information, complementary to knowledge of potential impacts.

The risk management approach to adaptation drives the need for new types of climate information and other global environmental change. Climate risks are assessed in the context of multiple other risks to an ecosystem, landscape, region, or the continent. The types of knowledge needed to evaluate the risks of a changing climate are determined by the practitioners themselves, and are created by collaborative research involving the stakeholders, ecologists, appropriate social scientists and economists.

6.1.4 Building on national and international research

The approach to adaptation research described above (sections 6.1.1 and 6.1.2) carries an emphasis on engagement with non-scientist stakeholders, sometimes at the national level but often at the local or regional level. This is an essential aspect of ensuring that research will meet the needs of end-users. However, Australian science and knowledge can build on that developed overseas and can benefit from interaction with and insights from overseas research and scientists. Similarly, Australian researchers can advise on overseas adaptation responses and thus contribute to global responses to climate change as a global challenge.

6.2 Financial resources

Rather than developing a comprehensive and detailed budget to underpin the implementation of this NARP, this section sets out the various types of funding that could contribute to a broadly-based and locally/regionally sensitive implementation strategy.

Seed funding will be provided under the Commonwealth Department of Climate Change and Energy Efficiency Adaptation Research Grants Program, in response to proposals aimed at addressing the research priorities described in the NARP. However, to fully address the key research questions described above, it will be necessary to access additional funding sources. Particularly relevant to the National Climate Change Adaptation Research Plan for Freshwater Biodiversity are key government organisations such as the Department of Sustainability, Environment, Water, Popoulation and Communities, universities and research institutions, and state and territory agencies entrusted with conservation and natural resource management. Likewise, collaborative research with local government can attract local government co-funding. Furthermore, the growing private conservation sector and some NGOs have a strong interest in this research and may contribute to the research effort both financially and through in-kind support such as knowledge exchange.

Funding and resources may also be accessed through Cooperative Research Centres with research agendas relevant to climate change adaptation research in line with this NARP. The CSIRO Adaptation Flagship is also a major contributor to freshwater biodiversity adaptation research.

For university-based researchers, the Australian Research Council (ARC) grants program is important for many researchers and research institutions that seek additional support. Relevant grants offered by the ARC include Discovery Projects; Future and Laureate Fellowships; Linkage Infrastructure, Equipment and Facilities; and Linkage Projects. The last of these supports collaborative research and development projects between universities and other stakeholders groups, which may be especially relevant for adaptation research.

For adaptation studies with a focus on impacts on Indigenous cultural heritage, funding may be obtained through the Indigenous Heritage Program. Research undertaken by Indigenous students or early career scientists may also attract funding from the ARC Discovery Indigenous Researchers Development grant program.

In summary, a wide range of funding sources is possible, with the potential to give a strong multiplier effect to the core NCCARF funding.

6.3 Research capacity

A number of research planning, funding and implementation activities are already responding to biodiversity issues in general, and climate change issues in particular. The Commonwealth Environment Research Facilities (CERF) Program co-funds multi-institutional environmental research across environmental, economic and social disciplines to support environmental policy development and decision-making, including responding to effects of climate change. A number of CRCs are also engaged in research on climate change impacts and adaptation. Many university-led projects are funded through State, Territory and Commonwealth governments, the Australian Research Council (ARC), and various Research and Development Corporations that are targeting either the impacts or responses to climate change.

Government agencies are working together to develop targeted outcome-based research programs to address climate change in freshwater systems. On the implementation side, research institutions and programs across Australia are also already responding to the widespread, high-risk impacts that climate change will bring and are focusing on targeted research, which is of relevance to this NARP. CSIRO has focused existing and new research on climate change impacts and adaptation in a new Climate Adaptation Flagship, including a specific theme on *Managing species and natural ecosystems*. CSIRO's climate-related research is often undertaken in collaboration with key agencies such as the Bureau of Meteorology. Various universities are establishing climate change-oriented units or centres that similarly signal a new focus on these issues.

All these activities signal an increasing focus and capacity in Australia on research to support climate change adaptation, either directly or indirectly. The vast majority of this work is biological and physical, with relatively little focus on social science or adaptation by people. A consequence of this rapid expansion in research effort is the potential for duplication of both research efforts and capability development. Ensuring clear links among these multiple processes and activities will provide for greater effectiveness in delivering priority information and efficiency in the allocation of limited research funds.

The Freshwater Biodiversity NARP has identified the most important adaptation research to assist the management of freshwater biodiversity in a changing climate and will thereby seek to align research priorities relevant to climate change adaptation across all or most of the above initiatives. The National Adaptation Research Network for Freshwater Biodiversity plays a significant role in the implementation of the NARP through information dissemination and collaboration among its growing membership, which includes researchers, state and federal government biodiversity and climate change units, major NGOs and other stakeholder groups.

Finally, there is scope to enhance Australian adaptation research capacity through international collaboration, as has happened with climate change science. Research institutes and programs focusing on climate adaptation have been established in many parts of the world – the Tyndall Centre in the UK and the Potsdam Institute for Climate Impact Research in Germany are two prominent examples. Interaction with such institutes and the international community more broadly ensures that Australian adaptation research maintains its position at the forefront of the international effort.

Further information about research capacity available and needed for this NARP will be available in its Implementation Plan.

6.4 Information, knowledge and tools transfer

Successful adaptation will require both sound research and the communication of research findings to end-user stakeholders who need them. Research uptake by stakeholders will be encouraged by the bottom-up, integrated approach outlined in Section 6.1, and will be supported by the research activities outlined in Section 4.6. This matter remains a significant challenge and will be a major component of future reviews of this NARP (see section 6.5).

6.5 Review of the National Climate Change Adaptation Research Plan

The FWB NARP provides a strategic framework for priority research for a five to seven year period. During this period, which will involve a rapidly changing research, knowledge and policy environment, the NARP will be reviewed to assess its effectiveness. Information about the process of the review will be available on the NCCARF website www.nccarf.edu.au.

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- The Centre for Tropical Biodiversity and Climate Change: http://www.jcu.edu.au/ctbcc
- Convention on Biological Diversity adaptation program: http://adaptation.biodiv.org
- CSIRO Adaptation Flagship: http://www.csiro.au/org/ClimateAdaptationFlagship.html
- Macquarie University Climate Risk CORE: http://www.climatecore.mq.edu.au
- NCCARF: http://nccarf.edu.au

List of Abbreviations and Acronyms

ARC	Australian Research Council
BVA	Biodiversity Vulnerability Assessment
CERF	Commonwealth Environment Research Facilities Programme
COAG	Council of Australian Governments
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCC	Department of Climate Change
DEWHA	Commonwealth Department of Environment, Water, Heritage and the Arts
DSEWPaC	Department of Sustainability, Environment, Water Population and Communities
GCM	General Circulation (or Global Climate) Model
IFD	Intensity-Frequency-Duration
IPCC	Intergovernmental Panel on Climate Change
NARP	National Climate Change Adaptation Research Plan
NCCARF	National Climate Change Adaptation Research Facility
NGO	Non-government Organisation

NLWRA	National Land and Water Resources Audit
NRM	National Resources Management
NWI	National Water Initiative

Appendix 1 Biodiversity Vulnerability Assessment (BVA)

Key messages and policy directions

The impacts of climate change on Australia's biodiversity are now discernible at the genetic, species, community and ecosystem levels across the continent and in our coastal seas. The threat to our biodiversity is increasing sharply through the 21st century and beyond due to growing impacts of climate change, the range of existing stressors on our biodiversity and the complex interactions between them.

A business-as-usual approach to biodiversity conservation under a changing climate will fall short of meeting the challenge. A transformation is required in the way Australians think about biodiversity, its importance in the contemporary world, the threat presented by climate change, the strategies and tools needed to implement biodiversity conservation, the institutional arrangements that support these efforts, and the level of investment required to secure the biotic heritage of the continent.

The key messages coming out of the assessment, presented further on, comprise an integrated set of actions. The order is arbitrary; they are highly interdependent and of similar priority. Taken together, they define a powerful way forward towards effective policy and management responses to the threat to biodiversity from climate change. The task is urgent. All key messages should be well towards full implementation within two years. Most need to be ongoing.

Reform our management of biodiversity

We need to adapt the way we manage biodiversity to meet existing and new threats – some existing policy and management tools remain effective, others need a major rethink, and new approaches need to be developed in order to enhance the resilience of our ecosystems.

As we are moving rapidly into a no-analogue state for our biodiversity and ecosystems, there is a need to transform our policy and management approaches to deal with this enormous challenge. Climate change presents a 'double whammy' – affecting species, ecosystems and ecosystem processes directly, as well as exacerbating the impacts of other stressors. Many effective management approaches already exist; the challenge is to accelerate, reorient and refine them to deal with climate change as a new and interacting complex stressor. The National Reserve System, the pillar of current biodiversity conservation efforts, needs to be enhanced substantially and integrated with more effective off-reserve conservation. Acceleration of actions to control and reduce existing stressors on Australian ecosystems and species is essential to increase resilience. However, there is a limit to how far enhancing resilience will be effective. Novel ecosystems will emerge and a wide range of unforeseen and surprising phenomena and interactions will appear. A more robust, long-term approach is to facilitate the self-adaptation of ecosystems across multiple pathways of adaptation that spread risk across alternative possible climatic and socio-economic futures. Active adaptive management – backed by research, monitoring and evaluation – can be an effective tool to support self-adaptation of ecosystems. An especially promising approach is to develop integrated regional biodiversity response strategies, tailored for regional differences in environments, climate change impacts and socio-economic trends.

Strengthen the national commitment to conserve Australia's biodiversity

Climate change has radical implications for how we think about conservation. We need wide public discussion to agree on a new national vision for Australia's biodiversity, and on the resources and institutions needed to implement it.

If the high rate of species loss and ecosystem degradation in Australia is to be slowed and eventually reversed, a more innovative and significantly strengthened approach to biodiversity conservation is needed. To meet this challenge – particularly under a rapidly changing climate – perceptions of the importance of biodiversity conservation and its implementation, in both the public and private sectors, must change fundamentally. A national discourse is therefore required on the nature, goals and importance of biodiversity conservation, leading to a major rethink of conservation policy, governance frameworks, resources for conservation activities and implementation strategies. The discourse should build a much broader and deeper base of support across Australian society for biodiversity conservation, and for goals that are appropriate in a changing climate. In particular, biodiversity education, policy and management should be reoriented from maintaining historical species distributions and abundances towards: (i) maintaining well-functioning ecosystems of sometimes novel composition that continue to deliver ecosystem services; and (ii) maximising native species' and ecosystem diversity.

Invest in our life support system

We are pushing the limits of our natural life support system. Our environment has suffered low levels of capital reinvestment for decades. We must renew public and private investment in this capital.

There is as yet no widely accepted method – be it changes in natural capital, adjusted net savings or other indicators – to account for the impact of changes in Australia's biotic heritage due to human use. However, by any measure, Australia's natural capital has suffered from depletion and under-investment over the past two centuries. Climate change intensifies the need for an urgent and sustained increase in investment in the environment – in effect, in our own life support system. The challenge is to establish an enhanced, sustained and long-term resource base – from both public and private investment – for biodiversity conservation. In particular, significant new funding strongly focused towards on-ground biodiversity conservation work – carried out within an active adaptive management framework – is essential to enhance our adaptive capacity during a time of climate change. Monitoring the status of biodiversity is especially important, as without reliable, timely and rigorous information on changes in species and ecosystems, it is not possible to respond effectively to growing threats. An effective monitoring network would be best achieved via a national collaborative program with a commitment to ongoing, adequate resourcing.

Build innovative and flexible governance systems

Our current governance arrangements for conserving biodiversity are not designed to deal with the challenges of climate change. We need to build agile and innovative structures and approaches.

While primary responsibility for biodiversity conservation resides with each state and territory, over the past two decades many biodiversity conservation policies and approaches have been developed nationally through Commonwealth–state processes. There has also been a recent trend towards devolution of the delivery of NRM programs to the level of regional catchment management authorities and local landcare groups. Dealing with the climate change threat will place further demands on our governance system, with a need to move towards strengthening and reforming governance at the regional level, and towards more flexibility and coherence nationally. Building on the strengths of current arrangements, a next step is to explore the potential for innovation based on the principles of: (i) strengthening national leadership to underpin the reform agenda required; (ii) devolving responsibilities and resources to the most local, competent level, and building capacity at that level; (iii) facilitating a mix of interacting regional governance arrangements sensitive to local conditions; and (iv) facilitating new partnerships with other groups and organisations, for example, with Indigenous and business entities. In addition, improved policy integration across climate change, environment protection and commercial natural resource use is required nationally, including across jurisdictional boundaries.

Meet the mitigation challenge

Australia's biodiversity has only so much capacity to adapt to climate change, and we are approaching that limit. Therefore, strong emissions mitigation action globally and in Australia is vital – and this must be carried out in ways that deliver both adaptation and mitigation benefits.

There is a limit above which biodiversity will become increasingly vulnerable to climate change even with the most effective adaptation measures possible. Global average temperature increases of 1.5 or 2.0°C above pre-industrial levels – and we are already committed to an increase of around 1.2 or 1.3°C – will likely lead to a massive loss of biodiversity worldwide. Thus, the mitigation issue is central to biodiversity conservation under climate change. To avoid an inevitable wave of extinctions in the second half of the century, deep cuts in global greenhouse gas emissions are required by 2020 at the latest. The more effectively the rate of climate change can be slowed and the sooner climate can be stabilised, the better are the prospects that biodiversity loss will be lessened. Societal responses to the mitigation challenge, however, could have significant negative consequences for biodiversity, over and above the effects of climate change itself. Examples include planting monocultures of fast-growing trees rather than establishing more complex ecosystems that both support more biodiversity and store more carbon, and inappropriate development of Australia's north in response to deteriorating climatic conditions in the south. However, with flexible, integrated approaches to mitigation and adaptation, many opportunities will arise for solutions that both deliver positive mitigation/adaptation outcomes and enhance biodiversity values.

Appendix 2 Terms used in this NARP

Adaptation: Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory, autonomous and planned adaptation.

Adaptive capacity: The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Connectivity: Landscape connectivity is the degree to which areas in a landscape are connected spatially, biologically and temporally in ways that facilitate or impede the movement of organisms between potential habitats. Landscape connectivity is thus a key factor in determining the capacity of species to move from less suitable conditions to more suitable conditions.

Maladaptation: Climate change adaptation initiatives that have negative or detrimental impacts elsewhere are termed maladaptations. This also includes adaptation activities that over time become less beneficial and more of a hindrance.

Perverse outcomes: Detrimental results of actions intended to yield beneficial outcomes. Perverse outcomes often result from actions applied to systems that are sufficiently complex or unknown that the results of the actions cannot be fully predicted.

Refugium - a refugium (refugia plural) is a region in which certain organisms persist during a period in which most of the original geographic range becomes uninhabitable because of climatic change. However, the term refugium may be used in other ways, particularly to mean a region to which species retract for short periods (i.e. for a number of years at the most) when large parts of their preferred habitats become uninhabitable because of drought or other effects. Yet another types of refugia comprise regions to which threatened species have retreated because of environmental changes set in train by European settlement.

Resilience: The widely accepted definition of resilience, originally derived from the ecological literature, is the capability of a system to experience shocks whilst retaining essentially the same function, structure, feedbacks and therefore identity. This so-called 'ecological' definition of resilience is relevant at various scales, including biodiversity, ecosystems, landscapes, and integrated natural resource management systems. It can also be applied to social systems.

Sensitivity: The degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g. a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g. damages caused by an increase in the frequency of coastal flooding due to sea level rise).

Transformation: Where change exceeds the adaptive capacity of a system, it may be appropriate to reduce the resilience of that system to facilitate transformation, for example of species composition and even ecological function. Transformation at one scale (e.g. change of species composition and even ecological function locally) may be necessary to enhance resilience at a broader scale (e.g. persistence of those species somewhere in Australia).

Vulnerability: The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.

Appendix 3 Research Prioritisation Matrix

The criteria listed below will guide the research planning process to set research priorities.

Essential

1. Severity of potential impact/ or degree of potential benefit

What is the severity of the potential impact to be addressed or benefit to be gained by the research? Potentially irreversible impacts and those that have a greater severity (in social, economic or environmental terms) will be awarded higher priority.

2. Immediacy of required intervention or response

Research will be prioritised according to the timeliness of the response needed. How immediate is the intervention or response needed to address the potential impact or create the benefit? Research that must begin now in order to inform timely responses will receive a higher priority than research that could be conducted at a later date and still enable a timely response.

3. Need to change current intervention and practicality of intervention

Is there a need to change the intervention used currently to address the potential impact being considered. If yes, what are the alternatives and how practical are these alternate interventions? Research that will contribute to practicable interventions or responses will be prioritised. Does research into the potential impact of the intervention being considered contribute to the knowledge base required to support decisions about these interventions?

Desirable

4. Potential for co-benefit

Will the research being considered produce any benefits beyond informing climate adaptation strategies?

5. Potential to address multiple, including cross-sectoral, issues

Will the research being considered address more than one issue, including cross-sectoral issues?

6. Equity considerations

Will research priorities recognise the special needs of particular groups in Australia?

	RESEARCH QUESTION	Essential			Desirable			Overall Priority Ranking
		Severity Or Benefit	Immediacy	Need to change intervention / Practicality	Potential co-benefits	Cross-sectoral relevance	Equity considerations	
	Goal 1: Incorporate climate change adaptation into management of freshwater species and ecosystems.							
1	Where are freshwater species and ecosystems currently at their climate limits?	**Medium** This helps inform adaptation planning.	**Medium** This is mainly concerned with vulnerability.	**Medium** This will help focus management investments.				**Medium**
2	How will freshwater species adapt and ecosystems change autonomously to climate change?	**Medium** This will help inform adaptation planning.	**Medium** This is mainly concerned with impacts.	**High** This will help overcome a key uncertainty.		**Yes** This question would inform other sectors.		**Medium**
3	How will climate change affect current freshwater biodiversity management effectiveness, and what changes will be required?	**High** This will improve current freshwater biodiversity management.	**High** This will generate information that can be immediately translated into current adaptation activities.	**High** This will help focus climate-related changes to management activities.		**Yes** Marine and terrestrial ecosystem management will also benefit.		**High**
4	How can climate change adaptation initiatives be developed for poorly understood species and ecosystems?	**High** There is very limited information about most freshwater ecosystems and this situation is unlikely to	**High** Management needs to be able to incorporate climate-related factors as soon as possible.	**Medium** Management needs to adopt analytical approaches able to generate sound proposals with limited data.		**Yes** All sectors could benefit; freshwater biodiversity could benefit from approaches developed for other sectors.		**High**

	RESEARCH QUESTION	Essential			Desirable			Overall Priority Ranking
		Severity Or Benefit	Immediacy	Need to change intervention / Practicality	Potential co-benefits	Cross-sectoral relevance	Equity considerations	
		change.						
5	What climate change adaptation initiatives are necessary to maintain freshwater ecosystem services?	**High** The delivery of ecosystem services is a key purpose for managing and conserving biodiversity.	**Medium** This will build on knowledge about freshwater ecosystem servicers and climate change impacts.	**High** Maintaining ecosystem services is vital for sustainability.	**Yes** This is specifically about gaining co-benefits.	**Yes** This is specifically about avoiding impacts of freshwater biodiversity from climate change adaptation.	**Yes**	**High**
6	What long-term observation systems are needed to evaluate the effectiveness of climate change adaptation initiatives for freshwater biodiversity?	**High** Long-term observational systems are now being developed. It is important to ensure they meet climate change adaptation needs.	**High** This is required to inform impending decisions.	**High** This will be useful for impending initiatives.		**Yes** This information will benefit other sectors.		**High**
7	How can flow-on effects from climate change impacts on other environmental conditions such as acid sulphate soils and sea level rise be managed.	**High** Existing stressors on freshwater biodiversity are likely to be affected by climate change impacts.	**High** Freshwater biodiversity is already being affected by external stressors.	**Medium** Reducing the impacts of external stressors is one of the most important ways to increase freshwater ecosystem resilience.		**Yes** Most external stressors are generated by other sectors.	**Yes**	**High**

	RESEARCH QUESTION	Essential			Desirable			Overall Priority Ranking
		Severity Or Benefit	Immediacy	Need to change intervention / Practicality	Potential co-benefits	Cross-sectoral relevance	Equity considerations	
	Goal 2: Identify climate change adaptation options for Australia's freshwater biodiversity refugia.							
8	How can the climate resilience of freshwater biodiversity refugia be increased?	**High** Refugia resilience to climate change impacts is a fundamental management objective.	**High** Increasing resilience is an ongoing long-term management goal.	**High** These initiatives would likely form the basis of future refugia management programs.		**Yes** Increasing resilience would involve managing impacts from other sectors.		**High**
9	What changes to Australia's conservation reserve system would improve protection of current and projected climate refugia and support connectivity for freshwater biodiversity?	**High** The reserve system is established to protect places of conservation significance.	**High** Early protection will better ensure protection as climate change impacts occur.	**High** The conservation reserve system's objectives are to protect places having high conservation significance, including refugia.		**Yes** Freshwater refugia also help conserve many species often classified as terrestrial, particularly during droughts.		**High**
	Goal 3: Understand climate change adaptation interactions between freshwater biodiversity and other sectors.							
10	How will climate change affect existing stressors to freshwater biodiversity, such as invasives and pollution?	**High** Most current stressors on freshwater biodiversity	**High** This knowledge needs to be included in climate change	**High** Managers of other sectors and biodiversity need to understand the	**Yes** This knowledge could help avoid	**Yes** This is specifically about understandin	**Yes** This will help improve understanding by stakeholders	**High**

	RESEARCH QUESTION	Essential			Desirable			Overall Priority Ranking
		Severity Or Benefit	Immediacy	Need to change intervention / Practicality	Potential co-benefits	Cross-sectoral relevance	Equity considerations	
		result from activities in other sectors.	adaptation plans for other sectors.	flow-impacts of climate change on other sectors to freshwater biodiversity.	maladaptation, perverse outcomes and inefficient investment.	g inter-sectoral climate change impacts.	having interests in differing sectors of the likely cross-effects of climate change.	
11	How will climate change adaptation and mitigation actions by other sectors affect freshwater biodiversity, such as increased use of surface or groundwater, introduction of new species or new agricultural areas?	**High** This will improve understanding about the implications of climate change adaptation by other sectors.	**High** This information will become important as other sectors develop and implement climate change impact responses.	**High** It will be very important to ensure climate change adaptation by other sectors does not detrimentally affect freshwater biodiversity.		**Yes** The question is specifically about understanding inter-sectoral climate change impacts.	**Yes** This will help ensure the interests of groups concerned with freshwater biodiversity can be included climate adaptation programs.	**High**
12	How can integrated climate change adaptation response plans be developed at the local, landscape and regional scales to improve the protection of freshwater biodiversity and other sectors to climate change impacts?	**High** This will help ensure adaptation options contribute to benefits in freshwater biodiversity and other sectors.	**High** Regional and NRM planning needs to integrate climate change as soon as possible.	**High** Climate change will increase the need to develop integrated regional and catchment plans and to integrate climate change adaptation in existing plans.	**Yes** This knowledge could help avoid maladaptation, perverse outcomes and inefficient investment.	**Yes** The question is specifically about developing synergistic adaptation responses that involve many sectors.	**Yes** This will support development of climate change adaptation initiatives that benefit several sectors and their interest groups.	**High**
13	How can climate change vulnerability and adaptation links between terrestrial, marine and freshwater biodiversity be identified and managed?	**High** This will support development of integrated biodiversity	**High** This needs to be concurrently with separate vulnerability and adaptation	**Medium** Current biodiversity planning seeks to integrate in this manner.		**Yes** This will support development of climate change		**Medium**

	RESEARCH QUESTION	Essential			Desirable			Overall Priority Ranking
		Severity Or Benefit	Immediacy	Need to change intervention / Practicality	Potential co-benefits	Cross-sectoral relevance	Equity considerations	
		vulnerability assessments and adaptation plans.	work.			adaptation initiatives that benefit several sectors.		
	Goal 4: Understand the role of national environmental policies in protecting freshwater biodiversity under changed climate conditions.							
14	How will climate change affect existing national conservation goals, policies and programs for freshwater biodiversity?	**High** Conservation goals form the basis for public investment in biodiversity conservation.	**High** Conservation goals undergo ongoing review.	**High** Conservation goals need to relate to community views and be informed by the best possible expert knowledge.		**Yes** Ensuring conservation goals are relevant and effective benefits many sectors.		**High**
15	What frameworks will provide guidance for climate change adaptation in different regions of Australia, including the semi-arid zone?	**Medium** A framework will support investment decisions.	**Medium** A framework would be developed as research produces information about differing regions.	**High** Frameworks for conservation investment decisions need to include climate change.		**Yes** Conservation investment decisions need to take account of other decisions.		**Medium**
16	What management initiatives are required to address the social and economic consequences of climate change impacts on freshwater biodiversity?	**High** Decisions about biodiversity management need to take account of	**High** Management of social or economic consequences needs to be integrated with	**High** Freshwater biodiversity management needs to take account of all factors.		**Yes** This is about managing inter-sectoral climate change impacts.	**Yes**	**High**

	RESEARCH QUESTION	Essential			Desirable			Overall
		Severity Or Benefit	Immediacy	Need to change intervention / Practicality	Potential co-benefits	Cross-sectoral relevance	Equity considerations	Priority Ranking
		social and economic consequences.	the original decision process.					