

Identifying low risk climate change adaptation in catchment management while avoiding unintended consequences

Anna Lukasiewicz, C. Max Finlayson,
Jamie Pittock



FINAL REPORT: IDENTIFYING LOW RISK CLIMATE CHANGE ADAPTATION

Identifying low risk climate change adaptation in catchment management while avoiding unintended consequences

Charles Sturt University

AUTHORS

A Lukaszewicz (Charles Sturt University)

CM Finlayson (Charles Sturt University)

J Pittock (Australian National University)



Published by the National Climate Change Adaptation Research Facility

ISBN 978-1-921609-93-0 NCCARF Publication 22/13

© 2013 National Climate Change Adaptation Research Facility

This work is copyright. Apart from any use as permitted under the Copyright Act 1968, no part may be reproduced by any process without prior written permission from the copyright holder.

Please cite this report as:

Lukasiewicz, A, Finlayson, CM, Pittock, J 2013 *Identifying low risk climate change adaptation in catchment management while avoiding unintended consequences*, National Climate Change Adaptation Research Facility, Gold Coast, pp.103.

Acknowledgement

This work was carried out with financial support from the Australian Government (Department of Climate Change and Energy Efficiency) and the National Climate Change Adaptation Research Facility.

The role of NCCARF is to lead the research community in a national interdisciplinary effort to generate the information needed by decision makers in government, business and in vulnerable sectors and communities to manage the risk of climate change impacts.

We are very grateful to all our key informants in catchments, as well as the New South Wales and Victorian state governments who willingly gave us their time and their knowledge of the issues. We are also grateful for the support of the Murray, Lachlan and Goulburn Broken CMAs for their dedication and ongoing support of this project. We especially would like to thank Trish Bowen (Murray CMA), Fin Martin and Joanne Lenehan (Lachlan CMA), and Pat Feehan and Wayne Tennant (Goulburn Broken CMA), who acted as key facilitators in our partnership with the CMAs and were always on hand to answer questions and provide advice.

Special thanks also go to all the workshop participants who came together for the Technical Workshop in May 2012 and the CMA workshop in August 2012 to lend their expertise and knowledge.

Disclaimer

The views expressed herein are not necessarily the views of the Commonwealth or NCCARF, and neither the Commonwealth nor NCCARF accept responsibility for information or advice contained herein.

Cover image © Doug Beckers, Flickr Creative Commons

Contents

LIST OF ABBREVIATIONS.....	7
GLOSSARY	8
ABSTRACT	1
EXECUTIVE SUMMARY	2
1. LOW-RISK ADAPTATION TO CLIMATE CHANGE	5
1.1 Outcomes	5
1.2 Methods.....	6
1.2.1 Literature review	6
1.2.2 Stakeholder workshops	6
1.2.3 Semi-structured interviews with key stakeholders.....	7
1.3 Limitations	9
1.4 Further research	9
1.4.1 Detailed pictures of climate change scenarios	9
1.4.2 Standardisation of criteria in relation to climate change adaptation.....	9
1.4.3 Greater availability of quantitative data	10
1.5 Reports produced by this project	10
2. ADAPTATION, MALADAPTATION AND MITIGATION: KEY CONCEPTS AND DEFINITIONS.....	11
2.1 Explanation of key concepts	11
2.1.1 Adaptation	11
2.1.2 Adaptive capacity	11
2.1.3 Freshwater resources and ecosystems	11
2.1.4 Maladaptation	11
2.1.5 Mitigation	12
2.1.6 Resilience.....	14
2.1.7 Vulnerability	14
2.2 The need for an integrated approach.....	14
2.3 What constitutes climate change adaptation?	15
2.4 Constraints to adaptation.....	16
3. CLIMATE CHANGE AND ADAPTATION IN THE MURRAY-DARLING BASIN	17
3.1 The current environmental condition of the MDB	17
3.2 Climate change projections.....	18
3.3 Climate change interactions with non-climate stressors.....	19

4.	INTRODUCTION TO THE CATCHMENTS	20
4.1	Murray Catchment	21
4.1.1	Climate change impacts and projections.....	22
4.1.2	CMA response to climate change	23
4.1.3	Freshwater management	23
4.2	Lachlan Catchment.....	23
4.2.1	Climate change impacts and projections.....	24
4.2.2	CMA response to climate change	24
4.2.3	Freshwater management.....	25
4.3	The Goulburn Broken Catchment.....	26
4.3.1	Climate change impacts and projections.....	26
4.3.2	CMA response to climate change	27
4.3.3	Freshwater Management.....	28
4.4	Summary	28
5.	AN ECOSYSTEM-BASED APPROACH TO CLIMATE CHANGE ADAPTATION.....	30
5.1	Environmental flows.....	31
5.2	Environmental works and measures	32
5.3	Thermal pollution control.....	33
5.4	Restoration of riparian vegetation	34
5.5	Freshwater habitat connectivity.....	35
5.6	Conservation of more resilient habitats	36
5.7	Conservation of gaining reaches.....	37
5.8	Geomorphic restoration	38
5.9	Management of exotic species.....	39
6.	THE CCA CATCHMENT ASSESSMENT FRAMEWORK.....	40
6.1	Catchment relevance	40
6.2	Climate change adaptation benefit.....	41
6.2.1	Discussion of adaptation benefits	43
6.3	Adaptation effectiveness under different climate change scenarios	44
6.3.1	Discussion of option effectiveness under different climate change projections.....	46
6.4	Potential for maladaptation	47
6.4.1	Discussion of maladaptation potential.....	50
6.5	Ecosystem services benefits.....	52

6.5.1	Discussion of ecosystem services	56
	Provisioning services	56
	Regulating services.....	56
	Supporting services.....	57
	Cultural services	58
6.6	Constraints to implementation	58
6.6.1	Discussion of adaptation option constraint.....	60
	Physical	60
	Financial	60
	Social	60
	Institutional.....	61
6.7	Socio-economic outcomes.....	62
6.7.1	Provision of environmental flows	64
6.7.2	Environmental works and measures	65
6.7.3	Thermal pollution control	66
6.7.4	Restoration of riparian vegetation	66
6.7.5	Freshwater habitat connectivity	67
6.7.6	Conservation of more resilient habitats	68
6.7.7	Management of exotic species	68
6.8	Risk assessment	69
6.8.1	Discussion of risks of failure	72
6.9	Catchment assessment conclusion.....	72
7.	KEY LESSONS FOR ADAPTATION	75
7.1	Adopting an 'ecosystem-based approach' to climate change adaptation	75
7.2	Implementing a suite of complementary measures	76
7.3	Addressing institutional complexity	77
7.4	Considering the triple-bottom line	78
7.5	Implementing adaptive management	78
7.6	The CCA Catchment Assessment Framework.....	79
7.7	Limitations	80
7.8	Conclusion.....	80
	REFERENCES	81
	APPENDIX 1: CCA CATCHMENT ASSESSMENT FRAMEWORKS	90

List of figures

Figure 1: Location of the three catchments within the Basin.....	21
Figure 2: The Murray Catchment	22
Figure 3: The Lachlan Catchment	24
Figure 4: The Goulburn Broken Catchment.....	26

List of tables

Table 1: Interview details	8
Table 2: Five types of maladaptation.....	12
Table 3: Potential issues with maladaptation in sequestering carbon	13
Table 4: Summary of catchment climate change impacts and policy responses	29
Table 5: Three pillars of protected areas for climate change mitigation and adaptation	30
Table 6: Catchment relevance of each measure	40
Table 7: CCA potential of each option in the three catchments	42
Table 8: Effectiveness of various CCA options under different climate change projections	45
Table 9: Maladaptation potential of the CCA options.....	49
Table 10: Ecosystem services of the nine options.....	54
Table 11: Constraints to implementation of the nine CCA options.....	59
Table 12: Summary of socio-economic impacts in the three catchments	63
Table 13: Risk assessment matrix	70
Table 14: Explanation of risk consequences	70
Table 15: Explanation of risk likelihood	70
Table 16: Risk assessment of the different CCA adaptation options	71
Table 17: The Murray CCA CAF	90
Table 18: The Lachlan CCA CAF.....	91
Table 19: The Goulburn Broken CCA CAF.....	92

LIST OF ABBREVIATIONS

BOM	Bureau of Meteorology
CAP	Catchment Action Plan (NSW)
CCA CAF	Climate Change Adaptation Catchment Assessment Framework
CMA	Catchment Management Authority (NSW and Victoria)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CWP	cold water pollution
DPI	Department for Primary Industries (NSW)
DSE	Department of Sustainability and Environment
EWM	Environmental Works and Measures
GB	Goulburn Broken
IPCC	International Panel on Climate Change
IUCN	International Union for Conservation of Nature
KP Works	Koondrook-Perricoota Works
MDB	Murray-Darling Basin
MDBA	Murray-Darling Basin Authority
NRM	natural resource management
NSW	New South Wales
NVIRP	Northern Victoria Irrigation Renewal Project
NWC	National Water Commission
OEH	Office of Environment and Heritage
PVP	Property Vegetation Plan
RCS	Regional Catchment Strategy (VIC)
SEWPAC	Department of Sustainability, Environment, Water, Population and Communities
VIC	Victoria

GLOSSARY

Diversions	Water taken from the river system or storage for consumptive purposes like irrigation or town water supply
Gaining reach	Where groundwater flows into a river channel
Groundwater	Water stored underground in pores, crevices or natural underground aquifers
Icon sites	Significant wetlands within the basin chosen to receive environmental water
Inflows	Large amounts of water moving into the river system
Losing reach	Where water in a river channel flows into a groundwater system
Outflows	Large amounts of water moving out of the river system
Refugia	Areas where special environmental circumstances have enabled a species, or an ecological community, to survive despite hostile conditions in surrounding areas
Runoff	Rainfall that does not seep into the ground or evaporate but runs along the surface and pools in low-lying areas and rivers.
Surface water	Water that collects on the ground from rainfall, found in rivers, streams, lakes and wetlands
Tributaries	A creek, stream or river flowing into a larger river or lake
Water yield	Runoff and groundwater available for use

ABSTRACT

Inherent in every adaptation measure are risks, costs and benefits. A challenge for decision-makers is how to choose adaptations that reduce risks from climate change impacts and provide overwhelmingly beneficial outcomes. This project focused on three catchments in the Murray-Darling Basin to test a method for more integrative climate change adaptation that increased resilience and avoided maladaptation. Water management under the highly variable Murray-Darling Basin climate has lessons and broad implications for climate policies, especially as some of the proposed climate change adaptation measures for ecosystems and water resources are overly narrow or maladaptive, and have a high risk of institutional failure.

We brought together a range of experts and Catchment Management Authority (CMA) representatives from the Goulburn-Broken, Lachlan and NSW Murray catchments to synthesise and integrate the risks, costs and benefits of climate change adaptation measures and assess the extent to which they may represent maladaptation or contribute to adaptation and resilience.

Specific methods included a literature review; a three-day technical workshop with representatives from the three CMAs as well as technical experts from academic institutions and government departments; three stakeholder workshops with the CMAs; and semi-structured interviews with 20 key stakeholder representatives in each case study. Limitations of this approach, mainly due to timing and financial constraints, included small sample sizes for the interviews, a CMA-only focus, reliance on expert opinion and limited opportunity to further test the results.

By working with the CMAs, we:

- showed how systemic climate change adaptation planning can better consider risks, costs and benefits to inform choice of measures
- produced research data on climate change adaptation options in specific catchments in southern Australia
- identified current stakeholder understanding of the complex issue of climate change adaptation at a catchment level
- confirmed the usefulness of an 'ecosystem-based approach' for climate change adaptation
- developed a 'CCA Catchment Assessment Framework' as a tool for regional management bodies in southern Australia to assess climate change adaptation.

The key lessons that emerged from this research are presented below. First, there are many activities underway that, if extended and linked, would comprise a substantial ecosystem-based approach to adaptation. It is notable that many of these activities had not previously been considered in an adaptation context. Second, the research confirmed the need to look at a suite of complementary actions that spread risk rather than investing in one or two perceived best actions. Third, the adoption of an ecosystem-based approach is constrained by institutional complexity and socio-economic considerations that should be included in assessments of climate change adaptation. Finally, adaptive management provides a basis for the implementation of an ecosystem-based approach to climate change adaptation.

EXECUTIVE SUMMARY

Water management under the highly variable climate in the Murray-Darling Basin has lessons and broad implications for adaptation policies. In particular, some climate change adaptation measures proposed for ecosystems and water resources in southern Australia are maladaptive, or involve a high level of risk of overly narrow adaptation and risk of institutional failure.

In this project, we brought together a range of experts and Catchment Management Authority (CMA) representatives to synthesise and integrate the risks, costs and benefits of climate change adaptation measures and assess the extent to which they represent maladaptation or may contribute to adaptation and resilience. The specific objectives of the project were to:

1. conduct detailed qualitative and quantitative assessments of the risks, costs and benefits of freshwater ecosystems adaptation options in collaboration with technical experts, CMAs and other key stakeholders
2. identify a framework for intervention measures for each catchment that best spread risk and increase freshwater ecosystems resilience to climate change
3. synthesise overarching lessons for adaption that would apply to southern Australian rivers.

In order to address the objectives, we developed a Climate Change Adaptation Catchment Assessment Framework (CCA CAF), which provides a holistic assessment of natural resource management (NRM) actions in the context of climate change adaptation. The Framework consists of six sections: catchment relevance; climate change adaptation benefit (including effectiveness under different climate change scenarios and the potential for maladaptation); ecosystem services benefits; implementation constraints; socio-economic outcomes; and risk assessment.

This report consists of seven chapters. The first explains the project objectives, methodology, outputs and suggestions for further research. Three methods were utilised in this project: literature review, stakeholder workshops and semi-structured interviews. The literature review provided a summary of important concepts, an overview of the current condition of freshwater bodies and climate change projections for the MDB, a list of nine adaptation options applicable to southern catchments and an introduction to the three case study catchments. Four stakeholder workshops were conducted, along with 20 semi-structured interviews. An initial three-day technical workshop was convened early in the project to investigate the benefits, risks and costs of proposed adaptation options in the three catchments. The technical workshop was followed by three separate all-day CMA workshops where the CCA CAF was used to structure discussions about the nine NRM actions being assessed. In between the technical and CMA workshops, a total of 20 semi-structured interviews were conducted with key CMA stakeholders. The limitations of these methods included a small sample size, a CMA focus and reliance on expert opinion.

The second chapter looks at the key concepts and definitions necessary for a discussion of climate change adaptation in the field of water management. The key concepts include adaptation and adaptive capacity, freshwater resources and ecosystems, maladaptation, mitigation, resilience and vulnerability. Definitions are followed by a discussion of how these concepts interact, the types of adaptation strategies that can be applied to NRM and the barriers to adaptation.

Chapters 3 and 4 look at climate change in the MDB and the three catchments analysed by this project respectively. Chapter 3 details the current environmental condition of the MDB and lists some of the climate change projections relevant to

freshwater ecosystems. Chapter 4 introduces the Murray, Lachlan and Goulburn Broken catchments, discussing their freshwater ecosystems, projected climate change impacts, adaptation policies and strategies for freshwater ecosystem management.

Chapter 5 introduces and explains the ecosystem-based approach to climate change adaptation that is used in this project. This approach focuses on interventions to improve environmental health as a way of ameliorating climate change impacts. Here, the nine NRM actions are introduced and defined: environmental flows; environmental works and measures; thermal pollution control; restoration of riparian vegetation; freshwater habitat connectivity; conservation of more resilient habitats; conservation of gaining reaches; geomorphic restoration; and the management of exotic species.

Chapter 6 introduces the CCA Catchment Assessment Framework and applies it to the three catchments. The results from the three catchments are discussed under each section and summarised in a series of tables. Assessments of the three catchments highlighted the high adaptation potential of six NRM actions:

- restoration of riparian vegetation
- freshwater habitat connectivity
- conservation of more resilient habitats
- conservation of gaining reaches
- geomorphic restoration
- management of exotic species.

The CCA CAF analysis provided support for further investment in these actions as part of an integrated regional NRM strategy that actively plans for climate change adaptation.

Chapter 7 summarises the key lessons for adaptation revealed through this project.

These lessons can be summarised under the following themes: implementation of the ecosystem-based approach at the catchment level; the need for a suite of complementary measures; addressing institutional complexity; consideration of the triple-bottom line and the implementation of adaptive management.

- The central tenet of the ecosystem-based approach is that it is expected that a healthy resilient ecosystem will be able to better withstand external shocks caused by climate change up to a certain point, and while NRM actions are often done in parallel, they have not been implemented explicitly as an integrated package for climate change adaptation.
- Complementary measures highlight the need to directing investment to a suite of actions, rather than selecting one or two 'best' actions for targeted investment. Institutional complexity constrains the full implementation of a system-wide approach through geographical, temporal and organisational boundaries and the limitations of the existing legal frameworks. This is exemplified by the need for environmental flows to be used as irrigation water and funding arrangements limiting what NRM actions can be undertaken on the ground.
- Financial incentives on their own, to landholders to implement freshwater biodiversity actions are insufficient if positive socio-economic-environmental consequences are to be realised

- Adaptive management is considered both essential in an ecosystem-based approach and difficult to implement in practice. From this research, two reasons were identified that explain this issue:: first, there is a lack of funding for monitoring programs to measure the effectiveness of undertaking actions; and second, there is very little social tolerance of NRM failures.

The chapter ends with an explanation of how the CCA Catchment Assessment Framework can assist decision-makers in incorporating the above-mentioned outcomes in their catchment decision-making.

1. LOW-RISK ADAPTATION TO CLIMATE CHANGE

Risks, costs and benefits are an inherent part of every adaptation measure. A challenge for decision-makers is how to choose adaptations that reduce risks from climate change impacts, are overwhelmingly beneficial, have minimal perverse impacts and are not so narrowly conceived that they fail with further climate change. This project focused on three catchments in the Murray-Darling Basin (MDB) as an example for testing a method for more integrative climate change adaptation that increases resilience and avoids maladaptation. The aim of the project was to provide guidance on increasing climate change resilience of freshwater ecosystems in the MDB by identifying the risks, costs and benefits of a range of options, and to identify a suite of measures to avoid overly-narrow and high risk climate change adaptation, or maladaptation. The project focussed on freshwater ecosystems as these are 'hot spots' of biodiversity and likely to be adversely affected by climate change (Sheldon et al. 2010). In particular, the project sought to:

1. conduct detailed qualitative and quantitative assessment of the risks, costs and benefits of freshwater ecosystems mitigation and adaptation options in collaboration with technical experts, Catchment Management Authorities (CMAs) and other key stakeholders
2. identify a framework for intervention measures for each catchment that can best spread the risk and increase the resilience of freshwater ecosystems to climate change
3. synthesise over-arching lessons for adaption for southern Australian rivers.

While the project initially sought to focus on both mitigation and adaptation measures, the former were largely excluded from subsequent assessments as there were few examples of climate change mitigation measures at catchment scale.

In meeting these objectives, additional information was provided by NCCARF as the results from relevant projects became available, and was integrated into the framework and synthesis. A key component of the work involved communication with relevant management institutions and other stakeholders to ensure a high level of information exchange.

1.1 Outcomes

By working with the Murray, Lachlan, and Goulburn Broken CMAs, the research team:

- showed how systemic climate change adaptation planning can better consider risks, costs and benefits to inform the choice of adaptation measures
- produced research data on climate change adaptation options in specific catchments in southern Australia
- identified current understanding by stakeholders of the complex issue of climate change adaptation at the catchment level
- confirmed the usefulness of an 'ecosystem-based approach' for climate change adaptation
- developed a 'CCA Catchment Assessment Framework' as a tool for regional management bodies in southern Australia to assess climate change adaptation.

1.2 Methods

A range of experts and representatives from the CMAs were brought together to document the risks, costs and benefits of climate change adaptation measures for freshwater systems, and to assess the extent to which they represented maladaptation or may contribute to adaptation and resilience. The Goulburn-Broken, Lachlan and NSW Murray catchments were used as case studies and the research undertaken in partnership with each of the CMAs in these catchments. Discussions with CMAs early in the project led to a focus on adaptation, rather than mitigation measures (as there were few catchment-based mitigation actions). The outcomes from the individual case studies were refined with stakeholders and reported in separate reports.

1.2.1 Literature review

This review involved distilling the academic literature that underpins climate change mitigation and adaptation, focusing on the latter. Concepts such as resilience, vulnerability, maladaptation and ecosystem-based approaches were also explored. Academic as well as grey literature from CMAs, state governments and other research institutions was used to define and describe a range of adaptation options that were applicable to specific catchments under different climate change scenarios. In line with resilience thinking, the ecological, social and economic dimensions of each adaptation option were explored using both qualitative and quantitative data.

The literature review provided a summary of important concepts, an overview of the current condition of freshwater bodies and climate change projections for the MDB, a list of nine adaptation options applicable to southern catchments and an introduction to the three case study catchments. The literature review is available as a separate report.

The literature review was augmented with a more specific review of information about climate change adaptation and the applicability of the adaptation options to the three catchments.

1.2.2 Stakeholder workshops

Initial ideas developed through the literature review were brought to the project partners and stakeholders through a series of workshops.

A three-day technical workshop was held from 7–9 May 2012 with the aim of thoroughly investigating the benefits, risks and costs of proposed adaptation options in the three catchments. There were 23 participants, including representatives from CMAs and government agencies as well as experts from academic institutions, government departments and non-government organisations.

At the end of the workshop, the initial list of adaptation options was expanded and clarified. Grey literature was also sourced from the CMA representatives to assist with the preparation of individual case study reports.

The technical workshop was followed by separate workshops with each of the CMAs. These were structured according to a background document that explained the CCA Catchment Assessment Framework (originally referred to as a Catchment Assessment Table). The CCA CAF promoted a discussion-based approach for CMAs to consider an ecosystem-based approach to climate change adaptation that systematically assessed the adaptation potential of various natural resource management actions. All three workshops followed the same format. The nine options were introduced and described, and then each section of the CAF was introduced, featuring some preliminary results gleaned from the literature review, the Technical Workshop and semi-structured interviews. Each section was discussed individually, facilitated by the research team.

The main discussion output from each section was the completion of the relevant table. Workshops were held in the relevant CMA office and lasted around six hours, excluding the lunch break (roughly from 10 am until 5 pm). Workshop participants were chosen by a representative of the CMA – a water management project officer who expressed interest in taking part in our research during project development. The CMA representative invited participants who were responsible for the on-ground implementation of water-related natural resource management (NRM) activities (especially the nine activities assessed) as well CMA staff working on climate change adaptation.

Details of the three workshops were as follows:

CMA	Date	Location	No of participants
Murray	17/8/12	Albury	9
Goulburn Broken	20/8/12	Benalla	9
Lachlan	23/8/12	Grenfell	7

The usefulness of the CCA CAF process became apparent as discussions progressed (see sections 6.2.1, 6.3.1, 6.4.1, 6.5.1, 6.6.1, 6.7, and 6.8.1). All NSW CMAs are legally required to periodically review Catchment Action Plans (CAPs), which provide a strategic framework for NRM within the catchment. The CAPs incorporate government priorities, best available science and local community values. A key component of the CAPs is adaptation to climate change. Victorian CMAs are also required to periodically review their Regional Catchment Strategies (RCS), which provide a strategic framework for NRM within the catchment.

1.2.3 Semi-structured interviews with key stakeholders

The Technical Workshop was followed by a period of grey literature review and stakeholder interviews that explored the triple bottom line implications of the proposed climate change adaptation actions. Stakeholders included CMA representatives who dealt with Aboriginal Elders and landholder representatives as well as subject-matter experts and government water managers and policy makers.

The interviews were conducted in July and early August 2012, and were mainly carried out as phone interviews (lasting between 40 minutes and 1 hour each). Twenty people were interviewed. Initial interviewees were with the CMA representative in each catchment, who then suggested other potential interviewees, meaning that interviewee selection followed the snowballing method (deMarrais, 2004).

Most of the interview respondents were CMA project staff (from the Murray, Lachlan and Goulburn Broken catchments) responsible for the implementation of freshwater-related NRM actions. The CMA project staff also liaises with key stakeholder groups (landholders and Aboriginal communities). State government water managers from New South Wales and Victoria were interviewed to provide a state-level perspective on climate change adaptation, since CMAs are influenced by wider state responses to climate change. The people interviewed were familiar with the respective catchments. Similarly, water managers from Commonwealth-level water institutions were interviewed to gain a basin-level perspective on climate change adaptation.

Each interviewee initially was contacted by email, with an explanation of the project, and provided with two short documents explaining the approach and demonstrating an early version of the CCA Catchment Assessment Framework. During the CMA interview, questions followed the different sections of the CCA CAF. Questions for state

and Commonwealth-level interviewees were less structured and focused on climate change adaptation strategies.

Analysis of data from interviews tends to focus either on the language (discourse or narrative analyses) or the content of interviews (King and Horrocks 2010). This analysis focused on the content. The major activity of data analysis involved categorising data based on themes and topics. Some of these were inductive – that is, they became evident from interview responses – but most were deductive, organised by the nine adaptation options. The software package NVivo (Version 9) was used to facilitate data analysis as computer-assisted coding allows for more complex and detailed codes, which can lead to greater insights and make with-in case, cross-case and comparative analyses (Bazeley 2009). Interview respondent details are listed in Table 1.

Table 1: Interview details

Catchment	Position	Date
Murray	CMA – water projects officer 1	17/07/2012
	CMA – water projects officer 2	17/07/2012
	CMA – community liaison	17/07/2012
	CMA – indigenous liaison	27/07/2012
	NSW Office of Water	23/09/2012
	Office of Environment and Heritage	20/09/2012
	Landholder	26/07/2012
Goulburn Broken	CMA – water projects officer 1	2/07/2012
	CMA – climate change officer	5/07/2012
	CMA – Landcare Coordinator	13/07/2012
	Winton Wetlands contact	13/07/2012
	CMA – water projects officer 2	19/07/2012
	Department of Sustainability and the Environment	1/08/2012
	Goulburn Broken Greenhouse Alliance	5/07/2012
Lachlan	CMA – water projects officer 1	13/07/2012
	CMA – indigenous liaison	26/07/2012
	Office of Environment and Heritage	3/08/2012
	CMA – water projects officer 2	22/10/2012
Basin-wide	Murray-Darling Basin Authority	2/08/2012
	Department of Sustainability, Environment, Water, Population and Communities	21/07/2012

Information drawn from these interviews is mentioned throughout the report and attributed to people using the above categories (for example, Lachlan CMA

Respondent 1, DSE Respondent or Murray Landholder) in order to preserve the respondents' anonymity and confidentiality.

1.3 Limitations

In this project, we developed a framework for assessing climate change adaptation options and then used it to assess specific options within the Murray Catchment. Limitations of this study are mainly due to timing and financial constraints leading to:

- Small sample size
- CMA focus
- Reliance on expert opinion
- Need for further testing

The number of people interviewed was small, and all were either a government or CMA employee or someone working closely with the CMA. Time constraints did not allow us to conduct large-scale interviews, but we have included landholder and Aboriginal viewpoints through CMA liaison officers.

The tables summarised in the CCA CAF were completed through a participative and interactive CMA workshop. This means that they rely on the expert opinion of a relatively small number of people. In the workshop, we were both introducing the tables and asking for information to complete them. At times, the participants did not understand nuances within the tables (such as the idea of high opportunity costs in Table 9). The information provided through expert opinion needs to be correlated with empirical evidence, but this may not always be possible. For example, it is difficult to empirically establish the effectiveness of the nine options under different climate change scenarios without extensive modelling. In many ways, the tables contained in this report could be viewed as suggestions for further research.

1.4 Further research

During the course of this project, we came across some knowledge and data gaps that hampered or limited the assessment.

1.4.1 Detailed pictures of climate change scenarios

The CCA CAF aims to use existing, standardised measurements and climate change projections. We have relied on the CSIRO Sustainable Yields project for the MDB, as this was a basin-wide assessment of future water availability that used the same methods and records to produce three different future scenarios. However, the scenarios produced through these assessments did not paint a comprehensive picture of what each catchment would look like in terms of changes to freshwater-dependent habitats and participants had to rely on their subjective assessments. Therefore, we recommend that more detailed (yet standardised) climate change modelling should be undertaken at a catchment scale (across the MDB and Australia as a continent) if climate change adaptation is to be fully integrated into routine NRM planning and management at a catchment scale.

1.4.2 Standardisation of criteria in relation to climate change adaptation

We endeavoured to utilise existing criteria for each section of the CCA CAF. However, some of the criteria have not been tested for applicability to climate change adaptation. There is a lot of literature on ecosystem services and we utilised existing ecosystem services criteria developed through the Millennium Ecosystem Assessment (2005).

However, we did not have the time or resource to explore whether the criteria we used in Table 10 were the most appropriate (and comprehensive) in terms of assessing NRM activities in the context of climate change adaptation.

1.4.3 Greater availability of quantitative data

Some quantitative data (especially relating to fish) is available through academic and grey literature and has been included in this report, however further quantitative data (for example, regarding economic costs or vegetation regeneration) could have further illuminated the assessments. An already stated problem is that available data comes from individual studies and is therefore not standardised across catchments, making catchment comparisons difficult.

1.5 Reports produced by this project

Outputs that detail the research undertaken for this project are published as:

- Lukasiewicz, A, Pittock, J and Finlayson CM 2012, *A review of climate change adaptation concepts and measures for freshwater biodiversity*, Institute for Land, Water and Society, Albury.

A literature review summarising key concepts and explaining ten climate change adaptation actions aimed at freshwater biodiversity.

- Lukasiewicz, A, Finlayson CM and Pittock, J 2012, *Identifying low-risk adaptation: a case study of the Murray catchment*, Institute for Land, Water and Society, Albury.
- Lukasiewicz, A, Finlayson CM and Pittock, J 2012, *Identifying low-risk adaptation: a case study of the Lachlan catchment*, Institute for Land, Water and Society, Albury.
- Lukasiewicz, A, Finlayson CM and Pittock, J 2012, *Identifying low-risk adaptation: a case study of the Goulburn Broken catchment*, Institute for Land, Water and Society, Albury.

These reports, produced in partnership with the relevant CMAs, examine nine climate change adaptation actions at catchment-level using an advisory tool developed in this project: the Climate Change Adaptation Catchment Assessment Framework (CCA CAF).

- Lukasiewicz, A., Finlayson CM. and Pittock, J 2012. *Incorporating climate change adaptation into catchment management: A user guide*. Institute for Land, Water and Society, Albury, Australia.

This guide is aimed at catchment water managers, explaining the CCA CAF and outlining a step-by-step process for an assessment of climate change adaptation.

- Koehn, J and Bond, N 2012, *Review of the impact of climate change on fishes*, Arthur Rylah Institute, Heidelberg, Victoria.

A desktop analysis of climate change impacts on fish and the conservation possible from applying nine climate change adaptation options, focusing on the Goulburn Broken Catchment.

2. ADAPTATION, MALADAPTATION AND MITIGATION: KEY CONCEPTS AND DEFINITIONS

This chapter looks at the key concepts and definitions necessary for a discussion of climate change adaptation in the field of water management. Such a discussion is necessary because there is growing evidence that climate change policies themselves can produce substantial additional and negative impacts on freshwater resources and ecosystems (Pittock 2011). For instance, the mitigation of greenhouse gas emissions often relies on technologies that consume a lot of water or have significant adverse impact upon freshwater ecosystems. For example, subsidies for biofuel production may decrease emissions from greenhouse gases but greatly increase water consumption (Pittock 2011).

2.1 Explanation of key concepts

This chapter explains the key terms used throughout this report as they pertain to climate change. Concepts like resilience and vulnerability have multiple definitions in both social and biophysical disciplines. Similarly, resilience and adaptive capacity are described differently by some authors and used interchangeably by others. Because the literature is fragmented and confusing, the definitions provided here are broad and general.

2.1.1 Adaptation

Refers to the actions that people take in response to or in anticipation of projected or actual climate change (IPCC 2007c, p. 27). In human systems, this is ‘the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities’. In natural systems, ‘it is the process of adjustment to actual climate and its effects’ (IPCC 2012, p. 3).

2.1.2 Adaptive capacity

Referring to a biophysical system, it is the ability of a system to adjust to climate change, to take advantage of opportunities, or to cope with or moderate the consequences (Gitay et al. 2011). Many natural systems have limited adaptive capacity (IPCC 2007b). Referring to a social system, it describes the potential for adaptation (Eisenack and Stecker 2012). As a region, Australia is judged by the IPCC (2007b) to have ‘substantial adaptive capacity due to well developed economies and scientific and technical capabilities’, but the IPCC acknowledges that Australia also faces considerable constraints to implementing adaptation options. Hence, high adaptive capacity does not automatically translate into adaptation action.

2.1.3 Freshwater resources and ecosystems

These include the river systems – that is, the river channels, tributaries, anabranches, adjoining billabongs, wetlands, lakes, groundwater aquifers, swamps and floodplains. They also include the plant and animal species that are dependent on aquatic ecosystems. The water within the ecosystem becomes a resource when it is used consumptively, for irrigation, manufacture or drinking water supply. Both the quantity and quality of water are important.

2.1.4 Maladaptation

Refers to actions that seek to avoid or reduce vulnerability to climate change but end up increasing it in other systems, sectors or social groups (Barnett and O'Neill 2010). Maladaptation does not just refer to unsuccessful adaptation (which implies that an action did not have the desired effect), but to actions that may have had the desired

effect but also produced unintended consequences (Barnett et al. 2011). The types of maladaptation described in the literature are summarised in Table 2.

Table 2: Five types of maladaptation

Maladaptation type	Description
Increasing emissions	Adaptation is maladaptive if actions end up contributing to climate change – for example, the increased use of energy-intensive air conditioners in response to the health impacts of heatwaves.
Disproportionate burden on others	Adaptation actions are maladaptive if, in meeting the needs of one sector or group, they increase the vulnerability of those most at risk, such as minority groups or low-income households. Alternatively, the consequences of a maladaptive action could be shifted to another sector or group.
High opportunity costs	Approaches may be maladaptive if their economic, social, or environmental costs are higher relative to alternative actions.
Reducing incentive to adapt	If adaptation actions reduce incentives to adapt – for example, by encouraging unnecessary dependence on others, stimulating rent-seeking behaviour or penalising early actors – then such actions are maladaptive.
Path dependency	Large infrastructural developments commit capital and institutions to trajectories that are difficult to change in the future, thus decreasing flexibility to respond to unforeseen changes in climatic, environmental, economic and social conditions.
Increasing existing stressors	Adding further stress to already degraded ecosystems reduces their adaptive capacity to deal with climate change impacts. For example, actions like promoting plantations for carbon sequestration may lead to reduced water availability downstream, which may place further stress on already degraded water ecosystems

Source: Barnett and O'Neill (2010).

Climate change policies in Australia are an ‘ad hoc collection of discrete and conflicting measures’ (Pittock 2011). To illustrate the concept of maladaptation, Table 3 explores potential maladaptation with references to carbon sequestration (through afforestation) and the maladaptation types explained in

Table 2.

2.1.5 Mitigation

This describes any action to prevent, reduce or slow climate change (Tompkins and Adger 2003). This can be done by reducing greenhouse gas sources and emissions, or enhancing greenhouse gas sinks (Barnett et al. 2011).

Table 3: Potential issues with maladaptation in sequestering carbon

Issue	Explanation	Potential type of maladaptation
Fire and drought	Drier climates and increased fuel loads will promote fire, placing sequestered carbon in vegetation at risk. Bushfires also have negative effects on water quality.	Increasing emissions (if sequestered carbon burns in a bushfire)
CO ₂ fertilisation	Increases in atmospheric carbon dioxide will increase the growth rates of vegetation, unless offset by substantial reductions in rainfall and frequent drought. Vegetation will also become more drought tolerant. More efficient shallow-rooted vegetation may increase deep infiltration rates when soil moisture is high, contributing to salinity. On the other hand, deep-rooted and biodiverse vegetation should be able to make use of increased soil moisture in higher growth rates.	Potentially contributes to existing stressor (salinity) Increased growth of vegetation may be beneficial for biodiversity at the site but increase pressure on downstream biodiversity through increased water interception
Reduced water supply	Vegetation growth intercepts water in catchments. If there is a requirement to purchase water rights before plantations can be established, the cost of these water rights may partially or wholly counterbalance the financial benefits of selling carbon.	High opportunity costs if water rights are purchased on the market
Species selection	Large changes in climate may affect the choice of species to be planted or may send existing vegetation into decline. Key plant species may also need to be established in specific locations to anticipate the migration of animal species or other plants under climate change.	High opportunity costs if climate-induced migration does not follow projected patterns
Weeds and pests	Changing patterns of weed and pest invasion may also affect survival of key native species.	Potentially contributes to existing stressor (the further spread of weeds and pests) through the poor management of plantations for sequestering carbon or because weed species are used in plantations

Source: Based on Jones et al. (2007).

2.1.6 Resilience

Denotes ‘the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions’ (IPCC 2012, p. 3). Across many disciplines, building resilience into both human and ecological systems is thought to be the optimal way to deal with future surprises, or unknowable risks (Tompkins and Adger, 2003). It can be investigated at different levels: individual, community, organisation or ecosystem (Boon et al. 2012). However, resilience is a complex idea, as a resilient system is not necessarily a desirable one (Nelson 2010).

2.1.7 Vulnerability

Vulnerability is ‘the propensity or predisposition to be adversely affected’ (IPCC 2012, p. 3). It has both a social and a biophysical dimension. The biophysical dimension focuses on exposure to hazards in terms of damage that occurs (Gitay et al. 2011), while the social dimension is concerned with social risks and capacities to absorb pressure. There are three elements to vulnerability: exposure, sensitivity and adaptive capacity (Bates et al. 2010). These elements are usually attributed to biophysical systems, but can apply to social systems as well. Vulnerability is mediated by resilience (Williams et al. 2008).

2.2 The need for an integrated approach

Both mitigation and adaptation reduce the risks of climate change (Barnett et al. 2011). Mitigation reduces vulnerability to climate change by limiting the degree of exposure, while adaptation is about building resilience (Global Leadership for Climate Action 2009). Adaptation is necessary because some impacts of climate change are already inevitable. Mitigation is necessary because adaptation measures alone can only go so far to ensure that unacceptable impacts of climate change are avoided (Barnett et al. 2011). While effective mitigation must occur at a global level, most adaptation takes place at the local and national levels. While the benefits of mitigation are global, its costs and secondary benefits are local. However, both the costs and benefits of adaptation generally occur locally (IPCC 2007b). Specific adaptation measures may also have a long lead time. For example, it took 30 years for the London flood management system (on the Thames River) to become operational (Reeder et al. 2009).

In the Australian context, climate change mitigation includes cleaner energy, energy efficiency and land-use change measures (NWC 2012). Adaptation measures in Australia are still in the formative stage, and not as well developed as mitigation. A recent Productivity Commission report on climate change adaptation in Australia promoted the idea of ‘no-regret’ or ‘low-regret’ reforms that built adaptive capacity and helped deal with current climate variability and extreme weather events (Productivity Commission 2012). The focus for adaptation is on managing risk, because of uncertainty surrounding the frequency, intensity, location and timing of extreme weather events (Productivity Commission 2012). Approaches include (NWC, 2012):

- reducing exposure to the risks
- reducing vulnerability by increasing resilience to climate change impacts
- tolerating some adverse impacts while ensuring that the system as a whole continues to operate
- clearly allocating responsibility for managing climate change risks.

In the context of freshwater sources, mitigation and adaptation measures will impact on balancing the supply of and demand for water, costs of water-related infrastructure and services, as well as having impacts on the environment and the broader community (NWC 2012). Freshwater biodiversity can be significantly affected by actions (including mitigation and adaptation activities) in other sectors. Specifically, what happens in the primary industries, infrastructure, settlement development and use can potentially affect freshwater resources and ecosystems (Bates et al. 2010). Therefore, climate change adaptation policies must be integrated across different sectors and take account of ecological, economic and social factors, and work at different levels of governance (such as local, catchment and national) in order to avoid maladaptation.

2.3 What constitutes climate change adaptation?

In general, adaptation responses can either reduce vulnerability by insulating against harsh conditions, or increase resilience and/or adaptive capacity by modifying patterns of production and consumption to better suit the climate (Patt 2009). Adaptation requires flexible institutional and policy interventions across multiple sectors and jurisdictions (Dovers and Hezri 2010). According to the IPCC (2007b), adaptation responses can be:

- technological (e.g. dams and weirs)
- behavioural (e.g. altered food and recreational choices)
- managerial (e.g. promoting different farm practices)
- policy-based (e.g. planning and regulation).

Specific adaptation strategies often commented on in the climate change literature (Bates et al. 2010; Hulme 2005; Lindenmayer et al. 2010; Pittock et al. 2008) include:

- maintaining effective monitoring and adaptive management programs
- incorporating climate change into current management practices
- reducing the threats and impacts arising from climate adaptation initiatives in other sectors
- reducing/tackling non-climate stresses on freshwater resources and ecosystems
- protecting intact habitats that act as refugia¹ (including those designated as protected areas and those that are not)
- ensuring appropriate connectivity between freshwater ecosystems
- preserving genetic stock (including the relocation of endangered species and captive breeding programs)
- reducing emissions and ensuring carbon capture (while this is actually a mitigation strategy, it does 'buy time' for adaptation)
- preparing for major natural disturbances.

¹ A refuge is defined as a place of shelter, protection or safety; while refugia are 'areas where special environmental circumstances have enabled a species, or a community of species, to survive despite extinction in surrounding areas' (Belski and Williams 2012). Refugia thus protect biodiversity during extreme events like floods and droughts (Steffen 2009).

2.4 Constraints to adaptation

Climate change researchers often point to the lack of specific data at an appropriate scale (Aldous et al. 2011; IPCC 2007c). However, management decisions cannot always be delayed until adequate data are available. Ongoing decisions regarding climate change adaptation and freshwater biodiversity management are made despite the inherent uncertainty regarding climate change impacts. The measures described in this literature review are 'no regrets' or 'low regrets' (Pittock 2009), having minimum negative consequences and therefore being low risk.

Any adaptation measure undertaken will potentially face four types of constraint that must be addressed (Arnell and Charlton 2009):

- physical constraints – constrain performance of the adaptation option
- financial constraints – refer not only to absolute cost of the option but also to ability of the implementing organisation to fund the option
- socio-political constraints – reactions and attitudes of stakeholders, affected parties and pressure groups to each adaptation option
- institutional constraints – institutional factors within the implementing organisation, regulatory or market constraints for the option.

3. CLIMATE CHANGE AND ADAPTATION IN THE MURRAY-DARLING BASIN

Climate change is already affecting Australia through increasing atmospheric and oceanic temperatures, sea-level rise, increasing ocean acidity and the accelerated melting of snow and ice (CSIRO and Bureau of Meteorology 2007). The climate is already locked into a period of unavoidable change (Newton 2009), necessitating adaptation measures to deal with what is already happening and what is yet to come. Key impacts of climate change on freshwater biodiversity (especially under the dry scenarios) include (Jenkins et al. 2011):

- changes to frequency, severity and duration of flooding
- increased evaporation
- increased water temperatures
- increased bushfires
- declining water quality
- reduced irrigation supply
- increased erosion upstream
- falling groundwater tables.

Significant impacts can occur with relatively modest increases in temperature (Bates et al. 2010), and direct climate change impacts can have disproportionate effects. For example, the IPCC estimated that in south-western Australia, a 20% reduction in rainfall since the mid-twentieth century has been accompanied by almost a 50% reduction in runoff (IPCC 2007a). Increased temperatures in freshwater ecosystems may exceed the thermal tolerance of aquatic fauna (Davies 2010). Also, the reduction in rainfall combined with decreased flooding and rising temperatures can exacerbate the drying of rivers and wetlands, which already happens as a result of river regulation (Kingsford 2011).

3.1 *The current environmental condition of the MDB*

The MDB is one of the most significant basins in Australia in terms of its economic and social importance. It covers one-seventh of the Australian continent and incorporates multiple bioregions, Australia's three longest rivers – the Murray, Darling and Murrumbidgee Rivers – and is home to over 30 000 wetlands, 16 of which are designated as being of international importance under the Ramsar Convention (Commonwealth of Australia 2011a).

The basin is predominantly semi-arid, with variable rainfall and high evaporation, and a geomorphology that often results in saline groundwater (MacNally et al, 2011). It has already been significantly affected significantly by water diversions (Kingsford, 2000) and land clearing which have resulted in changes to water volumes and quality as well as consequent impacts on biodiversity (Pittock and Finlayson 2011). Signs of environmental degradation due to reduced water availability in the rivers as a consequence of both extreme climate conditions and poor management as described above include (Kingsford and Thomas, 2001):

- rising water tables
- increased soil and groundwater salinity
- decreased surface water quality

- algal blooms
- coastal area degradation
- the death of around 70% of floodplain forest trees (especially River Red Gums)
- the disappearance of half of the Australian birdlife
- declines in native fish stocks
- conversion of freshwater wetlands into acidified and salinised water bodies.

The degradation is most severe in the lower third of the Murray River (Scanlon 2006). The ecological state of the MDB was assessed in 2008 through the Sustainable River Audit that was conducted by the Murray-Darling Basin Commission, which found 13 out of 23 valleys in the Basin to be in 'very poor' health, while a further seven were in 'poor' health (MDBC 2008).

The regulation of rivers through diversions, barrages, locks and weirs has permanently changed river flows. It has reversed the natural pattern of flows, reducing the inundation of wetlands and the volume, frequency and duration of small and medium-sized floods, which are critical to triggering wildlife breeding cycles. The changes to river flows has led to significant declines in the abundance and breeding activities of birds and mammals, and native fish numbers are now only 10% of pre-European levels (Balcombe et al. 2011). This reduction is also the reason why the Murray mouth closed for the first time in 1981 (due to lack of water flows), and why constant dredging was required to keep it open during the 2002–10 drought (Government of South Australia 2012).

Climate change is likely to increase the frequency and severity of extreme events such as droughts and floods. In 2006 and 2007, water inflows into the river system were the lowest on record due to severe drought conditions (Adamson et al. 2009). This had a substantial impact on agricultural production. In the lower MDB, the rice industry collapsed, with production falling from 1.75 million tonnes in 2001 to 20 000 tonnes in 2008 and substantial decreases in wheat and irrigated cotton production, as well as the Commonwealth government spending an estimated \$3 billion on drought subsidies since 2001 (McAlpine et al. 2009). A permanent changed climatic state is expected to have similar ongoing detrimental impacts into the future which can only be minimised with more positive management interventions urgently implemented.

Subsequent heavy rainfall in December 2010 led to widespread flooding throughout Queensland as well as northern and central-western NSW (BOM 2011). The flooding caused significant environmental damage through the drowning of ground dwelling fauna, bank erosion, contamination from agricultural and industrial systems as well as debris (Wildlife Queensland 2011). However, on a positive note, as a result of these significant water inflows into the basin, dams in New South Wales have been filled to capacity, drought management (including subsidies) has ended in the MDB (NSW DPI, 2013) and rice production has recovered (Eckersley 2010).

3.2 *Climate change projections*

Climate change projections are made using modelling, which uses various assumptions to reduce and quantify the uncertainty associated with the projections. Assumptions are made about the biophysical interactions between the atmosphere and earth surface as well as different scenarios of future greenhouse gas emissions (van Dijk et al. 2006). The modelling results in a band of possible outcomes that reinforce observed trends (van Dijk et al. 2006). The analysis of climate change effects is complicated because of the high levels of variability and uncertainty with respect to water inflows and outflows within river systems and their effects on water-dependent ecosystems (Adamson et al. 2009).

The most frequently used and comprehensive climate change projections for the Murray-Darling Basin come from the CSIRO Sustainable Yields project. The project produced four scenarios of climate and development based on analysis of 111 years of daily climate data (CSIRO 2008c). The scenarios for 2030 and 2070 are often referred to in the literature. The average surface water availability in 2030 is projected to increase by 7% under an 'extreme wet' scenario, decline by 12% under the 'median' scenario, and decline by 37% under the 'extreme dry' scenario given current land use patterns are maintained (CSIRO 2008c).

Some of the impacts of the 2030 scenario for the MDB include the following (Bates et al. 2010; CSIRO 2008c):

- 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.
- Surface water availability across the entire MDB is more likely to decline than to increase. The median decline for the entire MDB is 11% (9% in the north of the MDB and 13% in the south).
- Under the median 2030 climate, diversions in the driest years would fall by more than 10% in most New South Wales regions, around 20% in the Murrumbidgee and Murray regions and from around 35% to over 50% in the Victorian regions.
- Under the dry extreme 2030 climate, diversions in the driest years would fall by over 20% in the Condamine-Balonne, around 40–50% in New South Wales regions (except the Lachlan), over 70% in the Murray and 80–90% in the major Victorian regions.
- Under current water sharing arrangements groundwater use could increase by 2030 to be over one-quarter of total water use. Current groundwater use is unsustainable in seven of the 20 high-use groundwater areas in the MDB.
- Drought could become as much as 20% more common by 2030 over much of Australia.

3.3 *Climate change interactions with non-climate stressors*

For biodiversity, climate change is yet another stressor, interacting with and deepening existing problems (Lindenmayer et al, 2010).

In the case of the southern MDB, the interactions between existing stressors and climate change are explained by McAlpine et al. (2009), who note that extensive land clearing of native vegetation is likely to have contributed to a hotter and drier climate and exacerbated the El Niño effect in south-east Australia, which then puts pressures on contemporary governments in allocating diminishing water resources between consumptive and environmental uses. Pittock, Hansen and Abell (2008) argue that the existing non-climate change-related stresses and impacts from maladaptive policies will outweigh the negative impacts of climate change in the medium term. Kingsford (2011) agrees with that view, stating that the effects of river regulation remain the greatest threat to freshwater ecosystems in the foreseeable future. It is therefore clear that climate change adaptation options must take account of non-climate change related stresses in order to avoid maladaptation.

The CCA CAF was developed to consider 'low-risk' options that provided the most benefit to climate change adaptation by: (1) either directly addressing, or at least, by not increasing existing stresses; (2) implementing 'no regrets' measures; and (3) spreading the risks by intervening with complementary measures. 'No-regrets' measures are those where implementation will result in benefits for society or the environment, regardless of future climate change (Hallegatte 2009).

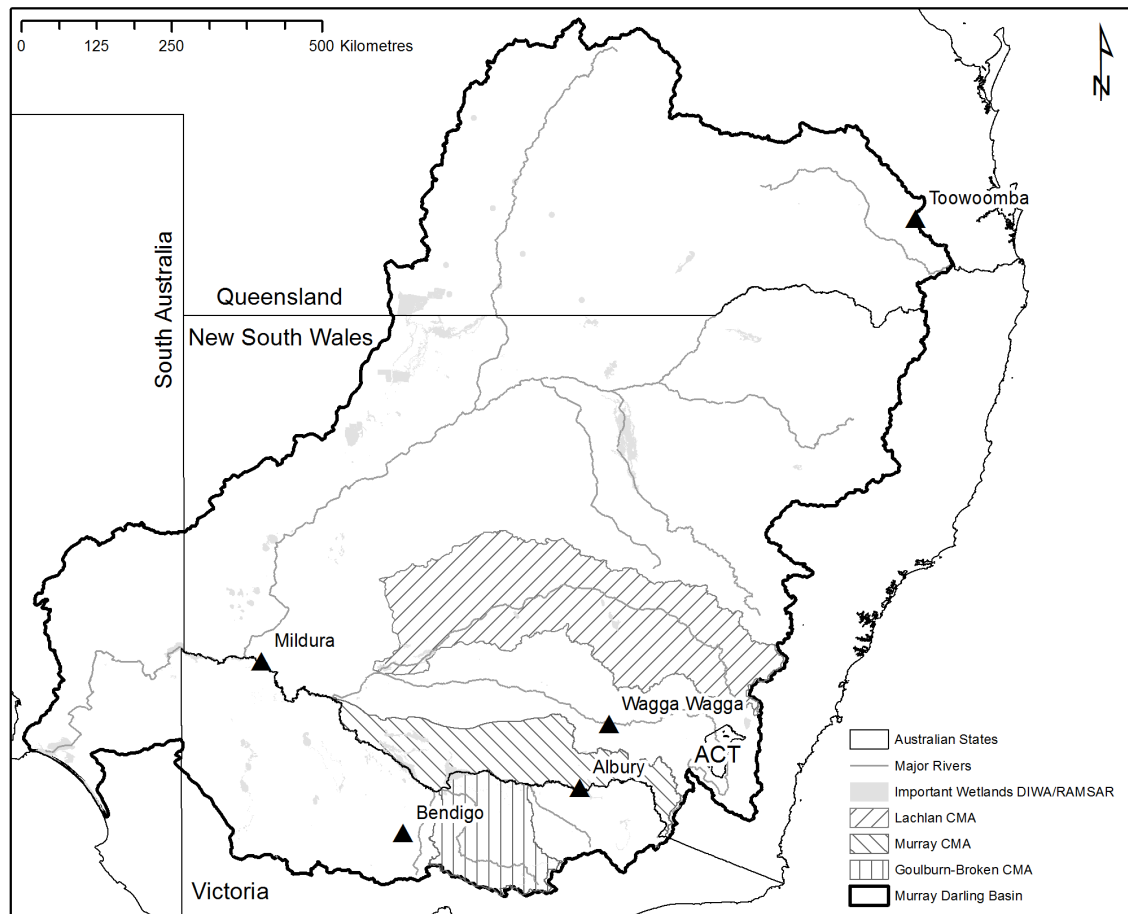
4. INTRODUCTION TO THE CATCHMENTS

In this chapter, the three catchments are introduced and discussed in terms of the potential climate change impacts and projections as well as policies for climate change adaptation and freshwater ecosystem management.

The Murray, Goulburn Broken and Lachlan catchments were chosen because of (1) the substantial capacities and extensive programs of these agencies that could illustrate the different adaptation options proposed in this project; and (2) the effective existing links between researchers and these agencies on which the project built. The three have many differences, but also share many similarities in their aspirations for climate change adaptation. In this respect, this research has some relevance to all of the 19 catchment management authorities in the basin and the 56 natural resource management organisations, as well as other state and territory agencies nationally.

The three selected catchments are very different. The Murray, because of its iconic status, has many major players, icon sites and Ramsar wetlands that have led to greater involvement of federal organisations, such as SEWPAC and MDBA: ‘Our relationship with flows is in who we know and how we build those relationships.’ (Murray CMA Respondent 1) The Goulburn Broken is very interconnected, with irrigation water stored in wetlands, making it very difficult to impossible to separate consumptive and environmental water: ‘It is not possible, in many instances, to separate the management of water for consumptive purposes from the management for environmental purposes.’ (GB CMA Respondent 1) The Lachlan, on the other hand, is an almost enclosed system, meaning that it does not have to share recovered water with other catchments, but there is less focus (hence funding and investment) on it from a basin level: ‘less funding, less incentive, less imperative for further water recovery, or works and measures to distribute Lachlan water more efficiently’ (OEH Lachlan Respondent). All of these particular characteristics present both challenges and opportunities that CMAs have to face.

Despite their differences, all three catchments have similar goals regarding climate change adaptation, and all three are in a similar stage of developing climate change-related policies. Interviews indicate that all three catchments aim to create resilient landscapes and communities. Climate change is a relatively recent concern that has been put into plans and strategies but not really operationalised: ‘it’s just starting to be on our radar’ (Murray CMA Respondent 2). The Goulburn Broken CMA has recently appointed a climate change officer whose main responsibility is to ensure that adaptation is considered across different CMA programs, and that climate-related risks and opportunities are identified (GB CMA Respondent 2). This project, investigating the climate change adaptation potential of a range of natural resource management (NRM) actions, fits within the CMAs’ desire to pursue adaptation strategies to increase catchment resilience. Figure 1 below shows the location of the three catchments within the Murray-Darling Basin.



Source: Spatial Data Analysis Network, Charles Sturt University.

Figure 1: Location of the three catchments within the Basin

4.1 Murray Catchment²

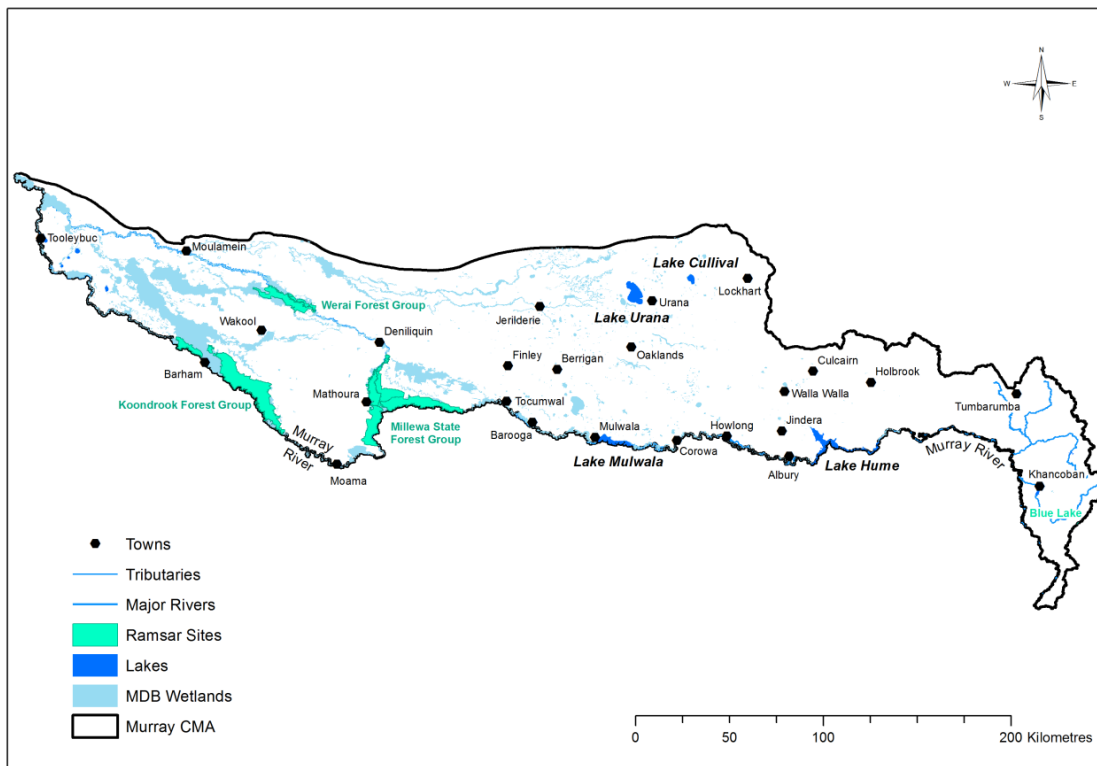
The Murray Catchment (see Source: Spatial Data Analysis Network, Charles Sturt University.

Figure 2) spans an area of 35 170km², with a population of around 101 000. It includes the Murray and Murrumbidgee Rivers, parts of the Australian Alps, and over 60 wetlands of national importance (Murray CMA 2012a). A number of these wetlands are also 'icon sites' of The Living Murray Program (CSIRO 2008d) and listed as internationally important under the Ramsar Convention.

The Murray Catchment has a highly developed, vibrant and diverse agricultural sector, with grazing, cropping, irrigation, forestry and horticulture being the main enterprises. Its freshwater biodiversity encompasses over 6350 wetlands and close to 22 500 kilometres of watercourses, supporting approximately 115 threatened species (Murray CMA 2012a). The Hume Dam is a major water storage located on the Murray River. The river system is supplemented with water stored in the Snowy Mountains Hydro-electric Scheme, Menindee Lakes on the lower Darling River and Lake Victoria in south-western New South Wales. The region uses over 36% of the surface water

² Subsequent to this research, the New South Wales Government has announced that CMAs will be merged with a number of other rural service agencies. Consequently, the planned catchment management processes for the Murray and the Lachlan described in this report may change significantly.

diverted for irrigation and urban use and over 11% of groundwater used in the MDB (CSIRO, 2008d).



Source: Spatial Data Analysis Network, Charles Sturt University.

Figure 2: The Murray Catchment

4.1.1 Climate change impacts and projections

The average annual rainfall for the Murray region is 340 mm, varying from around 1500 mm in the east to 300 mm in the west. Projections for water availability vary: the extreme wet scenario predicts a 7% increase for average diversions, a decrease of 14% in the moderate scenario and 41% in the dry scenario (CSIRO 2008d).

Some of the potential climate change impacts facing the Murray Catchment include the following (CSIRO, 2007):

- Increased evaporation, heatwaves, extreme winds and fire risk due to a warmer and drier climate are all likely
- Increases in extreme rainfall events are also likely
- There is potential for wheat yield to increase by between 9 and 13% by 2070, with the mean value of production increasing by \$13–\$24 million.
- Fruit tree yield and quality may decrease due to inadequate winter chilling brought on by higher temperatures.
- Higher temperatures could reduce the risk of damaging winter frosts.
- Viticulture harvests will be affected by earlier harvest times.

- The number of snow days and snow depths in the mountains in the east of the Murray Catchment may be reduced by 18–60% by 2020, and 38–96% by 2050.
- The reduction in snow-covered areas in the mountains may affect ski tourism, and may require a doubling of snow-making capacity.

4.1.2 CMA response to climate change

The Murray Catchment Climate Change Adaptation Policy seeks to build the 'Murray Catchment's resilience to the potential negative impacts of climate change and variability, and to assist our community to embrace the new opportunities that may arise' (Murray CMA 2011). The policy is relatively new and still in the process of being implemented.

The Murray CMA emphasises the concept of resilience, defining resilient landscapes as 'units of land that are ecologically sustainable and when challenged by change or disturbance, continue to function effectively and support the environmental, social, cultural and economic values of communities' (Murray CMA 2011).

The Murray CMA is applying its climate change adaptation policy by incorporating assessments of climate change risk into the planning and delivery of projects across the Murray Catchment. The CMA also seeks partnerships with recognised sources of technical advice on climate change in order to incorporate new knowledge and best science into planning and investment activities.

4.1.3 Freshwater management

The Murray CMA's Riverine Strategy (2010–20) is currently under review. It will direct resources into those areas where the greatest gains in natural resource management can be made in the most cost effective manner by identifying riverine assets and their threats. The Strategy will ensure that assets are protected where there is no existing threat and rehabilitated where the asset is threatened (Murray CMA 2012c).

Works have already been undertaken at three sites (in the Upper Murray Catchment, Billabong Creek and the Edward-Wakool system) to protect and enhance habitat, riparian vegetation and biodiversity refuges, which are all examples of enhancing climate change resilience. The Riverine Strategy (2010–20) will prioritise catchment riverine assets based on three criteria: the site's ecological value, resilience and vulnerability to climate change (Murray CMA 2012c).

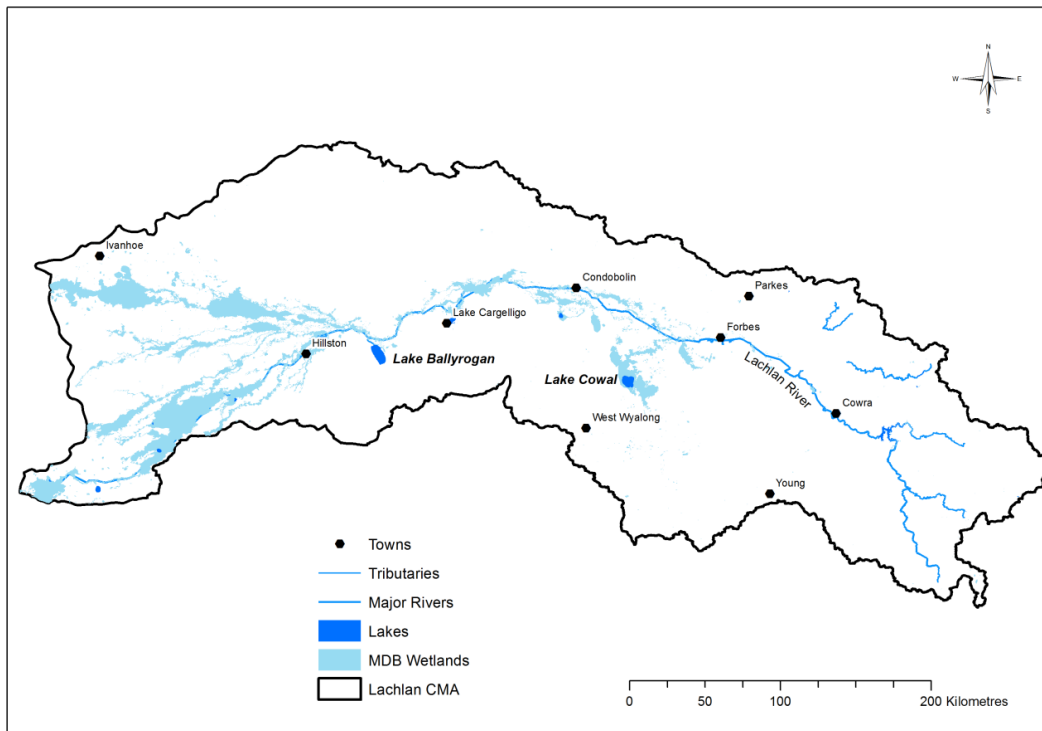
The Murray CMA is already undertaking extensive resource restoration and rehabilitation projects in order to arrest and reverse degradation that has occurred in the past. Most of the options assessed in this project are being undertaken for the purposes of biodiversity conservation.

4.2 Lachlan Catchment

The Lachlan Catchment is located in Central-Western New South Wales and covers an area of approximately 84 700 km² with a population of over 100 000 people (CSIRO 2007). Dryland pasture for sheep and beef cattle grazing dominates the landscape, but other enterprises include cotton, pasture, hay and cereal grain production (CSIRO 2008b). The irrigation industry is relatively diverse, stretching almost the full length of the catchment, with the majority of irrigation occurring along the riparian fringe of the Lachlan and Belubula Rivers and associated tributaries (Lachlan CMA 2012a).

The major water source in the catchment is the Lachlan River. Wyangala Dam, located on the Lachlan River upstream of Cowra, is the major water storage in the region and regulates 68% of all inflows (CSIRO 2008b). A number of water sources are listed as

nationally important wetlands, including Lake Cowal, Booligal Wetlands Cuba Dam, Great Cumbung Swamp, Lachlan Swamp, Lake Brewster, Lake Merrimajeel and Murrumbidgee Swamp, as well as Merrowie Creek (CSIRO 2008b). Certain 'regionally significant wetlands' have also been identified. These include: Lake Cargelligo, Lake Ita, Burrawang West Lagoon, Willandra Creek, Moon Moon Swamp, Yarnel Lagoon, Baconian Swamp, Upper Merrowie Creek, Mid Lachlan Floodplains and Billabongs (Lachlan CMA n.d.).



Source: Spatial Data Analysis Network, Charles Sturt University.

Figure 3: The Lachlan Catchment

4.2.1 Climate change impacts and projections

According to the CSIRO Sustainable Yields Study projections, water availability may vary: the extreme wet scenario predicts a 6% increase for average diversions in the catchment, a decrease of 11% in the moderate scenario and a decrease of 30% in the dry scenario (CSIRO 2008b). The Lachlan Catchment sits in a climatic zone where, historically, most inflows came from the spring/winter rainfall. However, this zone is predicted to shift southwards, causing south-western New South Wales to become more water-stressed as the majority of rainfall will occur in the summer when there is more evaporation (Lachlan OEH Respondent). While climate change may mean lower inflows, the most significant challenge for the CMA will be dealing with extreme weather events (Lachlan CMA Respondent 3).

4.2.2 CMA response to climate change

The Lachlan CMA is currently addressing climate change issues through its Catchment Action Plan, which emphasises resilience thinking as an overall management philosophy. As the Natural Resources Commission has determined that all NSW catchment documents must be based on resilience thinking, the Lachlan CMA has focused on identifying ecosystem feedback loops and finding points of intervention (Lachlan CMA Respondent 3). The Lachlan Environmental Working Group is currently

applying resilience thinking and adaptive management in its planning activities, and recently has received praise for engaging community and local interest groups (Lachlan CMA respondent 1).

The CMA is also currently involved in the following activities to improve knowledge about climate variability, catchment-specific climate change impacts and adaptation options (Lachlan CMA 2012c):

- development of a Catchment Action Plan and Annual Investment Plan
- development of macro water sharing plans
- information sessions about climate change and variability within the catchment
- workshops to enhance climate change training for land managers, staff and other stakeholders
- Property Management Planning, which involves physical property planning, whole-farm financial, enterprise evaluation and monitoring tools
- a Biodiversity and Native Vegetation Program, which assists with the improvement of environmental services
- working with the community to conserve remnant vegetation, revegetate riparian zones and over cleared landscapes, and encourage connectivity within the catchment.

Some examples of potential adaptation measures relevant to the Lachlan Catchment include (Lachlan CMA 2012c):

- improving water-use efficiency
- changing to crops that are more tolerant of heat and drought
- changing planting times and practices for crops
- providing more shade and cooling for livestock
- providing migration corridors for vulnerable animal species
- reviewing flood and fire management arrangements.

The CMA also took part in a carbon sequestration research project, which sought to develop a reliable tool for estimating carbon sequestration by environmental plantings in New South Wales. The project results showed that rates of carbon sequestration were influenced by rainfall, planting geometry (block or linear) and the species planted (Lachlan CMA 2012b).

4.2.3 Freshwater management

The Lachlan CMA has adopted a 'Working Rivers' philosophy, where it is understood that rivers that will not be able to be restored to a pristine condition will be restored to a stable healthy ecological condition, as judged by the community, while still providing community access to the water resource for consumptive purposes (Lachlan CMA 2012d).

A 2006 assessment of threatening processes to the aquatic environment concluded that the lower Lachlan was in an overall poor condition, and suggested the following actions to improve the health of freshwater systems (NSW DPI 2006):

- geomorphic restoration, reinstating and realigning existing woody debris
- riparian revegetation, revegetation and fencing
- management of exotic species, targeted removal of weed species
- maintenance or restoration freshwater habitat connectivity, fish passage remediation.

The Lachlan CMA recognises that the decline of freshwater systems in the Lachlan Catchment is caused by human, pest, disease and climatic influences. The CMA's goal is: 'To have a healthy aquatic ecosystem throughout the Lachlan Catchment that supports the reproduction and recruitment of all associated endemic species (aquatic and terrestrial)' (Martin 2011).

4.3 The Goulburn Broken Catchment

The Goulburn Broken is situated in northern Victoria and comprises the catchments of the Goulburn and Broken Rivers, as well as a part of the Murray River valley (Goulburn-Broken CMA 2012). It covers 2 431 655 ha and has a population of over 200 000. The region supports major agricultural (dryland and irrigated), food processing, forestry and tourism industries. Around 50% of the region is taken up by cereal cropping and grazing, and one-twelfth is irrigated dairy pasture and horticultural cropping (CSIRO 2008a).



Source: Spatial Data Analysis Network, Charles Sturt University.

Figure 4: The Goulburn Broken Catchment

While the major commodity is food, wool, timber, tourism and recreation are also important to the regional economy (Goulburn-Broken CMA 2012). The major water sources in the catchment are the Goulburn and Broken Rivers. A number of sites are listed as nationally important wetlands (CSIRO 2008a).

4.3.1 Climate change impacts and projections

In 2008, the annual rainfall and runoff for the Goulburn Broken region averaged 764 mm and 149 mm respectively (CSIRO 2008a). Decreases in rainfall and higher

evaporation rates are possible under climate change, resulting in less soil moisture and less water for rivers. According to the CSIRO Sustainable Yields Study projections, water availability may vary: the extreme wet scenario is a 3% decrease for average diversions in the catchment, a decrease of 14% in the moderate scenario and a decrease of 45% in the dry scenario (CSIRO, 2008a). Furthermore, the Northern Region Sustainable Water Strategy (2009, p. 22) estimates that if the low inflows of 1997-2007 and the extremely dry years of 2008 and 2009 were to continue, inflows into the Broken River system would decrease by 53% and inflows into the Goulburn River system would decrease by 49%.

Some of the potential climate change impacts facing the Goulburn Broken Catchment include (DSE, 2008):

- water demand increases as a result of warmer temperatures and population growth
- reduced water quality due to lower flows and higher temperatures, leading to algal blooms
- greater bushfire activity
- increased heat stress on dairy cattle, leading to reduced milk production
- inadequate winter chilling for some fruit trees, leading to reduced fruit yield and quality
- reduced risk of damaging winter frosts for other crops due to higher temperatures
- reduced grape quality due to higher temperatures
- although average changes in temperature, rainfall and evaporation will have long-term consequences for the Lachlan catchment, the impacts of climate change are predicted to be felt through extreme weather events. Projections suggest that there will be more hot days, bushfires, droughts and intense storms. These can all place human life, property and natural ecosystems at increased risk.

4.3.2 CMA response to climate change

Goulburn Broken CMA has a Climate Change Integration Strategy, which outlines a clear strategic position relative to climate change:

In dealing with climate change and likely impacts, the Goulburn Broken CMA will focus on adaptation strategies to increase catchment resilience; greenhouse gas sequestration activity such as carbon brokering will be engaged for the purpose of assisting adaptation responses; and mitigation initiatives led by local government will be actively supported. (Goulburn Broken CMA 2012, p. 2)

This statement focuses on the concept of resilience, acknowledges both adaptation and mitigation, and recognises the potential for climate change benefits and opportunities. The CMA is pursuing three interconnecting goals within its strategy. These are adapting to climate change, pursuing carbon sequestration opportunities and mitigating greenhouse gas emissions. The CMA is planning on integrating climate change into existing policy and programs by considering climate change risk and adaptation strategies at a range of planning scales. The Climate Change Strategy is relatively new, and is currently being implemented by a part-time climate change officer with responsibility to ensure that

adaptation is considered across different CMA programs and that climate-related risks and opportunities are identified (GB CMA Respondent 2).

The CMA is also a member of the Goulburn Broken Greenhouse Alliance, which is guided by the *Goulburn Broken Local Government Regional Climate Change Adaptation Plan*, a strategy for responding to the challenges of climate change across the Goulburn Broken region (Tucker 2011).

4.3.3 Freshwater Management

The Goulburn Broken CMA adopted a Regional River Health Strategy in 2005, which provides an integrated framework of actions to protect rivers of high quality and improve the quality of others for current and future generations. The guiding vision of the Goulburn Broken Catchment Regional Strategy is:

Healthy rivers, streams, wetlands, floodplains and adjacent land that support a vibrant range and abundance of natural environments, provides water for human use, sustains our native flora and fauna and provides for our social, economic and cultural values ... (Goulburn Broken CMA 2005, p. 1)

This vision conforms to the triple-bottom line idea, encompassing environmental, social and economic aspects of river management. It is to be achieved through four main objectives: protecting rivers with highest community values (preventing their decline); maintaining the condition of ecologically healthy rivers; improving the environmental condition of the remaining rivers; and preventing damage from inappropriate development (Goulburn Broken CMA 2005, p. 1). Many of the NRM actions proposed in this project as part of climate change adaptation are already being conducted under the auspices of the River Health Strategy.

The Goulburn Broken Catchment is home to a major wetland reconnection activity: the decommissioning of Lake Mokoan and the subsequent establishment of the Winton Wetland Reserve. Lake Mokoan was built in 1971 as off-river storage in the Broken River valley near Benalla. Along with Lake Eildon and Lake Nillahcootie, it was designed to regulate flow in the Broken River for stock and domestic as well as urban water requirements in the Broken River valley (URS 2003). However, the lake was prone to water turbidity, algal blooms and significant evaporation, and was slated for decommission in 2004 by the Victorian government, with work beginning in 2009. Following the decommissioning, the Victorian government provided \$20 million to restore the 8750 ha Winton Wetlands (Winton Wetlands Committee of Management 2011). Organisations involved in this project include the Winton Wetlands Committee of Management, the Victorian state government and Goulburn-Murray Water.

4.4 Summary

All three catchments are facing significant challenges from potential climate change impacts, and all have started the process of incorporating climate change adaptation into their NRM management plans. Climate change scenarios and policies are summarised in Table 4 for quick reference. The three scenarios are used in Chapter 6, section 6.3.

Table 4: Summary of catchment climate change impacts and policy responses

Catchments	Sustainable yields scenarios*			Climate change policy response	Freshwater management
	<i>Wet</i>	<i>Moderate</i>	<i>Dry</i>		
Murray	+7%	-14%	-41%	Murray Catchment Climate Change Adaptation Policy	Murray CMA's Riverine Strategy (2010-2020)
Lachlan	+6%	-11%	-30%	Addressing climate change through its Catchment Action Plan	'Working Rivers' philosophy
Goulburn Broken	-3%	-14%	-45%	Goulburn Broken Climate Change Integration Strategy	Regional River Health Strategy

* The scenarios indicate the gain or loss of average annual water availability (expressed as a percentage).

Source: Based on CSIRO (2008a, 2008b, 2008d); Goulburn Broken CMA (2005, 2012); Lachlan CMA (2012d); Murray CMA (2011, 2012c).

5. AN ECOSYSTEM-BASED APPROACH TO CLIMATE CHANGE ADAPTATION

In an ecosystem-based approach, interventions to improve environmental health are used to ameliorate climate change impacts. Such strategies include the maintenance and restoration of natural ecosystems, protection of vital ecosystem services, reduction of land and water degradation by controlling invasive, alien species and the management of habitats that act as breeding, feeding and nursery grounds for wildlife species and ensure plant genetic diversity (World Bank 2009). In 2008, the IUCN proposed protected areas as one of the solutions to climate change (Dudley et al. 2010) and the World Bank (2009) stressed that natural systems not only provided goods and ecosystem services but may also provide cost-effective protection against climate change impacts. The mechanisms by which protected areas can aid climate change mitigation and adaptation are outlined in Table 5 below.

Table 5: Three pillars of protected areas for climate change mitigation and adaptation

Carbon sequestration	Disaster relief	Supplying human needs
Carbon can be captured and stored in living and dead vegetation in:	Ecosystem services can reduce risks of:	Ecosystem services include:
• Forests	• Avalanche	• Clean water
• Grasslands	• Hurricane	• Fish spawning
• Inland waters	• Flooding	• Wild food
• Marine systems	• Tidal surges	• Building materials
• Soil and humus	• Drought	• Local medicines
		• Shelter
		• Agro-biodiversity
		• Pharmaceuticals
		• Genetic material

Source: Dudley et al. (2010).

It is similar to the condition-based NRM proposed by Curtis and Lefroy (2010). Cottingham and colleagues (2005) also advocate a similar approach by focusing on protecting, maintaining and restoring resilient, connected ecosystems that are capable of withstanding periodic shocks, that recover following natural and human-induced disturbance, and that ultimately become self-sustaining and capable of responding to large-scale processes such as climate change. Catford and colleagues (2012) echo this approach by suggesting that current conservation activities should focus on maximising diversity (of species, genetic stock and functions), increasing habitat diversity and maintaining the biogeochemical configuration of ecosystems.

Bond and Lake (2005) illustrate the need for a suite of complementary NRM approaches in their assessment of the effectiveness of habitat restoration efforts. They state that freshwater restoration efforts have focused on the provision of suitable habitats for aquatic life (geomorphic restoration and restoration of riparian vegetation). They highlight that even if freshwater habitats are restored, this may not result in

increased freshwater biodiversity. According to a Canadian review of 55 rehabilitation projects conducted by Smokorowski, Whithers and Kelso (1998), while 98% of the reviewed projects achieved their habitat targets, only 5% showed an increase in fish production. Bond and Lake (2008) point out that habitat restoration by itself will not ensure that freshwater biodiversity unless habitat connectivity is assured and sufficiently high environmental flows provided to enable native aquatic biota to colonise the restored sites. At the same time, invasive species must be prevented from dominating the restored habitats, and the restoration of freshwater habitats must provide refuge habitats to counteract other pressures affecting the larger landscape, like thermal pollution from upstream dams (Bond and Lake 2008).

In this project, the ecosystem-based approach to climate change adaptation is used as an underpinning philosophy, providing the rationale for assessing complementary NRM actions as a basis to climate change adaptations. This section introduces the nine adaptation options assessed in this project. The individual measures described here have been chosen based on Pittock and Finlayson (2011) and refined through the literature review process and discussions with project stakeholders. The above list is not exhaustive, and other NRM actions could be assessed by the CCA CAF, including managed aquifer recharge, captive breeding programs and plantation forestry projects. While the measures below are described individually, in an ecosystem-based approach, a number would be undertaken concurrently and they are complementary.

5.1 Environmental flows

The provision of environmental flows refers to the quantity, timing and quality of flows released from water storages in order to benefit from socially valued healthy, resilient freshwater systems (*The Brisbane Declaration* 2007). These flows were conceived as redressing excessive consumptive water diversions that have caused the degradation of river systems, but could be increased as an adaptation to changes in water availability brought on by climate change (Pittock et al. 2010).

The provision of environmental flows is the primary adaptation measure proposed in Australia to counteract reduced flows caused by climate change and most effective for offsetting the effects of regulation (Jenkins et al. 2011). It is particularly important for improving the health of the MDB wetlands (Gross et al. 2011). Environmental flows are being used to try to reinstitute more natural patterns of wetting and drying to the ecosystem. Current regulations attached to environmental water also greatly constrict a system-wide approach to watering, since water acquired from buybacks is still governed by irrigation rules that significantly restrict its use for overbank flooding.

There are many positive socio-economic benefits from environmental watering (CSIRO 2012). In this project, it was highlighted that environmental flows provide benefits in the form of floodplain pastures and recreational fishing. The environmental watering of wetlands can also have a powerful positive psychological effect on people negatively affected by drought, as a number of Murray workshop participants attested.

The effectiveness of environmental flows may decrease if there are wetter conditions (as they would be less necessary) and also decrease under extremely dry conditions when environmental water may not be available. While environmental flows are very beneficial in terms of reducing vulnerability to existing stresses and increasing resilience to climate change impacts (such as by supporting vegetation, recharging groundwater and maintaining functional ecosystem services), there are some identifiable detrimental impacts. Large releases from dams exacerbate cold-water pollution. Flows can exacerbate existing stresses (such as carp) and create new ones, such as assisting in the spread of insect-borne diseases (although the likelihood of that is unknown).

The acquisition of environmental water continues to be perceived by some rural stakeholders as placing a disproportionate burden on irrigation communities. Furthermore, overbank flooding necessary for minor and medium floods may disrupt agricultural activities and can cut the access of landholders. Economically, grazing activities benefit from environmental water more than irrigation. Frequent environmental watering could thus transfer water benefits from irrigation to grazing, since overbank flooding deposits moisture and nutrients for pastures and stock (unlike crops) can be moved off paddocks during floods.

The delivery of environmental water (overbank or in-stream) also conflicts with deliveries of irrigation water as there is limited space in the river channel. Thus rural community support for environmental watering is higher when water is confined to the river channel and overbank flooding is avoided.

5.2 *Environmental works and measures*

This refers to engineering approaches that aim to supply less water in ways that sustain larger areas of wetlands. Actions include artificial watering through diversion canals or pumping, and the construction of levees, weirs and regulators to help mimic natural flooding. The term 'environmental works and measures' (EWM) is often loosely used to describe a wide range of engineering works, including fish passage devices, re-snagging and removing 'constraints' to larger flows. In this research we are limiting the term to works to divert water and pool it on floodplains. Some argue this will enable conservation of areas of flood plain wetlands with climate change, but others criticise this approach as being maladaptation, or overly narrow adaptation (Pittock and Finlayson 2011).

Flooding is essential for riparian and floodplain vegetation. The survival of River Red Gums requires periodic flooding that, due to reduced water availability, is now often achieved artificially through weirs and pumping (Mac Nally et al. 2011). Engineering solutions to produce artificial flooding are undertaken in many parts of the basin to deliver environmental flows where only slight alterations of the heights of existing weirs are required to water the floodplains. For example, temporary pumps were used to water the Ramsar-listed Hattah Lakes from the Murray River in 2006 and 2009 (Aldous et al. 2011).

Artificial watering has proven to be a viable adaptation option for improving the ecological health of selected floodplain vegetation by mimicking natural flooding patterns. However, it is financially costly and its large-scale application is limited. While these engineering solutions can be thought of as part of the emergency management for some selected species, they cannot replace natural flooding patterns (Aldous et al. 2011). For example, artificial inundation through EWMs may not enable watering of wetland types at higher elevations on the floodplain – for example, Black Box forests (Pittock and Finlayson 2011). Furthermore, the benefits of artificial flooding on vegetation survival can be negated by subsequent grazing (Mac Nally et al. 2011), which once again points to the necessity for integrated water and floodplain management.

The ecological costs and benefits of EWMs are largely dependent on the size of the structure. Large-scale works such as at the Koondrook-Perricoota Forest have the potential to affect significant areas, whereas regulators placed on tributary creeks control flows to relatively isolated areas.

EWMs have similar benefits as environmental flows in reducing vulnerability and increasing resilience. However, catchment assessments showed this to be the option with the highest maladaptive potential, and comparatively less adaptation and ecosystem service benefits than the other options examined in this project.

Furthermore, large-scale EWMs may be redundant under extreme conditions – both wet and dry ones – since they would be unnecessary during periods of high flows and unworkable during periods of extremely low flows. However, smaller-scale works may be more effective under all climatic conditions. The fact that these works can only flood easily accessible sites means that ecological communities in elevated or hard-to-reach places are left unwatered. An argument could therefore be made that reliance on EWMs places those ecological communities at a significant disadvantage, and increases their vulnerability to climate change. The economic efficiency and impacts of EWMs (versus water buybacks) is debated between government and irrigator communities (Cheesman and Wheeler 2011; Commonwealth of Australia 2011b).

EWMs significantly lower the risk of flooding private land, which is a major community concern around environmental flows. The smaller works on tributaries were generally thought to have very positive socio-economic consequences, because they pose much less risk of damage to private property since they allow smaller amounts of water to be used and give greater control over how long an area is watered. Environmentally, they allow the watering of small, isolated wetlands that otherwise would go unwatered.

Significant positive consequences from EWMs have been observed for inundated freshwater dependent vegetation. However, what is good for trees is not necessarily good for fish. EWMs work by pooling water on surrounding areas and spreading smaller amounts of water further, diminishing hydrological diversity. Unfortunately, these create ideal conditions for blackwater events and the spawning and recruitment of carp, which is a potential undesirable social and environmental consequence.

EWMs were generally considered to have a high maladaptive potential in catchment assessment, partially because of perceived lack of effectiveness under extreme conditions and the high opportunity cost of investing in EWMs rather than water buybacks. Also, EWMs lock in path dependency since investment in large structures creates economic and political impetus for them to be used. Policies that aim to conserve more habitats with less water decrease political will to lower water extractions. EWMs can also increase existing stresses by spreading invasive species, exacerbating salt loads and algal blooms and potentially increasing methane emissions. Finally, there is a high risk of institutional failure with EWM, as to be effective compared with other adaptation options they require maintenance and operational funding, skilled staff and fast decision-making.

5.3 Thermal pollution control

The installation of multiple-level off-takes that allow for the control of cold water pollution (CWP) from dams would allow greater flexibility in adjusting water temperatures, including under climate change. CWP can potentially have four negative effects: decreased water temperature during warmer months; increased water temperature during cooler months; shifts in seasonal patterns; and a decrease in the annual temperature range (Astles 2001). Addressing CWP will improve downstream river habitat, and thus increase resilience to negative climate change impacts. Technical options include the fitting of multiple level off-takes, propellers, adjustable pipes or curtains. This is a climate change adaptation option for large dams where temperature stratification occurs.

The construction of large dams has not only changed the quantity of water available in rivers but also its temperature. Large dams have thermally stratified reservoirs that periodically release either cold or warm water (Olden and Naiman 2010). For example, water released from the bottom of large dams can be between 3 and 12°C colder than natural flows, and can affect water temperatures up to 300 km downstream (Pittock and Finlayson 2011). Water temperature is a key environmental variable for fish,

affecting their metabolism and swimming ability, and – indirectly – their distribution and abundance (Booth et al. 2011). Cold water pollution has contributed to the large reductions of native fish in regulated rivers (Balcombe et al. 2011) and has been linked to the localised extinction of native species such as Murray Cod, Trout Cod, Macquarie Perch, Silver Perch and Golden Perch (Koehn 2001).

Apart from decreased water temperatures, cold water pollution also causes reductions in the thermal amplitude in streams, delays of summer temperature peaks, reduction of the naturally occurring rapid rises in stream temperature that occur in spring and sudden temperature drops that happen when large amounts of water are released (Ryan et al. 2001). Thus actions designed to return river systems to natural patterns will not achieve optimum outcomes if CWP is not addressed.

The common response in all three catchments examined in this project was that thermal pollution control was too expensive (although modest compared to current federal government funding for retrofitting irrigation infrastructure) and that the benefits cannot justify the cost. CWP is identified as a concern by government departments and scientists, but not by the general community, where other water quality issues are more readily identified.

The Murray and the Goulburn Broken catchments face specific constraints to addressing CWP. In the Murray, there have been discussions about operating the Hume Dam differently by releasing more water through the spillway rather than through the electricity generator, but the electricity provider is guaranteed certain amounts of water, and this cannot be varied. In the Goulburn Broken, an active trout industry has been built around cold water flows.

Discussions of how thermal pollution control would fare under drier conditions revealed that it would become less of a problem under extremely dry climate change scenarios since there will be very little water stored in dams (with less opportunity for stratification to occur and thus no cold water pollution). The option also has maladaptive potential of possibly increasing emissions, depending on what technology is used (with cheaper technologies like curtains and propellers requiring electricity to operate). There is also a possibility of greater methane emissions due to the disruption of water stratification.

Thus thermal pollution control has been deemed economically unfeasible and opportunity costs have been deemed to be too high. Socially, cold water pollution caused by large dams does not seem to be important for irrigators and the general community, although it is an issue raised by recreational fishermen.

5.4 Restoration of riparian vegetation

Riparian vegetation increases freshwater habitat quality (providing food, shelter and nutrients to native fauna) and can decrease water temperatures raised through climate change. Actions to restore riparian vegetation include planting riparian flora, fencing off riparian zones, ongoing weed control in riparian zones and the provision of off-river watering points for domestic stock.

The loss of indigenous riparian vegetation influences stream ecosystems by enabling ingress of sediment that smothers benthic communities and spawning sites, increasing harmful algal growth, reducing the inputs of organic carbon, destabilising riverbanks and causing loss of shade and shelter for fish (Sanger 2009). High water temperatures are critical in determining whether or not a blackwater event³ will lead to native fish and

³ A blackwater event occurs when carbon is leached from leaf litter during a flood and darkens the water. A severe blackwater event can reduce the amount of oxygen available to fish and

crustacean deaths (Hladyz et al. 2009). Riparian revegetation provides shading that decreases water temperature and thus may help counteract climate change impacts. For example, in south-western Australia, a 10% increase in riparian revegetation is required for a 1°C decrease in water temperature (Davies 2010). Other benefits of riparian vegetation include reduced channel erosion and increased nutrient cycling. These benefits may be visible even if riparian restoration is implemented at the individual farm scale (Arnaiz et al. 2011). Thomson et al. (2012) found that the benefits of local riparian vegetation increased along with increasing air temperature. Therefore the restoration of riparian vegetation may also act as a mitigation option, especially in warmer climates (Thomson et al. 2012). To be fully successful as a conservation action, riparian restoration requires increased flooding, as well as the management of non-water flow factors such as salinity and grazing (Mac Nally et al. 2011).

The restoration of riparian vegetation is a significant activity for CMAs. While program specifics vary, all CMAs have financial incentives to undertake activities on private land that is utilised by landholders. However it is noted that in each catchment there is a core group of people who refuse to participate for economic and emotional reasons. Economic arguments against taking up incentives focus on the responsibility for maintenance of fencing after flooding while emotional reasons concern the belief that governments and the community should not interfere with activities on private land. There are also common misperceptions that the land is locked up and constitutes a fire and weed hazard. While economic benefits exist (feed for stock, assistance with drought-proofing, easier stock management and increasing carrying capacity of the land), they have been under-sold since they are hard to quantify.

The full effect of riparian restoration for water quality is most visible if land is fenced on both sides of the stream, but this requires the cooperation of multiple landholders. However, despite this, the restoration of riparian vegetation appears to be most beneficial in terms of both reducing vulnerability to existing stressors and increasing resilience to climatic changes and benefits to ecosystem services. Some maladaptive potential has been identified. Under extremely dry conditions, planting of native species would not be undertaken. The incentive programs offered by the CMA are designed to overcome perceived landholder opportunity costs. The restoration of riparian vegetation could contribute to the spread of invasive species and potentially lead to reductions in water availability.

5.5 Freshwater habitat connectivity

This option focuses on the provision of in-stream connectivity. It involves the provision of fishways and fish ladders, the removal of redundant in-stream barriers (such as weirs and road crossings) and the reconnection of wetlands to rivers. Its CCA benefit is that species can migrate into more favourable habitats when conditions become unfavourable.

Migration appears to have been the primary way in which species responded to past climate changes (Lee et al. 2007). The current fragmentation of protected areas poses a problem for migration, especially for those species with poor mobility or those who face human-made barriers (Noss 2001). Habitat connectivity is therefore a necessary component of providing climate refugia if species change their migration patterns due to climatic changes (Lee 2008). The fragmentation of native habitats has also contributed to the decline in aquatic biota (Barrett and Mallen-Cooper 2006) and contributes to the frequency of blackwater events (Hladyz et al. 2009).

other organisms. Although it is a natural occurrence, severe events can sometimes lead to markedly reduced water quality and extensive fish deaths (MDFRC 2009).

There are thousands of weirs, road crossings and other barriers that block fish passage in the basin's streams (Barrett and Mallen-Cooper, 2006). Although there are no systematic programs protecting and restoring key tributaries along the length of the MDB, the 'Sea to Hume Dam' program is a significant project designed to remove identified barriers for fish-passage along the River Murray (Pittock and Finlayson, 2011). A second fish passage project is the Fish Superhighways, the largest fish passage restoration program in Australia (NSW State Water, 2012). The Fish Superhighways project is overseeing the construction of 12 fishways and the removal of six redundant weirs and has so far opened up 1317 km of waterways (Urquhart 2012).

Catchment assessments indicate that freshwater habitat connectivity is directly beneficial to almost all types of ecosystem services and the benefits of re-connection within streams seem to be immediate, as fish move in as soon as barriers are removed. The option also has little maladaptive potential, apart from the potential to benefit movement of carp and other exotics. It was recognised that fishways need minimum flows in order to operate and would cease to function under extremely dry conditions (which has happened during the Millennium Drought). Despite some progress with providing fish passage, large dams (such as the Hume in the Murray and Wyangala in the Lachlan) remain significant obstacles to fish movement.

Few negative socio-economic consequences have been identified in the catchment assessments. It can be argued that farm practices have been planned around the existence of weirs and river flow heights are also altered through weir removal, affecting stock management. In terms of positive socio-economic consequences, recreational fishing benefits significantly from habitat connectivity and can boost local tourism opportunities. For example, the removal of Lake Mokoan seeks to provide social and economic benefits through the development of a regional tourism industry centred on the restored Winton Wetlands and creating local employment opportunities.

5.6 Conservation of more resilient habitats

More resilient habitats include free-flowing or undisturbed rivers as well as rivers with favourable physical characteristics such as a north-south orientation, topographic shading and a gradual habitat gradient. These habitats could potentially conserve freshwater biodiversity under climate change because they may remain cooler, retain natural variability in ecosystem processes, and enable migration of species and ecosystems. The protection and conservation of undisturbed and favourable freshwater systems is likely to provide more biodiversity benefits than heavily regulated or already degraded systems. Actions include fencing and restoring river banks, preventing the regulation and development of these river reaches, and reducing water extractions.

Free-flowing rivers⁴ and rivers with favourable micro-climates may require less intervention (than heavily modified and degraded rivers) and provide more benefits for climate change adaptation. A river with north-south orientation that runs between tall mountain ridges is subject to more shade during the day meaning that the water temperature will not increase as much as other rivers. Elevation increases theoretically also provide opportunities for species and ecosystems to migrate to higher, cooler locations in a warming climate. In the MDB, the conservation of habitat corridors is important to facilitate species movement to higher altitudes (Turak et al, 2011).

The idea of prioritising resilient, rather than degraded, habitats is very well established at state government level in NSW and Victoria. State governments prioritise areas with

⁴ Free-flowing rivers have no (or very few) artificial structures

high conservation values, loosely defined as having multiple environmental benefits (DSE respondent, NOW Respondent). Prioritisation is based on assets such as: the presence of threatened species, breeding habitats for birds, fish and frogs, large diversity of vegetation and habitat size (Murray CMA workshop participant, GB CMA workshop participant). Future climate change considerations are partially incorporated in this approach since habitats being prioritised are the core areas that contain core genetic seed stocks for re-colonisation following shocks such as an extended drought.

However, the definition of resilient habitats still largely rests on an assessment of present conditions, rather than on considerations of where optimal habitat may be located with climate change (workshop participants). The conservation of more resilient habitats becomes more important as conditions get drier, but it was recognised as potentially being maladaptive in that prioritisation of habitats in relatively good condition placed stressed and degraded habitats at a further disadvantage, including those areas that may be more important for conservation in the future.

At a catchment level, CMAs offer incentives to protect intact remnants through a system of Property Vegetation Plans (PVPs) for private land holders. The PVPs were part of native vegetation reform and they are intended to constrain landowner's private activities in order to protect a public good (native vegetation). However, there is a perception in the communities that the value of the property is lessened by having any kind of a covenant or a PVP. Also it appears that PVPs are mostly used as a trade-off to offset development somewhere else.

5.7 Conservation of gaining reaches

Gaining reaches are places along the river where groundwater flows into the stream channel (Pittock and Finlayson, 2011). Conserving freshwater gaining reaches may provide many benefits for biodiversity because groundwater can be a more reliable source of high quality water independent of yearly variability. Actions include establishing conservation zones, riparian restoration and the prevention of excessive groundwater abstraction.

Groundwater needs to be carefully managed in light of its interaction with surface water and climate change. In the MDB, groundwater extraction increased as a response to decreased allocations of surface water (van Dijk et al, 2006). Groundwater recharge depends on factors such as climate, topography, geology and vegetation and operates over long time periods, which means that climate change impacts may not be immediately visible (Bates et al. 2010). There is some evidence that gaining reaches can be cooler than losing or neutral reaches in the same region, providing pockets of thermal refugia (Chessman 2009).

Gaining reaches are being identified in the three catchments and assessed for their potential as fish refuges. During the millennium drought, deep pools (fed by groundwater) were targeted to receive environmental water (if it was available) to keep native fish alive. However, while gaining reaches are linked to fish drought refuges and deep pools, it has been noted that some groundwater patches are hyper-saline. Conserving gaining reaches is beneficial in providing fresh, cool water during periods of low surface flows (assuming that this water was not saline), and assists with the dilution of salinity, turbidity and temperature issues. Thus the effectiveness of the action would increase under dryer climate change scenarios, and would not be a priority in very wet conditions.

There is great awareness of ground-surface water interactions and that groundwater usage has an effect on gaining reaches (especially on the Belabula River in the Lachlan Catchment). Thus protection of gaining reaches must be done in conjunction with sustainable groundwater management, which depends on groundwater-sharing

plans that are established and reviewed through state government processes. The action does have an opportunity cost, since landholders may face restrictions on pumping groundwater.

5.8 Geomorphic restoration

Geomorphic restoration involves improving the stream substrate to retain and enhance the various niches that particular aquatic biota require to thrive. For instance, deep pools in the stream bed may provide drought refuge for fish under climate variability and change, but they are at risk of sedimentation. Actions include conserving deep pools, controlling bank instability and erosion, stabilising or removing sand slugs and re-snagging.

Geomorphic restoration plays an important role in protecting and maintaining aquatic refugia that include waterholes, lagoons and deep pools, as well as logs, wet patches under banks, riffles, sub-surface stream sediments, yabby holes, and littoral and riparian vegetation (Bond et al. 2008). Deep pools are especially important as thermal and hydrological refuges, especially for coldwater fishes (Chessman 2009). The survival of aquatic biota in refugia increases their capacity to recover from shocks such as drought (Lake 2003). The restoration and protection of deep pool refugia may be of more importance than the provision of suitable habitats in water bodies that experience frequent disturbances (such as extreme floods and droughts) (Bond and Lake 2005). Re-snagging (using timber structures) provides a diversity of in-stream habitat offering shelter and spawning sites to fish and other aquatic biota. It has been proven to be an effective way to increase the abundance of fish, but its success depends on permanent flows (Bond and Lake 2005). Miller, Buddy and Schmidt (2010) found that restoring in-stream habitats with woody debris significantly improved the number of macro-invertebrate taxa but had little effect on macro-invertebrate density. They also found that greater improvement was seen if in-stream restoration was coupled with riparian revegetation (Miller et al. 2010), once again underscoring the importance of undertaking a suite of complementary restoration activities.

The big question with geomorphic restoration is whether it actually increases the population of native fish. Monitoring done in the three catchments indicates that snags are almost immediately utilised by native fish – but are fish populations increasing or simply being moved around? Monitoring in the Goulburn Broken is currently being undertaken to answer that question.

There is an acknowledgement that any improvement of fish habitat has the potential to improve the habitat for exotic species such as carp and *Gambusia*. Therefore, the management of exotic species really complements geomorphic restoration.

In this project, discussions of geomorphic restoration in the Murray, Lachlan and Goulburn Broken catchments have shown that it is more directly beneficial than detrimental in terms of increasing resilience and reducing vulnerability to climate change impacts. In terms of effectiveness under different climate change scenarios, very wet conditions could undo a lot of the restoration works and may be unnecessary. The benefit to ecosystem services would be high, with examples mainly concerning the role of deep pools during droughts (providing drinking water and fish refuges, increasing fishing opportunities).

Restoration actions are perceived in some sections of the community as increasing the risk of flooding, and there is some uncertainty over the release of methane and other carbon gases from sediments that are disturbed by geomorphic restoration works. Also, re-snagging can potentially alter local hydraulic functions to relocate problems downstream.

5.9 Management of exotic species

Preventing the introduction of exotic species, identifying and eradicating incursions and sleeper species (species that may become a greater threat in the future), preventing the spread and containing species that are beyond eradication are all interventions for controlling invasive plants and animals. Control of exotic species will decrease the vulnerability of native flora and fauna to the climate induced spread of invasive species. Actions include identification and eradication of newly observed invasive species, controlling vectors like the aquarium and nursery trades, weeding, the removal of exotic trees from riverbanks, fencing and installing carp cages in streams.

Discussions of exotic species have focused on willows and carp (as iconic examples of exotic flora and fauna). Willow removal and replacement with native vegetation constitute a significant and ongoing management activity in most catchments. It faces some opposition from a small section of the community, which believes that willows are good for erosion or who have an emotional connection to willows.

CMAs acknowledge that carp eradication is impossible: carp-control programs aim to reduce the overall carp biomass. Carp harvesting programs (using carp cages) are planned for the Murray and Lachlan catchments to establish a carp harvesting industry. However, in the Goulburn Broken, carp management is not prioritised because of a belief that, due to the interconnectedness of the freshwater systems, carp harvesting is a futile activity. Programs to turn carp harvesting into an economically viable business are difficult to accomplish due to the relative low value of carp. Furthermore, Jackson (2009) estimates that a viable commercial utilisation of harvested carp for a crayfish bait or fertiliser business would require in the order of 40 to 50 tonnes of carp per annum.

Exotic species management is very beneficial in terms of reducing vulnerability to existing stressors, but the opportunity costs and failure risks of individual actions are species-dependent and could vary from negligible to high. Effectiveness would decrease under wetter conditions, since most non-native flora and fauna rejuvenate during wet conditions and droughts act as a natural barrier. Carp control could also have the potential to lead to bird decreases by removing carp as a food source for birds, or other unforeseen changes in the ecological state.

Nevertheless the management of exotic species can provide local economic benefits. For example, pig traps used in the Lachlan are locally produced. The CMAs are also trying to get employment opportunities for Aboriginal people in weed management by providing funding for training and equipment in weed removal. However, these opportunities are reliant on short-term (12 months) funding and do not create long-lasting employment.

6. THE CCA CATCHMENT ASSESSMENT FRAMEWORK

In this section, we detail the CCA Catchment Assessment Framework in relation to the three catchments. The CCA CAF is an advisory, rather than a directory tool. It considers relevance, climate change adaptation benefits, maladaptation potential, ecosystem services benefits, implementation constraints and the risk of adaptation failure. It is meant to highlight a suite of options to enable decision-makers to select those that present the maximum amount of benefits along with the least amount of risk.

Each section of the CCA CAF is introduced below and explained individually. Each section contains a table that summarises results from the workshop. However, results of the interviews, workshop discussions and literature searches are then incorporated into discussions that follow each table. The completed CCA CAF for each catchment summarises each individual section and is located at the end of the document (Appendix 1). The tables should be viewed as a summary of discussion points that need to be considered rather than a directive tool that decides the 'best' option.

6.1 Catchment relevance

In the Catchment Assessment Framework, we describe the relevance of each of the nine options for the catchment using the following categories, based on stakeholder interviews and grey literature reviews:

- Currently Implemented (CI) at least in part
- Not Yet Implemented (NYI)
- Considered and Rejected (CR)
-

Table 6: Catchment relevance of each measure

Measures	Murray	Lachlan	Goulburn Broken
Environmental flows	CI	CI	CI
Environmental works and measures	CI	NYI	NYI
Thermal pollution control	CR	CR	CR
Restoration of riparian vegetation	CI	CI	CI
Freshwater habitat connectivity	CI	CI	CI
Conservation of more resilient habitats	CI	CI	CI
Conservation of gaining reaches	CI	CI	CI
Geomorphic restoration	NYI	CI	CI
Management of exotic species	CI	CI	CI

6.2 Climate change adaptation benefit

The climate change adaptation potential is established by considering how each option either reduces vulnerability to existing stressors and/or increases resilience to climatic changes. Non-climate stressors affecting freshwater bodies include habitat fragmentation, river regulation, rising salinity, erosion, biodiversity loss and decreasing water quality. Several criteria have been developed to determine the adaptation potential of the nine options (through reviewing climate change literature, consultations with experts and the technical workshop):

- 1 Reducing vulnerability caused by non-climate change stressors:
 - Conserves or restores past or existing habitat refugia.
 - Mitigates cold water pollution from dams.
 - Mitigates other reductions in water quality (such as salinity, turbidity).
 - Reduces the sediment budget.
 - Prevents or reduces invasion by exotic species.
- 2 Increasing resilience to climatic shocks/changes:
 - Conserves or enables access to future habitat.
 - Extends habitat connectivity and migration paths for biota.
 - Mitigates changes in water volumes.
 - Mitigates changes in water temperatures (higher in-stream water temperature).
 - Mitigates changes in the timing of water flows (due to changed rainfall patterns, frequency and duration of extreme events).
 - Mitigates carbon emissions.
 - Preserves genetic stock.

See Table 7⁵ for an initial assessment that was completed during the CMA workshop in August 2012. The table utilises ticks and crosses to indicate the *presence* and *desirability* of impacts for each option without indicating their *magnitude* which would have been too difficult to gauge, given the discussions below.

⁵ Legend for Table 7

✓	Potentially directly beneficial	M	Murray CMA
✗	Potentially directly detrimental	L	Lachlan CMA
?	Unknown impact	GB	Goulburn Broken CMA
	No direct impact		

Table 7: CCA potential of each option in the three catchments

		Environ-mental flows			Environment al works and measures			Thermal pollution control			Restoration of riparian vegetation			Freshwater habitat connectivity			Conservation of resilient habitats			Conservation of gaining reaches			Geomorphic restoration			Management of exotic species		
		M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB
Reducing vulnerability caused by non-climate change stressors	Conserves or restores past or existing habitat refugia	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	Mitigates thermal pollution	✓	✗		✓			✓	✓	✓	✓	✗	✓					✓	✓	✓								
	Mitigates other reductions in water quality	✓	✓	✓		?	✓✗	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓✗	✓✗	✓✗	✓	✓	✓	✓	✓	✓
	Reduces sediment influxes	✓	✗	✓	✓		✓				✓	✓	✓			✗	✓	✓	✓			✓	✓	✓	✓	✓	✓✗	
	Prevents or reduces invasion by exotic species	✗	✗	✗	✗	✗	✗			✓	✓	✓	✓	✗	✗	✗		✓	✓				✗	✓	✓✗	✓	✓	✓
Increasing resilience to climatic shocks/ changes	Conserves or enables access to future habitat	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	
	Extends habitat connectivity and migration paths for biota	✓	✓	✓	✓		✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	
	Mitigates changes in water volumes	✓	✓	✓	✓	✓	✓				?		?							✓	✓	✓	✓		✓	✓	✓	
	Mitigates changes in water temperature	✓	✓		✓			✓	✓	✓	✓	✓	✓							✓	✓	✓		✓	✓		✓	
	Mitigates changes in the timing of water flows	✓	✓	✓	✓	✓	✓					✓									✓	✓			✓			
	Mitigates carbon emissions	?	✓✗	?	?	✓✗	?	?	?		✓	✓	✓				✓	✓	✓							?		
	Preserving genetic stock	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

6.2.1 Discussion of adaptation benefits

The restoration of riparian vegetation appears to be most beneficial in terms of both reducing vulnerability to existing stressors and increasing resilience to climatic changes in all three workshops. It was followed by environmental flows, conservation of gaining reaches, conservation of resilient habitats and geomorphic restoration. All of the nine options conserve present habitat refugia, and therefore preserve genetic stock. Interestingly, the option with the most identified negative impacts was the provision of environmental flows. However, since environmental flows are regularly utilised and discussed in water management, it could be that much more is known about their effects (both beneficial and detrimental) than some of the other options.

During discussions of climate change adaptation benefits, Murray workshop participants raised the issue of methane emissions rising from freshwater bodies and questioned the ability of environmental water, environmental works and measures, and thermal pollution control to mitigate carbon emissions. There is also a question mark against the mitigation of changed water volumes under restoration of riparian vegetation since workshop participants were unsure how riparian vegetation affects overbank flooding.

The conservation of gaining reaches was thought to be both directly beneficial and detrimental to the mitigation of other reductions in water quality in the Murray system because groundwater sources are generally believed to positively contribute to water quality unless the groundwater itself is saline (as some are in the Murray Catchment), in which case it would be detrimental to water quality.

In the Lachlan Workshop, CMA representatives pointed out that the effects of riparian vegetation would differ between upper and lower parts of the Lachlan Catchment. For example, in discussing the mitigation effects of changes in the timing of water flows, it was thought that riparian vegetation would extend the time and concentration of floods and flatten the flood peak in the middle and upper Lachlan. The conservation of gaining reaches was also thought to positively impact on the mitigation of changes in the timing of water flows, as it was noted that conservation of the Boorowa River maintained base flows during the last drought.

The provision of environmental flows was thought to be directly detrimental to mitigating thermal pollution in the Lachlan because the flows would come out of Wyangala Dam, the main source of cold-water pollution in the Lachlan. Geomorphic restoration was found to be beneficial for mitigation of changes in water temperature through maintenance and protection of deep pools that provide a source of cooler groundwater to surface water streams heated up through increased temperature. The management of exotic species was thought to be directly beneficial for reducing the sediment budget and mitigating change in water volumes. It was also thought that the removal or reduction of carp would act positively on the sediment budget, while the removal/poisoning of willows would mitigate changes in water volumes since willows are known to impact water availability.

Goulburn Broken workshop participants discussed the sediment budget at length, and differentiated between longitudinal and lateral sedimentation. They also pointed out that there are two types of thermal pollution: cold-water pollution from dams (addressed through thermal pollution control) and rising water temperatures caused by climate changes in temperature and water availability (addressed through riparian reforestation).

The Goulburn Broken workshop participants highlighted that the management of exotic species has different outcomes depending on whether one is dealing with the flora or fauna. Hence managing carp is directly beneficial for reducing the sediment load;

however, the removal of willows may lead to increases in the sediment load, which is undesirable. On the other hand, the removal of willows can mitigate changes in water flows locally because once willows are removed, greater water volumes are available on a local scale.

Workshop discussions also highlighted that impacts would differ under different timeframes. So the management of exotic species can mitigate changes in water temperature in the long term. If full-grown willows are uprooted and replaced with native seedlings, it means shade is initially lost until the seedlings grow and are able to provide shade and shelter.

In terms of carp management, the CMA is actively restoring habitat for native species in an effort to reduce the numbers of exotic fish. However, there is an acknowledgement that any improvement of fish habitat has the potential to improve the habitat for exotics. That is why geomorphic restoration was thought to be both detrimental and beneficial, with the assumption that the direct beneficial impacts of improving native fish numbers by re-snagging and geomorphic restoration would be much greater than the directly detrimental impacts of indirectly improving the habitat for carp. Geomorphic restoration was also thought to be beneficial for mitigating higher in-stream temperature because of the protection, maintenance and restoration of groundwater-fed deep pools.

There was a lot of uncertainty about the impacts of environmental flows and EWMs on carbon emissions in the Barmah Forest. Environmental water can lead to greater vegetation growth, which would have potentially beneficial impacts on carbon emissions (but would that impact be big enough to make a difference?). Participants expressed a lot of uncertainty over the potential methane emissions from movements of large amounts of water.

The effect of riparian restoration on the reduction of the sediment load was discussed at length, especially the differences between increases in longitudinal and lateral sedimentation. The CMA representatives pointed out that point-source pollution is adequately controlled within the catchment. Riparian vegetation is thought to be beneficial for water quality if the influx of sediments come from near-stream and in-stream sources.

6.3 *Adaptation effectiveness under different climate change scenarios*

In order to investigate the benefit of the nine measures for climate change adaptation, we considered how their usefulness would be affected by climate change projections. To do this, we turned to the widely used CSIRO sustainable yields projections for 2030 that model how surface water availability would change under degrees of wet and dry climatic changes (CSIRO 2008d). The 2030 scenarios were chosen rather than the 2070 ones because they have more relevance to the short- and medium-term planning that is in evidence in the three catchments.

The three sustainable yields scenarios (wet, moderate and dry) are summarised in

Table 4 for all three catchments. However, for this assessment, we have added a fourth 'very dry' scenario, based on the peak of the millennium drought. This was thought to be necessary because the reduction in surface water availability in the last drought represents a short-term historical extreme, and provided an opportunity to test the adaptation measures against the extreme conditions. Thus the very dry scenario has been included as a worst case.

- 1 At the Murray workshop, it was suggested that the surface water availability decreased by 65% along the River Murray during the peak of the drought.
- 2 The Lachlan River ceased to flow west of Condobolin at the peak of the drought (November 2009), when the New South Wales state government halved the flows from Wyangala Dam (Wilkinson and Cubby 2012).
- 3 In the Goulburn Broken, the Northern Region Sustainable Water Strategy (2009, p. 22) modelled water availability for Victorian river systems and estimated that if the low inflows of 1997–2007 and the extremely dry years of 2008 and 2009 continued, the share of water available to Victoria as a whole would decrease by 49% of the pre-1997 average, while inflows into the Broken river system would decrease by 53% and inflows into the Goulburn river system would decrease by 49%.

This assessment of the climate change scenario against each option was based on expert judgement from the project research team and CMA representatives (including consultations with scientists researching these options), which was then checked against the literature. A 'current conditions' column was added during workshops, since the three workshops took place soon after a flood of the system and workshop participants in all three catchments judged the current conditions of the time to be unusually wet. See Table 8 for an initial assessment.

Table 8: Effectiveness of various CCA options under different climate change projections

CCA Options	Current Conditions			Wet			Moderate			Dry			Very Dry		
	M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB
Environmental Flows															
Environmental Works & Measures															
Thermal Pollution Control															
Restoration of Riparian Vegetation															
Freshwater Habitat Connectivity															
Conservation of more Resilient Habitats															
Conservation of Gaining Reaches															
Geomorphic Restoration															
Management of Exotic Species															

Legend for Table 8



likely to be effective and beneficial



Murray CMA

	less effective or with lower benefits		Lachlan CMA
	not effective or redundant		Goulburn Broken CMA
	not applicable to current conditions		

This table utilises a traffic light approach by categorising each option under the four climate change projections and current conditions:

- green (likely to be effective and beneficial)
- amber (less effective or with lower benefits)
- red (not effective or redundant)
- white (not applicable to current conditions).

This is a similar approach to that used by Gross et al. (2011) in their study of climate change adaptation limits in the Coorong and Lower Lakes.

An option will thus be rated green if it meets one or more of the above criteria. However, the same option could rate as amber under a different climate change projection if the effectiveness of the option decreased and red if the extreme climate change projection rendered it ineffective or redundant. White is only used in the assessment of current conditions to indicate that the option is currently not being pursued in the catchment.

6.3.1 Discussion of option effectiveness under different climate change projections

All three workshop discussions revealed that, as the conditions became drier, CMA goals and objectives would change from restoration and expansion of biodiversity assets under wetter conditions to the protection of refugia under drier periods. Lachlan workshop participants pointed out that the effects of the nine options under different climate change scenarios would very much depend on the various Water Sharing Plans that were in place.

In the Murray CMA workshop, environmental flows were rated amber under the wet scenario because they were thought to be less effective in naturally wetter conditions and red under the extreme dry scenario because of the assumption that there would be no or very little environmental water under prolonged extreme dry conditions.

EWMs referred to by the Murray workshop participants are the Koondrook-Perricoota (KP Works, representing large infrastructure projects). They are rated as red under the wet scenario because they are seen as redundant and red under the extremely dry scenario because of the no-water assumption. They are rated as green under current conditions because they are achieving their goals of allowing the ecological systems to recover from the drought. The CMA believed that the smaller infrastructure projects would be rated green under all conditions (including both climatic extremes).

In the Murray workshop, restoration of riparian vegetation and freshwater habitat connectivity was rated amber under the extreme dry scenario because in extremely low flows the fish ladders would stop operating (as had happened during the recent drought) and large-scale plantings would not be attempted. The conservation of more resilient habitats and gaining reaches was rated amber in a wet scenario, as it was thought to be less important. Geomorphic restoration was rated amber only under the wet scenario because the increased volumes of water could damage/undo a lot of restoration.

Lachlan workshop participants thought that both thermal water pollution control and EWMs would be progressively less effective the drier the scenario, and redundant under very dry conditions. The drought peak scenario assumes there will be very little water stored in dams (with no chance for stratification to occur, and thus no cold water pollution) and low to non-existent flows through the river system (making environmental works and measures redundant).

Lachlan workshop participants also rated environmental flows, and EWMs were less effective under the wet scenario since they would not be needed. Freshwater habitat connectivity, geomorphic restoration and the management of exotic species were rated as less effective under current (extremely wet) conditions because the latter two were judged to be unnecessary post-flooding, while the management of exotic species has been made more difficult as both native and non-native flora and fauna rejuvenate after the drought.

There was a lot of discussion around EWMs in the Goulburn Broken workshop. The Northern Victoria Irrigation Renewal Project is generally considered to be an example of a EWM. However, in this research project, we have limited the definition of EWMs to works designed to divert water and pool it on floodplains. Since the NVIRP does not meet our definition of EWMs, the Goulburn Broken CMA's assessment of EWMs in Table 8 is generic and not referring to a specific project. There was an understanding that in the current conditions there are limited opportunities for the CMA to undertake further EWMs. It was also pointed out that EWMs would only work on regulated streams and not on unregulated ones; however, regulated streams are more numerous in the Goulburn Broken Catchment.

In the Goulburn Broken workshop, there was also discussion around the effectiveness of riparian vegetation in the very dry scenario, and it was decided that the green categorisation assumes already established vegetation and also assumes that revegetation activities would not be initiated in the very dry scenario.

6.4 Potential for maladaptation

The maladaptation potential of the nine options was evaluated through the expert judgement of the project team and CMA representatives, and a review of grey and academic literature. For each option, we listed the existing or likely maladaptations and ranked them as non-existent/negligible; medium; high; and unknown. This type of ranking allowed us to show the magnitude of the maladaptation. These rankings are based on expert judgement.

Six types of maladaptation are possible (Barnett and O'Neill 2010):

- 1 Increasing emissions:
 - Adaptation is maladaptive if actions end up contributing to climate change. For example, the increased use of energy-intensive air conditioners in response to the health impacts of heat-waves
- 2 Disproportionate burden on the most vulnerable:
 - Adaptation actions are maladaptive if, in meeting the needs of one sector or group, they increase the vulnerability of those most at risk (like minority groups or low-income households) or shift the consequences to another sector or group
 - In this project, we also want to include most vulnerable ecological communities

3 High opportunity costs:

- Approaches may be maladaptive if their economic, social, or environmental costs are higher relative to alternatives

4 Reducing incentive to adapt:

- If adaptation actions reduce incentives to adapt, for example by encouraging unnecessary dependence on others, stimulating rent-seeking behaviour, or penalising early actors, then such actions are maladaptive.

5 Path dependency:

- Large infrastructural developments commit capital and institutions to trajectories that are difficult to change in the future, thus decreasing flexibility to respond to unforeseen changes in climatic, environmental, economic and social conditions

6 Increasing existing stressors:

- Adding further stress to already degraded ecosystems reduces their adaptive capacity to deal with climate change impacts. For example, actions like promoting plantations for carbon sequestration may lead to reduced water availability downstream which may place further stress on already degraded water ecosystems.

See Table 9⁶ for an initial CMA assessment completed during the CMA workshops in August. The ranking in this table represent the *magnitude* of impacts for different options without indicating whether it is desirable, positive and negative.

⁶ **Legend for Table 9**

•	Maladaptive potential is negligible	M	Murray CMA
•	Medium maladaptive potential	L	Lachlan CMA
●	High maladaptive potential	GB	Goulburn Broken CMA
?	Maladaptive potential is unknown		

Table 9: Maladaptation potential of the CCA options

	Increasing emissions			Disproportionate burden on the most vulnerable			High opportunity costs			Reducing incentive to adapt			Path dependency			Increasing existing stressors		
	M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB
Environmental flows	?	•	•	•	•/●	•	•/•	•	•	•	•	•	•	●	•	•/•	•	•
Environmental works and measures	•/•	•/•	•/•	•/●	•	•	•/●	●	•	?	?	?	●	●	●	•	•	•
Thermal pollution control	•/•	•/•	•/•/?	•	•	•/•	●	●	●	•	•	•	•	•	•	•	•	•
Restoration of riparian vegetation	•	•	•	•	•	•	•/•	?	?	?	•	•	•	•	•	•	•	•/?
Freshwater habitat connectivity	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Conservation of more resilient habitats	•	•	•	•	•	•	?	•	•	?	•	•	•	•	•	•	•	•
Conservation of gaining reaches	•	•	•	•	•	•	?	•	•/•	•	?	?	•	•	•	•	•	•
Geomorphic restoration	?	•	•	•	•	•	•	•/•	?	•	•	•	•	•	•	•	•	•
Management of exotic species	•	•	•	•	•	•	•	•→●	●	•	•	•	•	•	•	•	•	•

6.4.1 Discussion of maladaptation potential

Some participants pointed out that the magnitude of maladaptation potential depended on one's point of view. Therefore, some options in Table 9 have more than one measure to acknowledge that while potential maladaptation may be negligible for the CMA as an organisation, it may have greater negative impacts on other parties, such as individual landholders. Regarding thermal pollution control, for example, Goulburn Broken workshop participants pointed out that the magnitude of maladaptation potential did depend on one's point of view: thermal pollution control would have a negative effect on the trout industry (commercial fishing and recreation) in the mid-Goulburn region. This negative impact was judged to be medium by the CMA participants, but they did acknowledge that the industry itself would probably rate that impact as high.

In the Murray workshop, a distinction was also made between large-scale environmental works like the Koondrook-Perricoota structures and smaller-scale weirs on tributary creeks. The maladaptation potential of larger structures differs from smaller structures in several respects, as explained below.

The contribution of EWMs to emission increases was discussed in all three workshops. Small-scale pumping (which does increase emissions) has been utilised in the Lachlan in the past and is currently utilised in the Murray. Large-scale gravity-fed regulators (such as the Koondrook-Perricoota works) would not require electricity to operate, but do require the building of substantial infrastructure. The potential to increase emissions through thermal pollution control was also discussed in all workshops and was seen to be dependent on which thermal pollution control method is used. The operation of multi-level off-take towers would not increase emissions, but the operation of curtains or propellers would. The workshop participants also expressed uncertainty over the possibility of greater methane emissions due to the disruption of water stratification.

In the Murray workshop, there was uncertainty (and hence a question mark) over the potential increase in emissions from releasing methane and other carbon gases from sediments disturbed by the provision of environmental flows and geomorphic restoration works. Such a release is possible, but the extent to which it would constitute a problem is unknown. These releases were also discussed in the Goulburn Broken workshop, where it was thought that it would have negligible consequences for increasing emissions in streams, but the effect of environmental water provision over floodplains were unknown.

The discussion of potentially placing a disproportionate burden on the most vulnerable people focused on irrigation communities in all workshops through the acquisition of environmental flows. There was a strong feeling among the participants in all workshops that the acquisition of water for environmental flows was placing real and perceived stress on water-using communities at the local and regional scale, regardless of Commonwealth and Basin-wide reports to the contrary (Arthur 2010; NWC 2009).

Environmental flows also result in overbank flooding of private lands which led to loss of access for farmers and sometimes crop and infrastructure damage. This was highlighted in the Murray workshop and mentioned in the other two. In the Lachlan workshop, environmental flows were perceived by the CMA participants to transfer water benefits from irrigation to grazing. It is recognised that environmental flows have negative effects on irrigation activities: they can compete with irrigation water and overbank flooding can submerge irrigation equipment, but environmental flows are overall very positive for grazing as overbank flooding deposits moisture and nutrients for pastures, and stock (unlike crops) can be moved from the paddocks during flooding. Since the environment is one of the biggest water users in the Lachlan Catchment, the provision of environmental flows can affect productive enterprises (Lachlan OEH Respondent).

A particularly interesting point was raised in the Murray workshop during a discussion on the limitations of EWMs. The fact that these works can only flood easily accessible sites means that ecological communities in elevated or hard-to-reach places were being left unwatered. An argument could therefore be made that reliance on EWMs places those ecological communities at a significant disadvantage, and increases their vulnerability to climate change. A similar concern was expressed in workshops over the CMA's practice of prioritising more resilient habitats. There is recognition that this creates a disproportionate burden on the non-targeted communities. Effectively, those ecological communities that are already fragmented and degraded are further marginalised because investment is concentrated in more intact, more valuable habitats.

A high opportunity cost occurs when the option has higher environmental, social or economic costs than its alternatives. This idea of opportunity cost often seemed to get lost in discussions that kept on revolving around high economic costs. In the Murray and Lachlan workshops, economic opportunity costs were the primary consideration when assigning a high maladaptive potential to the environmental works and measures option, as it was agreed that water buybacks were more financially effective than large infrastructure projects. However, it was pointed out in the Murray that smaller works and measures have lower economic costs. Murray participants thus decided that opportunity costs for big infrastructure projects like the Koondrook-Perricoota were higher than for smaller regulators on tributaries. In this case, it was clear that this referred to economic as well as the environmental and social costs. In the Goulburn Broken workshop, participants rated the opportunities costs of EWMs as negligible, since some works can reduce the cost of environmental water delivery (depending on location). Thermal pollution control was judged to have high financial costs relative to effectiveness in both the Lachlan and Goulburn Broken workshops. However, some participants in the Murray workshop argued strongly that the high financial cost was not that much when compared to the amount of public funds allocated to water management in the basin.

Differences in points of view were prominent in the discussion of opportunity costs for the restoration of riparian vegetation and the conservation of more resilient habitats. There was recognition in all the workshops that, while there were negligible opportunity costs for the CMA, they were higher or unknown for landholders. Individual opportunity costs and benefits would greatly depend on the values, beliefs and circumstances of individual landholders. Different financial incentive programs offered by the CMAs were designed to overcome perceived landholder opportunity costs.

In all three workshops, participants rated the freshwater habitat connectivity option as having a medium potential for maladaptation because they viewed fish ladders and weir removal as moderately expensive, but very effective. The opportunity costs for the conservation of gaining reaches were unknown in the Murray, medium in the Lachlan and small to medium in the Goulburn Broken because all participants recognised that sustainable groundwater management in the connecting aquifers is required to conserve gaining reaches, and that is an opportunity cost for landholders who would have to limit their reliance on groundwater for productive purposes.

Workshop participants were unsure of the opportunity costs of geomorphic restoration, with Murray participants rating the opportunity costs as medium, Lachlan participants as negligible or medium and Goulburn Broken participants rating as unknown. However, monitoring is currently being done in the Goulburn Broken catchment to determine whether the way geomorphic restoration is done is the most effective method. The estimates of opportunity costs also varied for the management of exotic species, with Murray participants rating them as negligible and Goulburn Broken participants rating them as high. In the Lachlan workshop, it was decided that

opportunity costs for the management of exotic species were entirely species-dependent and could vary from negligible to high.

Assessing the 'reducing incentive to adapt' maladaptation was difficult. It was agreed in all three workshops that the potential was unknown for EWMs because the idea of conserving more with less for the environment may decrease political will to decrease water extractions. In the Murray workshop, the potential was also unknown for the restoration of riparian vegetation and the conservation of more resilient habitat (because the impetus to implement climate change adaptation may be reduced outside of the targeted areas). The maladaptive potential of conservation of more resilient habitats was judged to be medium in the Goulburn Broken for this reason.

In both the Lachlan and Goulburn Broken, the potential was also unknown for the conservation of gaining reaches, since the action by itself is insufficient and requires sustainable groundwater management in the connected aquifer and management actions required to conserve groundwater may be resisted by some landholders. The potential of environmental flows to reduce the incentive to adapt was rated as medium in the Murray because flooding improves grazing potential and therefore can reduce the incentive to improve grazing management.

The potential of path-dependency was overall negligible except for the EWM option, where it could be argued that the building of new infrastructure (especially large-scale works) increases the political impetus for it to be used for the life of that infrastructure. However, the Lachlan workshop also rated environmental flows as having high maladaptive potential to create path dependency, because they are seen as the primary response to climate change adaptation. Reliance on only one option for climate change adaptation may lead to a reluctance to consider other climate change adaptation approaches. Also in the Lachlan, the management of exotic species was rated as having a medium potential for path dependency because it leads to landholder reliance on government pest-control programs (as opposed to individual efforts).

In terms of increasing existing stressors, environmental flows, environmental works and measures, and freshwater habitat connectivity may all assist in the spread of invasive species (especially carp). However, in the Goulburn Broken workshop, the effects of environmental flows and EWMs were thought to be no different from natural flows. Goulburn Broken participants also pointed out that EWMs can exacerbate salt loads and algal blooms, and that there is potential for environmental flows to assist in the spread of insect-borne diseases, although the likelihood is unknown.

Murray participants recognised that the restoration of riparian vegetation can potentially lead to reductions in water availability, and Goulburn Broken participants pointed out that the contribution of riparian revegetation to fire risk was unknown. In the Goulburn Broken, geomorphic restoration and the management of exotic species (specifically willow removal) were both thought to be perceived by the community as increasing the risk of flooding and bank instability respectively.

6.5 Ecosystem services benefits

This analysis is based on information from stakeholder interviews and technical reports. It uses the concept of ecosystem services identified in the MDB, described in Reid-Piko et al. (2010). The types of ecosystem services identified in the basin are explained and listed below.

- *Provisioning services:* provide or produce goods such as food, fibre, fuel, genetic resources, biochemicals, natural medicines and pharmaceuticals, ornamental resources and fresh water.

- *Regulating services*: include benefits gained from regulation of ecosystems such as air quality regulation, climate regulation, water regulation, erosion regulation, water purification and waste treatment, disease regulation, pest regulation, pollination and natural hazard regulation.
- *Supporting services*: those that underpin the other services; include soil formation, photosynthesis, primary production, nutrient cycling and water cycling.
- *Cultural services*: can include non-material benefits such as cultural diversity, spiritual and religious values, knowledge systems, educational values, inspiration, aesthetic values, social relations, sense of space, cultural heritage values and recreation and ecotourism.

Systemic consequence refers to reaching an ecological threshold that signals a change of the ecosystem into an alternate state (see Nelson et al. 2007 for an explanation of resilience concepts). For example, the change in climatic conditions may result in a decrease of one exotic pest and emergence of another that has profound but different effects on the ecosystem. Table 10⁷ matches the adaptation options against the ecosystem services that they support. It was completed during the CMA workshop in August. The table also indicates the *presence* and *desirability* of impacts for different options.

⁷ **Legend for Table 10**

✓	Potentially directly beneficial
✗	Potentially directly detrimental
?	Unknown impact
	No direct impact

M	Murray CMA
L	Lachlan CMA
GB	Goulburn Broken CMA

Table 10: Ecosystem services of the nine options

Ecosystem Services		Environmental flows			Environmental works and measures			Thermal pollution control			Restoration of riparian vegetation			Freshwater habitat connectivity			Conservation of resilient habitats			Conservation of gaining teaches			Geomorphic restoration			Management of exotic species		
		M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB
Provisioning services	Drinking water for humans and/or livestock	✓	✓	✓x	✓		✓				✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓
	Food for livestock	✓x	✓		✓	✓					✓	✓	✓			✓	✓			✓		✓				✓x	✓	✓
	Wood, reed, fibre and peat	✓	✓		✓	✓	✓				✓	✓	✓			✓	✓	✓	✓	✓		✓	✓					
	Medicinal products	✓	✓	✓	✓	✓	✓				✓	✓	✓				✓	✓	✓	✓		✓	✓					
	Other products and resources (genetic material)	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Regulating services	Groundwater replenishment	✓x	✓	✓	✓x	✓	✓				✓x					✓	✓x		✓	✓	✓	✓				✓x		
	Water purification/waste treatment or dilution	✓x	✓	✓	✓x		✓	✓	✓	✓	✓			✓	✓	✓	✓		✓	✓x	✓	✓x			✓	✓	✓	✓
	Biological control agents for pests/disease	✓		✓	✓		✓				✓	✓	✓	✓x		✓	✓	✓	✓						✓	✓	✓	✓
	Flood control, flood storage				✓	✓	✓				✓x	✓	✓	✓		✓	✓	✓	✓				✓	✓	✓			✓
	Coastal shoreline, river bank stabilisation, storm protection				x	✓					✓	✓	✓			✓	✓		✓	✓		✓	✓	✓	✓	✓x	✓	✓
	Local climate regulations/ buffering change	?			?						✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
	Carbon storage/sequestration	?	✓	✓	?	✓	✓				✓	✓	✓			✓	✓	✓	✓			✓				?		
	Hydrological maintenance of biogeochemical processes	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓

Ecosystem Services		Environmental flows			Environmental works and measures			Thermal pollution control			Restoration of riparian vegetation			Freshwater habitat connectivity			Conservation of resilient habitats			Conservation of gaining reaches			Geomorphic restoration			Management of exotic species		
Supporting services	Nutrient cycling	✓	✓	✓	✓	✓	✓	✓ x			✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	
	Primary productivity	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓ x		✓		
	Sediment trapping, stabilisation and soil formation	✓	✓	✓	✓						✓	✓	✓			✓	✓		✓			✓	✓	✓	✓ x		✓	
	Physical habitat	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓	
	Systemic consequence (ecological surprise)	✓	✓	✓	✓	✓	✓				✓		✓	✓	✓	✓	✓	✓	✓			✓			✓		✓	
	Natural or near-natural wetland ecosystems	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	Priority wetland species and ecosystems	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	Ecological connectivity	✓	✓	✓	✓ x	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓ x	✓	✓
	Threatened wetland species, habitats and ecosystems	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Cultural services	Science and education values	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	Cultural heritage and identity	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	Contemporary cultural significance	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	Aesthetic and sense of place values	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓ x	✓	✓ x	
	Spiritual, inspirational and religious values	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓			✓	✓	

6.5.1 Discussion of ecosystem services

Discussions of ecosystem services were fairly provisional due to the large amount of services listed. This discussion was left out of the Lachlan CMA workshop due to time constraints. However, Lachlan CMA input was provided via electronic communications from two participants after the workshop. The participants focused on identifying direct benefits and did not identify knowledge gaps or detrimental impacts.

Provisioning services

When discussing provisioning services, the provision of drinking water and food for livestock was most prominent in all three workshops. Murray CMA participants pointed out that smaller environmental works and measures structures placed on tributary streams have the potential to provide these, rather than the large-scale works and measures projects like the KP Works. In the Lachlan workshop, it was thought that, apart from environmental flows, the restoration of riparian vegetation would be directly beneficial because it would improve downstream water quality, while the conservation of gaining reaches would ensure that water was available during droughts (since groundwater-fed systems are less likely to dry out). In terms of providing food for livestock, environmental flows can be both directly beneficial and detrimental because they eliminate pastures during flooding, but enhance their quality after floodwaters recede. Goulburn Broken workshop participants noted that in terms of providing drinking water for livestock, environmental flows can be both directly beneficial and detrimental because they ensure water in waterways, but can cause blackwater events that would make water undrinkable. Both environmental water and EWMs were thought to indirectly contribute to groundwater replenishment through groundwater–surface water interactions. Murray workshop participants pointed out that geomorphic restoration was thought to provide drinking water through the re-establishment of deep pools that can act as water sources for stock during droughts. In the Goulburn Broken workshop, participants also noted that gaining reaches were thought to indirectly provide food for livestock because groundwater-fed vegetation had a greater chance of survival during drought.

Regulating services

Both environmental flows and EWMs were thought to positively recharge groundwater in the Murray and Lachlan workshops. Murray workshop participants also pointed out that the restoration of riparian vegetation and the conservation of habitats would decrease evaporation and provide shading, thereby increasing water availability generally; however, trees also transpire large amounts of water.

The conservation of gaining reaches was recognised for its benefits to water purification. Lachlan participants pointed out that it can assist with the dilution of salinity, turbidity and temperature issues and Goulburn Broken participants noted that it can be both beneficial and detrimental to water purification because the influx of groundwater can reduce the risk of blackwater events and dispel other forms of pollution; however, it can also become problematic if the groundwater is saline. Lachlan participants also thought that the management of exotic species (carp control) had the potential to reduce turbidity.

In terms of providing biological control agents for pests and diseases, it was pointed out in the Murray workshop that environmental flows and EWMs contribute to ibis breeding, which acts as an effective pest control. As well, improving habitat for native fish was also thought to act as a biological control agent in the Goulburn Broken workshop because it improves the capacity of native fish to predate on exotic fish species like carp.

The flood-regulating effects of riparian restoration were discussed at length in the Murray workshop. Riparian vegetation was thought to be able to hold water back in a medium flood, but would actually increase the flow rate in an extreme flood by providing a corridor for the overbank spill.

The management of exotic species can be both beneficial and detrimental for riverbank stabilisation when it comes to the removal of willows. Although willows were originally planned to prevent erosion, there is some anecdotal evidence that they actually contribute to it instead. However, their replacement with native species, while beneficial in the long term, can contribute to erosion in the short term while the root systems of new plantings are established.

In terms of regulating climate at a very local level, the conservation of gaining reaches and geomorphic restoration were both thought to positively impact on microclimates by protecting and restoring deep pools that act as fish refuges in droughts in the Murray workshop. Also, freshwater habitat connectivity in the Winton Wetlands and the Lower Goulburn sub-catchment were thought to have benefits for local climate regulations as well as carbon storage and sequestration. Groundwater replenishment and climate buffering were thought to benefit at a very local level from the removal of willows. When discussing the replication of big floods, Murray workshop participants were uncertain how environmental flows and EWMs would affect the local climate.

There was a lot of uncertainty about carbon storage in the Murray workshop. The effect of environmental flows and works and measures on carbon storage and sequestration was also a question mark because it is unknown to what extent methane emissions from water bodies constitute a problem. Also in terms of management of exotic species, it was unknown if the removal of willows and their replacement with saplings would make any difference to carbon storage. The Goulburn Broken workshop participants seemed certain that gaining reaches help carbon storage and nutrient cycling since riparian forests fed by gaining reaches would store carbon.

Supporting services

The potential for systemic consequences was recognised in all three workshops. In the Murray workshop, participants pointed out that environmental flows and EWMs were thought to potentially increase the spread of insects while the restoration of riparian vegetation could lead to an increase in exotics. Geomorphic restoration (through re-snagging) was thought to potentially alter local hydraulic functions to relocate problems downstream. The management of exotic species (in terms of carp control) also has the potential to lead to reduced food being available for fish-eating birds other unforeseen changes in the ecological state. In the Goulburn Broken workshop, it was recognised that riparian restoration led to systemic consequences resulting in elevated pathogens and possibly more exotic species using the restored habitats. The removal of exotic species could potentially open the system to invasion by another pest or lead to algal blooms.

In the Lachlan workshop, the management of exotic species was thought to benefit nutrient cycling because control of European vegetation reduced the extent of nutrient input from leaf fall in autumn. Also, the maintenance of natural and priority wetland ecosystems benefited from carp-control measures that reduced the pressure on native species. All of the nine options were judged to be directly beneficial for ensuring ecological connectivity and the protection of threatened wetland species, habitats and ecosystems. In the Goulburn Broken, the restoration of riparian vegetation was identified as being especially beneficial for a range of ecosystem services.

Cultural services

All the options were thought to be highly beneficial for different cultural services by improving aesthetic values, fishing opportunities and boat passage. However, Goulburn Broken workshop participants judged the removal of willows and other exotic species to be both beneficial and detrimental to aesthetic values, since people generally enjoy seeing vibrant native vegetation; however, for those who are used to seeing willows lining their waterways, willow removal can be distressing.

6.6 Constraints to implementation

Constraints (referred to as barriers in the literature) to implementation of climate change adaptation options are divided into four categories in the literature (Arnell and Charlton 2009)

- *Physical* – either in terms of infrastructure or natural conditions: constrains performance of the adaptation option.
- *Financial* – cost and funding: refers not only to absolute cost of the option but also to ability of the implementing organisation to fund the option.
- *Social* – Includes community attitudes, landholder personality and the landholder's economic circumstances that may prevent them from adopting the options: reactions and attitudes of stakeholders, affected parties and pressure groups to each adaptation option.
- *Institutional* – refers to complexity (number of different entities involved and how they interact) and responsibility (accountability for outcomes): institutional factors within the implementing organisation, regulatory or market constraints for the option.

In this project, we chose to call them constraints because they are not necessarily preventing an option from being implemented, but rather impact on the scale of uptake. Table 11⁸ represents the *magnitude* of impacts for different options.

⁸ Legend for Table 11

•	Constraint exists but not preventing implementation of option	M	Murray CMA
•	The uptake of the option would be greater if constraint was overcome	L	Lachlan CMA
●	Constraint preventing the option from being fully or largely realised	GB	Goulburn Broken CMA
?	The extent of the constraint cannot be accurately gauged		
	Constraint not applicable to the option or not mentioned		

Table 11: Constraints to implementation of the nine CCA options

	Physical						Financial			Social									Institutional					
	Infrastructure			Natural			Funding			Personality			Community attitude			Economic circumstances			Complexity			Responsibility		
	M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB
Environmental flows	•/●	•	●	•	•	●	●	•	●	•	•		•/●	•	•/●				●	•		●	•	
Environmental works and measures	•	•		•	•		●	●	●		•		●	•					•	•		●	•	•
Thermal pollution Control	●	•	●				●	●	●				•	•				•		•			•	
Restoration of riparian vegetation							●	●	●	●	•/•	•	●	•	•	•	•	●			•			
Freshwater habitat connectivity	●	●			•		●	●	●			●	•	●	●			●			●	•	•	●
Conservation of more resilient habitats							•	●	●				•		•		•		•		●	•		
Conservation of gaining reaches				•	•	•		•	●		•		•				•		•	•	●	•	•	
Geomorphic restoration				•	●		•	●	●				•	•	•				•		●	•		
Management of exotic species					●		●	●	●	●	•	●	•	•	●		•			•	●	•	•	●

6.6.1 Discussion of adaptation option constraint

Overall, funding, peer pressure and economic circumstances of private landholders were emphasised strongly as barriers and constraints to adopting those CCA options that required landholder participation.

Physical

All three CMA workshops identified physical constraints to both environmental flows and thermal pollution control. Murray CMA participants pointed out that there are greater constraints to providing water for isolated wetlands than within streams. In the Lachlan, both natural and infrastructure features were a medium constraint to directing environmental flows while Goulburn Broken workshop participants identified them as high. In the Murray, constraints to EWMs were deemed negligible because the CMA participants were only discussing small infrastructure projects on tributary streams with which the CMA is involved, unlike the large-scale works on the Murray over which the CMA has no control. Infrastructure constraints were rated as high for thermal pollution control in the Murray and Lachlan and medium in the Goulburn Broken, because it was thought that the main constraint was financial (which all three CMA workshops identified as high). Infrastructure was a high constraint for freshwater habitat connectivity in the Murray and the Lachlan, since the Hume and Wyangala Dams both represent a significant barrier to fish movement.

In the Lachlan workshop, natural physical features of the catchment were identified as a physical constraint for geomorphic restoration, including sand slugs and woody debris in the upper Lachlan, as well as the actual hydrology of the Lachlan River. The remoteness of the Lachlan was also identified as a high natural constraint for the management of exotic species.

Financial

Funding was identified as a major constraint for most of the options in all three workshops. While both the Murray and Lachlan CMAs are not financially responsible for acquiring environmental flows, they wanted to conduct monitoring programs to measure and demonstrate success, but lacked the financial means to do so. The main constraint in establishing monitoring programs was the lack of long-term, ongoing funding as well as a lack of expertise and time (both of which could be solved with funding) (Murray CMA Respondent 3).

As mentioned above, funding was a high constraint to thermal pollution control in all three workshops. In the Goulburn Broken there was also recognition that the community opposition to thermal pollution control came out of the financial benefits provided by the trout industry. Funding is also a major constraint for freshwater habitat connectivity, where the Murray CMA has a list of redundant dams for removal and 'goes back to dam removal when funding is available' (Murray Workshop Participant). In the Lachlan workshop, the conservation of gaining reaches was also a medium constraint because it was thought that actions to conserve gaining reaches did not require money *per se* (as they would be done as part of groundwater-sharing plans), but their conservation had a medium opportunity cost to the landholders.

Social

Community attitudes were identified as a constraint to environmental flows in all workshops. However, Murray and Goulburn Broken CMA workshop participants distinguished between in-stream flows, which are generally accepted, and overbank flows, which are of much greater community concern due to the possibility of flooding private lands. Interestingly, the Lachlan CMA workshop participants judged community attitudes to be a negligible constraint for environmental flows and a medium constraint

for EWMs. However, during interviews the Lachlan OEH respondent talked at length about the social constraints of environmental watering: it works well in a situation where a particular wetland is targeted through a regulator to receive a small amount of water, but to take a system-wide approach and create a moderate flood to naturally water a floodplain carries too much socio-economic risk (and cannot be done with current licences that forbid overbank spillage): 'We could create a flood but do we have the political will and social capital within the system to actually cause a flood? Probably not.' (Lachlan OEH Respondent).

In the Murray, community attitudes about the management of exotic species were identified as a medium constraint because the lack of community concern over exotic species was seen to hinder management efforts. In the Goulburn Broken, the conservation of more resilient habitats and geomorphic restoration was rated as medium for community attitude due to unfulfilled community expectations of what these measures ought to achieve, while in the Lachlan community attitude was a high constraint for freshwater habitat connectivity because there is an 'upper-lower catchment dichotomy'; a lack of awareness about the lower catchment from the upper catchment (Lachlan CMA Respondent 1).

Community attitudes and landholder personality were thought to be a medium constraint for riparian revegetation in the Goulburn Broken workshop. Aversion to government intervention and community 'interference'; and a perception that doing these types of work leads to being labelled as 'greenies' by their peers were mentioned during interviews (GB CMA Respondent 4). As Goulburn Broken CMA Respondent 3 explained, 'It's hard for landholders to go down the pub and talk to people when they're doing something totally different to everyone else'. Also, individuals who grew up with unfenced waterways on their properties may question the need for change, particularly when the benefits have not been explained to them. As Goulburn Broken CMA Respondent 4 put it, 'the thought of the CMA coming in putting up a fence and pulling willows out with an excavator is a bit hard to digest'. The landholders' economic circumstances were thought to be a major constraint for adopting riparian revegetation measures due to the co-investment required by the landholder.

Institutional

Institutional constraints were identified for those options that would involve multiple state, federal and regional agencies. For example, the conservation of gaining reaches depends on groundwater-sharing plans that are established and reviewed through state government processes. Similarly, building EWMs or undertaking carp-control programs usually involves state and federal government funding and or involvement. The Lachlan OEH respondent highlighted institutional considerations in using environmental water. The environmental water manager has to be a 'responsible member of the catchment' (Lachlan OEH Respondent), and fit in with other water users. A goal of environmental watering is to restore and maintain natural wetting and drying cycles; however, ideally environmental water should be utilised outside of the irrigation season so there is no competition for space in the channel between water for irrigation and the environment. For example, the Great Cumbung Swamp naturally dries out in late summer and should not be receiving environmental water at that time, but late summer is also when irrigation demand is lessening (and space is available in the channel) and, due to the nature of water licences, that is when environmental water would become available (Lachlan OEH Respondent).

Lack of knowledge within management institutions was also identified as a constraint in the Goulburn Broken workshop, especially when it came to the successful management of aquatic exotic species and geomorphic restoration. Also, lack of institutional knowledge and recognition about the conservation of gaining reaches was recognised as a significant constraint. For example, a groundwater atlas is being completed by the Department for Sustainability and the Environment in order to

address basic knowledge gaps and enable effective management in a relatively new area (DSE Respondent). Acquiring expertise and funding to overcome knowledge gaps is in itself a constraint, as groundwater ecosystems are complex and costly to research (DSE Respondent). Lack of knowledge about system responses is also a potential constraint for the Winton Wetlands project – there is no baseline data (other than anecdotal) on how the system was before the water storage was constructed (Winton Wetlands Respondent).

It is worth noting that while the categories in Table 11 are based on the climate change adaptation literature, the examples of ‘social’ constraints (personality, economic circumstance and community attitude) are based on outcomes of interviews and workshop discussions. The categorisation of social constraints was therefore an inductive process. However, identifying individual constraints to participation in NRM is not new. There is a lot of research trying to categorise landholders in relation to their participation in NRM. Some researchers link their landholder classifications directly to participation. Ferraro (2008) segments landholders into ‘low-cost’ and ‘high-cost’ landholders. The cost refers to how much it takes to gain and maintain the landholders’ participation. Others attempt more general categories in an effort to explain what stops landholders from adopting recommended NRM practices. For example, landholders can be classified according to demographic (e.g. age), or structural variables (e.g. size of farm, income) or farming styles (e.g. full-time, aspirational) (Vanclay 2004). These variables potentially produce their own constraints to adoption of NRM actions (a full-time farmer may be time-poor; a hobby farmer may lack specific skills). Morrison and colleagues (2012) focus on specifying constraints regardless of landholder classification, such as business orientation, social connectedness, trust, time and capital constraints, as well as individual satisfaction. These constraints are based on a combination of the above-mentioned demographic, as well as structural variables and social and human capital, and could be used in future assessments.

6.7 Socio-economic outcomes

The semi-structured interviews provided a wealth of detailed information about the specific projects undertaken in the catchment. A number of socio-economic concerns were raised about the potential and actual consequences or outcomes of current and planned projects. These concerns largely related to the impact that the proposed action would have on individual landholders and specific groups. Some options are not mentioned in the summary below because they are either not being implemented in the catchment or they had no socio-economic concerns identified.

Table 12 summarises the socio-economic outcomes that are elaborated on in the discussions below. It is important to note that many of these issues are either perceived or hypothetical.

Table 12: Summary of socio-economic impacts in the three catchments

Measure	Positives	Negatives
Environmental flows	Benefits for recreational fishing	Impacts of acquiring water on regional communities
		Possibility of flooding infrastructure/crops
	Created 'havens' during drought	Some socially important wetlands that people perceive as natural do not receive water
	Reactivation of soil moisture	Conflicts between irrigation and environmental water delivery
		Complaints about fluctuations in river heights
		Loss of access to farm land during large flows
		Blackwater events leading to fish kills
Environmental works and measures	More control and ability to water isolated wetlands	Landholders are apprehensive with some of the proposed EWMs
	Building of infrastructure provides local economic benefits	Potentially bad for native fish and recreational fishing
		EWMs sometimes intentionally confine benefits to public land
Thermal pollution control	Of interest to recreational fishers	Trout fishing industry would be negatively impacted
Restoration of riparian vegetation	Economic benefits (feed for stock, assistance with drought-proofing and increasing carrying capacity of the land)	Responsibility for maintenance and replacement falls on landholder
	Aesthetics	
	Adding value to a property	
	Makes stock control easier	
	Green spaces provided a psychological positive for communities	Training for Aboriginal communities does not cover business management skills
	Restoration projects provide NRM training, temporary employment for Aboriginal communities	
	CMAs helping Aboriginal groups and landholders to enable access to land for Aboriginal communities	Employment for Aboriginal people dependent on continued funding
	Works protecting sites of cultural significance.	Providing business opportunities to already established groups
Habitat connectivity	In the Lachlan, development of a regional tourism industry good for regional economy	Paddock and grazing planned around the existence of the weirs and flow heights
	Winton Wetlands: Economic activities aimed at Aboriginal	

Measure	Positives	Negatives
	communities	
	Good news story, people like to hear about how fish travel	Winton Wetlands: Providing business opportunities to already established groups
	Anglers benefit from improved habitat for fish	
	Economic benefits to local business from attracting anglers	
Conservation of more resilient habitats	Better value for money	PVPs perceived to lessen property values in irrigation communities
		PVPs used as trade-offs to offset other development
Management of exotic species	Pig trapping in the Lachlan very positive for local employment - materials built locally	Willow removal programs do not provide lasting employment benefits
	Willow removal programs provide training and employment for Aboriginal people	People have an emotional connection to willows
	Carp harvesting good for regional economy	Establishing a viable carp industry difficult
		Positive benefits of carp project dependant on economic viability of carp harvesting
	Carp harvesting: Employment for Aboriginal people	Establishing an industry based on a pest species could provide an incentive to keep the pest in the system

6.7.1 Provision of environmental flows

Since the economic benefits of flooding accrue downstream, extensive environmental flooding has more perceived costs than benefits from the perspective of individual landholders. These costs include having to remove irrigation equipment from flooded land, loss of access to parts of the property and the possibility of pastures rotting when flooded (Murray CMA 2012b). Loss of access is the most frequently cited issue, and can interrupt NRM activities undertaken by landholders, such as noxious weed treatment, pest control and stock management. It can have an economic impact when it results in interruptions to harvest operations or community firewood collection and it has social consequences for recreational access and hunting (Murray CMA Respondent 1). The Murray CMA has produced a number of reports outlining the costs of environmental flows provision as a result of community concern over this issue. For example, the communities between the Hume Dam and Yarrawonga have issues related to the impacts of elevated flows while the Central Murray Region communities are concerned about third party impacts due to releases in the Edward-Wakool system. These issues are not insurmountable, but they do require active and ongoing communications between water delivery managers and landholders. In some cases it is necessary to ameliorate loss of access with government provision of bridges and easements, which add to the cost of environmental watering (NOW Respondent).

A further potential conflict occurs between environmental flows provision and irrigation water delivery. Because of the climatic changes in the catchment, competition in timing

between environmental and irrigation water delivery (e.g. during summer rainfall) is increasing (Murray CMA Respondent 1). This issue can potentially become more problematic in the future as the 'window' for action to provide environmental flows is getting smaller (Murray CMA Respondent 1) and therefore there is less and less flexibility to accommodate seasonal irrigation activities. Due to changing rainfall patterns in the Lachlan, there will also be increased competition between irrigation and environmental water delivery. As the Lachlan environmental water manager is the 'single biggest irrigator in the valley, holding 20% of available allocation', environmental allocations can significantly impact the rest of the catchment (Lachlan OEH Respondent). Environmental watering requires the creation of moderate-scale floods down the Lachlan River that would inundate private properties. Also, the replication of natural wetting and drying cycles means increasing fluctuations in river heights, about which landholders with river pumping licences will complain (since pumping licences are based on a certain river height and benefit from constant, unchanging flows). There is also discontent around Lake Cargelligo, which is a socially important body of water for local landholders, but is currently not receiving environmental water.

Some positive socio-economic outcomes for environmental watering have been mentioned. Environmental watering can reactivate or increase soil moisture. During the droughts, wetlands watered with environmental flows were seen as 'havens' by irrigators and the community (Murray CMA Respondent 3), and had a powerful positive psychological effect on people negatively affected by the drought. Environmental flows also provide direct social positives for recreational fishing by improving fish habitat.

A positive social outcome for environmental flows is that the Lachlan River Catchment is relatively remote, with a relatively small population in relation to its land-mass. The population is also more comfortable with environmental watering since the introduction of water sharing plans, as most of the conflicts were dealt with then. Therefore, the CMA finds it easier to establish cooperative relations with landholders (Lachlan CMA Respondent 1). A follow-up positive is the fact that the Lachlan is recognised as a case study in effective local environmental water management and has won two Green Globe state environmental awards (Lachlan CMA Respondent 3).

6.7.2 Environmental works and measures

The smaller works on tributaries were generally thought to have very positive socio-economic consequences because they pose much less risk of private property damage because they allow smaller amounts of water to be used and give greater control over how long an area is watered. Environmentally, they allow the watering of small, isolated wetlands that would otherwise go unwatered.

It is important to note that New South Wales CMAs have no control over environmental flows and there is a lot of misinformation about this in the general community in the Murray Catchment (Murray CMA Respondent 3) since landholders receive their news from Victoria where CMA operating rules are different.

The buyback versus infrastructure debate was raised during the CMA workshop and in some stakeholder interviews. Water buybacks continue to be promoted by the government as an efficient process with mostly positive socio-economic impacts (Cheesman and Wheeler 2011) despite community belief over the negative socio-economic impacts of water buybacks, which prompted a parliamentary inquiry (Commonwealth of Australia 2011b). After this inquiry, the Commonwealth government ceased general tenders for buybacks (but continued with targeted purchases) in 2011 and 2012, and has now introduced a new buyback program (the Strategic Sub-System Reconfiguration Program) that tries to address concerns raised by the inquiry (Burke 2013). During workshop discussions, some workshop participants argued that any building of infrastructure provides some local economic benefits in terms of labour and

resourcing of material. There is still 'angst' against water recovery in irrigation community around Deniliquin (Murray Workshop Participant).

EWMs are perceived to have a more positive socio-economic effect than the water buyback program at a local level. Significant positive consequences also exist for freshwater dependent vegetation. However, what is good for trees is not necessarily good for fish. EWMs work by pooling water on surrounding areas and spreading smaller amounts of water further, diminishing hydrological diversity. Unfortunately, these create ideal conditions for the spawning and recruitment of carp, which is a potential undesirable social and environmental consequence.

In terms of the large KP works in the Murray, a decision was made to limit watering benefits to forests held on public land. This means that parts of the forest held on private land will not benefit from the works and that potentially denies these landholders the ability to adapt to climate change (Murray CMA Respondent 3). The reason for this exclusion is not clear, but may be related to the fact that governments may only want to invest on land that is in their control since they are accountable for how effective financial investments are.

While no specific EMWs are currently in place in the Lachlan, several are proposed. The CMA is aware that some landholders are 'apprehensive' about some of these proposals, especially about putting regulators in Willandra Creek and Booberoi Creek (Lachlan CMA Respondent 1). Their apprehension is centred on concerns that the regulators will affect stock and domestic flows.

6.7.3 Thermal pollution control

Thermal pollution control is not pursued in any of the three catchments due to its high costs (see maladaptation discussion above). Socially, cold water pollution caused by large dams does not seem to be important for irrigators and the general community, although it is an issue raised by recreational fishermen. In the Hume Dam, the release of water is strictly governed by hydropower generation concerns, so there is limited scope for dam reoperation.

The importance of cold water below Lake Eildon (in the Goulburn Broken Catchment) for the trout industry has been mentioned several times during the interviews and the CMA workshop. Therefore, actions to ameliorate CWP negatively impact on the trout industry. However, prohibitive economic costs are the main reason why this option is not pursued.

6.7.4 Restoration of riparian vegetation

Green spaces provided a psychological positive for communities in the Murray Catchment. The environmental benefits of riparian revegetation are appreciated by landholders who are generally very connected to rivers and creeks on their properties (Murray CMA Respondent 3). However the economic benefits of riparian revegetation (feed for stock, assistance with drought-proofing and increasing carrying capacity of the land) are mostly undersold in the promotion of riparian activities because it is hard to quantify the benefits. The potential increase in carrying capacity is also directly linked to the adoption of ecological grazing practices (Murray CMA Respondent 3).

Although the CMAs cover either all or a substantial portion of the economic costs of implementing fencing and re-vegetation, the responsibility for maintenance and replacement rests with the landholders. This becomes an economic issue in flood-prone areas if fencing is damaged and has to be replaced. While the Murray CMA insists on a minimum buffer zone of 20 metres, landholders may extend it, thus minimising the chances of flood damage to fencing. However, few choose to go above the minimum because the buffer strip is still seen as land that is taken out of

production. Similarly, in the Goulburn Broken the CMA covers a substantial portion of the economic costs of implementation, the replacement of fencing and/or watering points after a flood are the responsibility of landholders. As Goulburn Broken CMA Respondent 3 explains, landholders usually give up a minimum buffer strip, increasing the chances of the fence being damaged in a flood – which is a real possibility in the lower Goulburn and Broken Creeks. During the 2010 floods, lots of fences had been wiped out by floodwaters and some Landcare groups have utilised their own funding to repair the damage (GB CMA Respondent 3).

The CMAs increasingly are involved in facilitating partnerships between Aboriginal communities and local landholders to enable access to land and protection of sites of significance for Indigenous peoples. For example, the Murray CMA offers a special incentive for landholders who provide access for Aboriginal peoples to their sites of significance on private properties. This is a significant social benefit, as lack of access to land is a common complaint of Aboriginal communities throughout New South Wales. Economic opportunities are also being created by forming NRM work crews who undertake restoration activities and promoting reed weaving as an economic activity (in the Murray and Lachlan catchments).

Several positive socio-economic benefits have been identified in the CMA's activities around riparian vegetation in the Lachlan. The West Women Weaving project in Lake Cargelligo involves the restoration of lake reeds, which are then used in traditional reed basket weaving by local Wiradjuri women. Reed weaving classes were sponsored in November 2005 to establish a nascent local reed weaving industry. More broadly, in working to restore riparian vegetation, the CMA is increasingly involved in facilitating partnerships between Aboriginal communities and local landholders to enable access to land and protecting sites of significance for Aboriginal communities (Lachlan CMA Respondent 2). As a result, landholders are increasingly becoming aware of sites of cultural significance, especially scar trees and carve trees (Lachlan CMA Respondent 2).

One possible negative social outcome was identified in the Flakeney Creek project, which was reported to experience 'problems with management' (Lachlan CMA Respondent 2). While the project aimed to build the capacity of local participants (including Aboriginal groups) in carrying out on-ground works (providing riparian fencing, revegetation and removal of exotic species), not enough focus was paid to transferring the necessary business and administration skills to effectively manage these types of project (Lachlan CMA Respondent 2).

Several positive socio-economic benefits of riparian revegetation were identified during the semi-structured interviews in the Goulburn Broken Catchment. Riparian revegetation provides stock shelter, and can increase pasture growth (trees providing shelter); it also makes stock control easier (by fencing off waterways). Revegetation around waterways provides aesthetic qualities and can add economic value to the property (GB CMA Respondent 4). Also, while water quality benefits flow downstream, the soil structure on the property where revegetation is undertaken improves quite quickly: 'within the first 12 to 24 months, they will see some form of improvement' (GB CMA Respondent 3). However, the financial cost of fencing was the reason that many landholders were reluctant to take up the incentive.

6.7.5 Freshwater habitat connectivity

The removal of weirs to ensure habitat connectivity can have negative economic impacts in the Lachlan Catchment since paddocks and grazing practices have been planned around the existence of weirs. River flow heights are also altered through weir removal, affecting stock management.

The Winton Wetlands restoration project seeks to provide social and economic benefits through the development of a regional tourism industry centred on the restored Winton Wetlands. The long-term objective is that tourism development will eventually pay for the restoration, but this is predicated on establishing a viable tourism industry (Winton Wetlands Respondent). The Winton Wetlands Committee is currently establishing itself as a credible land manager by managing fire risk, pests and weeds, creating emergency access to the site, bringing the public facilities up to a good standard and increasingly involving the community in the planning of the ecological restoration and the development of wetland reserve.

The Winton Wetlands Committee has so far employed four people for on-ground works as a direct result of the project. However, more economic activity is being generated by employing contractors to undertake pest management control (weed spraying and killing rabbits). The wetland site is also very significant to the local Aboriginal communities and the Committee has partnered with the Yorta Yorta Aboriginal Corporation. The creation of employment activities aimed at the Aboriginal communities is part of the cultural and tourism aims of the project (Winton Wetlands Respondent). Thus while there are many potential positive outcomes of the Winton Wetlands project, a hypothetical negative is that the Committee is favouring already established groups. There are other Aboriginal groups in the area, but Yorta Yorta is the only recognised Aboriginal group and the Committee has a statutory obligation to deal with recognised Aboriginal bodies (Winton Wetlands Respondent).

The previous work undertaken to open fish passages through weir removal and the introduction of fishways has provided a number of social benefits to the community. Increased fish movement means recreational fishers can now fish in more places. Also, it is 'a good news story' for the rest of the community, since people like to hear about how fish travel and that they go back to the same spot (GB CMA Respondent 4). Attracting recreational fishers provides economic benefits to local economies and there is reciprocity between recreational fishing and geomorphic restoration since funding for geomorphic works partially comes from recreational fishing licenses (GB CMA Respondent 4).

6.7.6 Conservation of more resilient habitats

This option relies on prioritising areas of higher biodiversity to those which are less intact because investment-wise, they represent better value for money. Both Murray and Lachlan CMAs have a policy of prioritising areas of higher biodiversity and have a system of Property Vegetation Plans (PVPs) for private land holders. However, there is a perception in irrigation districts that value of the property is lessened by having any kind of a covenant or a Property Vegetation Plan (Murray CMA Respondent 1; Lachlan Respondent 3). Also it appears that PVPs are mostly used as a trade-off to offset development somewhere else (Murray CMA Respondent 3; Lachlan CMA Respondent 3).

6.7.7 Management of exotic species

The benefits of reducing carp numbers have always been tested under controlled conditions, meaning that the scientific evidence for carp removal is weaker than generally assumed. However, there is some direct evidence that carp displace native fish, which are solitary by nature and do not like a school of carp taking over a snag (Murray CMA Respondent 2).

One of the biggest management actions being undertaken by the Murray CMA is the carp harvesting project, currently in its nascent stage. It relies on the installation of a number of automatic carp separation cages that will periodically be emptied by an Indigenous group (Yarkuwa Indigenous Knowledge Centre), which will then sell the harvested carp for fertiliser (Charlie's Carp). For the Murray CMA, this project is a way to offset the potential

unwanted consequences of environmental watering and habitat connectivity works that may benefit carp as well as native fish (Murray CMA Respondent 2). The project can have potentially significant socio-economic benefits for Aboriginal communities in terms of providing employment. However, it is dependent on the economic viability of carp harvesting that is quite difficult to establish as carp migration is seasonal and a business needs a regular supply of carp biomass (300 tonnes of carp) to be viable. For example, Pedigree used to put carp in cat food because it was a cheap source of fish protein, but stopped because a lack of regular supply made it economically unviable (Murray CMA Respondent 2).

There are several potential/hypothetical social concerns should such a business prove to be economically viable. First, there is a potential that economic benefits are provided inequitably to specific already established groups (Charlie's Carp, Yarkuwa Centre). There is also a question that establishing an industry based on a pest species could provide an incentive to keep the pest in the system, but this is countered by a belief among CMA respondents that we will never get rid of carp anyway. A potential animal rights concern is the plan to use ice slurries to transport the captured carp. At this stage, these concerns are entirely hypothetical, as the carp harvesting project has not yet been implemented.

In the Lachlan, the Kalare River Cleanup project involved willow removal and has focused on training and employing Aboriginal people, creating six employment positions in the past and currently employing two Aboriginal people. The project also included a traditional ecological knowledge component. This can be viewed as a significant economic benefit to the community, but it also provided a social benefit through recognition of traditional knowledge and the attachment that Aboriginal people have to the river (Lachlan CMA Respondent 2).

However, while the Lachlan CMA is continually trying to establish employment opportunities for Aboriginal people, these opportunities are generally reliant on short-term (12 months) funding, and do not create long-lasting employment. The CMA is currently trying to encourage five-year projects to ensure some employment continuity for trainees. Lack of ongoing job opportunities could potentially lead to disillusionment among the Aboriginal community.

The management of feral pigs in the Lachlan involves traps that are produced locally at a business in Hillston, providing significant local economic benefits.

The Lachlan CMA maintains the position of trying to develop viable carp businesses. However, turning carp into a viable commercial business is hampered by their relative low economic value. Stuart and colleagues (2006) report that business enterprises prefer high-quality live carp, requiring a regular, constant supply of a seasonal fish. Also the market value of an individual carp was quite low: \$2.50/kg at Preston market in Victoria in February 2006 and \$1.50–\$2/kg in a Sydney fish market, with a maximum demand of about 2.5 tonnes per week. Stuart et al. (2006) estimate that up to 10 tonnes of carp are necessary to achieve cost efficiency for transport and processing.

Community opposition to the removal of willows was highlighted at the Goulburn Broken CMA workshop and during semi-structured interviews; 'in the community, there's probably more people annoyed with the fact that willows have been removed but they know the stance of the CMA' (GB CMA Respondent 3).

6.8 Risk assessment

In this section, we look at the likelihood and consequences of the adaptation option failing. To look at the risk, we have adopted a risk assessment matrix consistent with Australian Standard AS4360 on Risk Management (adapted from Umwelt 2009), shown in Table 13. Tables 14 and 15 explain the Consequences and Likelihood classifications.

Table 13: Risk assessment matrix

Likelihood of the consequence	Maximum reasonable consequence				
	(1) Insignificant	(2) Minor	(3) Moderate	(4) Major	(5) Catastrophic
(A) Almost certain	High	High	Extreme	Extreme	Extreme
(B) Likely	Moderate	High	High	Extreme	Extreme
(C) Occasionally	Low	Moderate	High	Extreme	Extreme
(D) Unlikely	Low	Low	Moderate	High	Extreme
(E) Rare	Low	Low	Moderate	High	High

Table 14: Explanation of risk consequences

(1) Insignificant	Limited damage to minimal area of low significance
(2) Minor	Minor effects on biological or physical environment. Minor short-medium term damage to small area of limited significance
(3) Moderate	Moderate effects on biological or physical environment (air, water) but not affecting ecosystem function. Moderate short medium-term widespread impacts.
(4) Major	Serious environmental effects with some impairment of ecosystem function. Relatively widespread medium-long term impacts.
(5) Catastrophic	Very serious environmental effects with impairment of ecosystem function. Long-term, widespread effects on significant environment.

Table 15: Explanation of risk likelihood

(A) Almost certain	Consequence is expected to occur in most circumstances
(B) Likely	Consequence will probably occur in most circumstances
(C) Occasionally	Consequence should occur at some time
(D) Unlikely	Consequence could occur at some time
(E) Rare	Consequence may occur in exceptional circumstances

Based on these, we have utilised the expert judgement of the CMA workshop participants to rank each option under the different climate change scenarios (see Table 16).

Table 16: Risk assessment of the different CCA adaptation options

Climate change scenarios	Environmental flows			Environmental works & measures			Thermal pollution control			Restoration of riparian vegetation			Freshwater habitat connectivity			Conservation of more resilient habitats			Conservation of gaining reaches			Geomorphic restoration			Management of exotic species				
	M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB	M	L	GB		
Wet	L	L	L	L	L	L	L	M	E	L	L	L	L	L	L	L	L	L	L	L	L	E	H	H	L	H	E	H	E
Moderate	M	M	L	L	L	L	L	M	M	L	L	L	M	L	M	L	L	L	L	L	L	L	E	L	M	H	M	M	
Dry	H	E	H	M	H	M	M	M	L	M	H	L	H	M	H	M	H	H	M	H	H	M	H	L	M	H	M	M	
Very dry	E*	E	E	E*	H	E	H	L	L	H	H	M	E	H	E	H	E	H	H	H	H	H	H	M	L	E	H	L→	E

*This option would not be done under such extreme conditions

Legend for Table 16

L	Low risk of failure	M	Murray CMA
M	Medium risk of failure	L	Lachlan CMA
H	High risk of failure	GB	Goulburn Broken CMA
E	Extreme risk of failure		

6.8.1 *Discussion of risks of failure*

Although encouraged to consider social and economic risks as well, the conversations in all the CMA workshops revolved around the risk of ecological failure. However, various workshop participants pointed out that it was hard to picture how these scenarios would affect individual streams, so these exercises were somewhat abstract due to a lack of knowledge at a very local level.

Discussions around risks in the Lachlan workshop focused on the idea that each scenario presents both threats and opportunities. For example, drier conditions provide more options for the management of exotic species – especially control of carp and willows, since both thrive in wetter conditions. In terms of thermal pollution control, while the risk of failing in very dry conditions was thought to be low, this option was unlikely to be implemented because there would be insufficient water stored to produce cold water pollution.

Workshop participants in the Murray and Goulburn Broken workshops pointed out that the goals of some of these options would change under different scenarios. So, in the Goulburn Broken, the goals of environmental flows would be different in wet years than in dry years. In drier years, the focus would be on protecting habitat refugia and key ecosystem functions, and in wet years it would be restoration and enhancement of biodiversity. Also, it was noted that riparian vegetation would not be planted in a drier season. In the Murray workshop, it was noted that under the very dry scenario, environmental flows and EWMs would not be used because they are not designed for such extreme conditions.

The risk of geomorphic restoration failing was rated as extreme in the eastern end of the catchment and high overall in the Murray workshop. This was due to the increased variability in the eastern end of the catchment, which is not captured by CSIRO modelling. It is this variability (in the volumes and timing of water flows), rather than any median decrease of overall water availability, that Murray CMA workshop participants indicated was going to be the hardest to manage.

The risk of failure for the management of exotic species under the very dry scenario was thought to be species-dependent, and thus ranged from low to extreme in the Murray and Goulburn Broken catchments. Carp management was thought to be relatively easy, but management of other species that are used to drier conditions may fail. When discussing the 'wet' scenario for exotic species management, it was pointed out that it represented greater danger for the spread of most invasive species, since the drought acted as a natural barrier (for example, carp numbers dropped significantly in the drought and exploded after the floods). For the Goulburn Broken, the risk under the 'wet' scenario for pest vegetation (willows) was high and for pest fish (carp) it was extreme.

6.9 ***Catchment assessment conclusion***

This chapter provides a thorough analysis of nine climate change adaptation options considering their:

- degree of catchment relevance
- climate change adaptation potential based on assessments of climate change benefit, effectiveness under different scenarios and maladaptation potential
- ecosystem services benefit
- constraints to implementation

- actual, perceived and hypothetical socio-economic outcomes of individual projects
- risk assessment of option failure.

Tables 17–19 in Appendix 1 summarise the above sections in relation to the Murray, Lachlan and Goulburn Broken catchments. The tables should be viewed as a summary of discussion points that need to be considered, rather than a directive that points to the ‘best’ option. In using the CCA CAF, the process of considering the issues is more important than the summary table that is produced.

The CCA CAF takes a holistic look at climate change adaptation, but also takes into account ecosystem services and socio-economic considerations. As such, looking at Tables 17–19, it can be seen that each measure has risks, costs and benefits that require managers to make informed, qualitative judgements in preparing adaptation strategies for implementation. Looking at the sections related to climate change, we can see that the restoration of riparian vegetation, freshwater habitat connectivity, the conservation of more resilient habitats and gaining reaches, geomorphic restoration and the management of exotic species all either increase resilience and reduce vulnerability or both, as well as being rated very effective under all of the climate change projections. These options also tend to have lower levels of maladaptation potential, multiple ecosystem services benefits and lesser risk levels. The analysis also clearly points out that thermal pollution control has been judged as less effective under all climate change scenarios, has high maladaptation potential in terms of higher opportunity costs and does not support as many types of ecosystem service benefits as the other options.

The discussions of the individual options suggest that adaptation measures at catchment scale should focus on pursuing existing NRM actions in order to adapt an ecosystem-based approach that encourages ‘no regrets’ ecosystem resilience by prioritising the protection and restoration of natural habitats. Specifically, this report highlights the high adaptation potential of six NRM actions:

- restoration of riparian vegetation
- freshwater habitat connectivity
- conservation of more resilient habitats
- conservation of gaining reaches
- geomorphic restoration
- management of exotic species.

It is notable that in the past year, resources to implement these options have been dramatically reduced with cuts by the New South Wales and Victorian governments to their catchment management authorities and by a number of states to the shared programs (for example, the MDB Native Fish Strategy) administered by the Murray-Darling Basin Authority. By contrast there is extensive federal funding for environmental flows and EWMs as part of the Murray-Darling Basin Plan implementation.

Decisions concerning the other three options – environmental flows, environmental works and measure and thermal pollution control – are more complicated. There are potentially higher risks and costs for these measures, but these negative characteristics may be outweighed if the benefits are great, or managed in such a way that they are reduced to acceptable levels. This framework enables such issues to be identified systematically, and incorporated into integrated decision-making on natural resource management investments.

The analysis shows that there are many 'low regrets' climate change adaptation measures that are practical at the catchment level to conserve freshwater biodiversity. The CMAs are already undertaking most of these measures and this analysis provides support for further investment in these actions as part of an integrated regional NRM strategy that actively plans for climate change adaptation.

7. KEY LESSONS FOR ADAPTATION

There are key lessons emerging from this work for climate change adaptation. First, there are many activities underway that, if extended and linked, would comprise a substantial ecosystem-based approach to adaptation. It is notable that many of these activities had not previously been considered in an adaptation context. Second, the research confirms the need to look at a suite of complementary actions that spread risk rather than investing in one or two perceived best actions. Third, the adoption of an ecosystem-based approach is constrained by institutional complexity and socio-economic considerations that should be included in assessments of climate change adaptation. Finally, adaptive management is a key strategy for the implementation of an ecosystem-based approach to climate change.

We used fish as iconic elements of a river ecosystem to independently test how the nine adaptation measures could perform in conserving the range of species under climate change. By systematically assessing nine different adaptation options with local experts for each action, we were able to identify and synthesise the potential contribution, risk of failure, additional ecosystem service benefits and barriers to implementation to inform decision-making. This approach now enables catchment management decision-makers to take informed choices about the adaptation actions that are most beneficial, have the least risk and minimise the costs for freshwater conservation. This method, the CCA Catchment Assessment Framework, can be extended to climate change adaptation planning in many other sectors.

7.1 Adopting an ‘ecosystem-based approach’ to climate change adaptation

In an ecosystem-based approach, interventions to improve environmental health are used to ameliorate climate change impacts. The central tenet of this approach is that a healthy resilient ecosystem will be better able to withstand external shocks caused by climate change. Strategies include the maintenance and restoration of natural ecosystems, protection of vital ecosystem services, reduction of land and water degradation by controlling invasive, alien species and the management of habitats to ensure plant genetic diversity, and that act as breeding, feeding and nursery grounds for wildlife species (World Bank 2009).

In this project, we have proposed that a combination of nine actions evaluated at each catchment forms the basis of an ecosystem-based approach. Six actions in particular offered the lowest risks and highest benefits under different climate change scenarios:

- restoration of riparian vegetation
- freshwater habitat connectivity
- conservation of more resilient habitats
- conservation of gaining reaches
- geomorphic restoration
- management of exotic species.

These are actions that are commonly undertaken at the catchment level by state government and regional natural resource management bodies. However, while often done in parallel, they have not explicitly been implemented as an integrated package for climate change adaptation.

A common goal for catchment management is to create resilience – be it in terms of resilient landscapes, ecosystems and communities or the use of resilience thinking (Goulburn Broken CMA 2012, p. 2; Lachlan CMA Respondent 1; Murray CMA 2011). We propose that an ecosystem-based approach using a combination of actions (such as those proposed above) be adopted as a catchment goal to achieve ecological resilience as a way of adapting to climate change.

The nine actions examined in this project are currently viewed largely in terms of biodiversity conservation and addressing degradation caused by past practices. Because of this, their potential for climate change adaptation may be overlooked. For example, one of the potential impacts of climate change will be rising temperatures and changing rainfall patterns (CSIRO 2008b, 2008d; DSE 2008), resulting in higher evaporation (Lachlan OEH Respondent) and stream temperatures. The restoration of riparian vegetation can directly lower stream temperatures (Davies 2010), and the conservation of gaining reaches provides a source of cooler water feeding into streams that can further ameliorate high temperatures and provide a drought refuge for native fish (Chessman 2009) under conditions of climate change. The nine actions examined in this project are not exhaustive: others may include bushfire management, managed aquifer recharge and captive breeding programs.

In summary, many existing catchment activities already mimic an ecosystem-based approach to climate change adaptation, but are undertaken as a response to existing degradation, and their climate change adaptation potential has not been considered. We propose that climate change adaptation strategies should focus on increasing the scale and speed of these existing measures and implementing them in a more integrated fashion in order to increase catchment-wide resilience.

7.2 *Implementing a suite of complementary measures*

Our case study assessments of nine actions found that the effect of their implementation was complementary in contrast to the benefits of one or two individual actions. We suggest that committing to an ecosystem-based approach means directing investment to a suite of actions, rather than selecting one or two ‘best’ actions for targeted investment. For example, our catchment partners recognised that undertaking any actions to improve fish habitat and refuges (such as geomorphic restoration, riparian revegetation or the conservation of gaining reaches) must be counteracted with actions to manage exotic species so that restored fish habitats will not become havens for carp (Murray CMA Respondents 1 and 2; Lachlan CMA Respondents 1 and 3). The need for a suite of integrated, complementary actions to improve freshwater biodiversity is well accepted in the literature (Bond and Lake 2008).

One of the benefits of using the CCA CAF method developed in this project is that it promotes the systematic consideration of the adaptation potential of existing actions in terms of benefits, effectiveness with change and maladaptation, ecosystem benefits, implementation constraints and risks of failure.

We believe that individual assessments of the costs and benefits of different actions paint an incomplete picture (see Tables 17–19 in Appendix 1). For example, thermal pollution control has been assessed in the catchments we studied and was considered too expensive (Lachlan CMA Respondent 1), as not providing value for money (GB CMA Respondent 4) and as not being seen as a problem by the community (Murray CMA Respondents 1–3). However, an integrated approach to ecosystem-based adaptation considers the pervasive impact of cold-water pollution and its effects on other actions. For example, the ecosystem services benefits of environmental flows are reduced downstream of dams (such as Wyangala in the Lachlan and the Hume in the Murray) because of the water temperature (Lachlan CMA Respondent 1; Murray CMA

Respondent 1). Modelling of altered flow regimes in the Murray Catchment shows that efforts to increase native fish populations through freshwater habitat connectivity will have ‘little overall effect’ without mitigating cold water pollution (Baldwin et al. 2003, p. 15).

Our assessments also indicate that environmental works and measures have the highest maladaptive potential and comparatively less adaptation and ecosystem service benefits than the other options examined in this project (see Tables 17–19 in Appendix 1). Furthermore, workshops with CMA partners revealed that large-scale EWMs may be redundant under extreme conditions, both wet and dry, since they would be unnecessary during periods of high flows and inoperable during periods of extremely low flows. However, small-scale regulators on creeks and tributaries allow the watering of isolated wetlands in the Murray Catchment that are ecologically significant yet very small (Murray CMA Respondent 1), have less detrimental impacts and maladaptive potential, and complement other actions – such as riparian and geomorphic restoration.

Works and measures direct environmental water to specific sites, meaning that, regardless of scale, they have geographical limitations. By using environmental water through EWMs, managers focus on selected sites rather than the whole floodplain (Murray NOW Respondent). We suggest that investment for climate change adaptation should not be over-reliant on large-scale works and measures, but rather target a suite of complementary actions, of which works and measures may be one (under optimal circumstances).

7.3 Addressing institutional complexity

We have found that the current institutional context of implementing existing actions is complex and constrictive in terms of an ecosystem-based approach. Freshwater management is governed by a range of Commonwealth, state and regional bodies. This is especially true for iconic parts of the river system, such as the Murray River. While the different actors are establishing working relationships, rules and funding arrangements still constrain the full implementation of an ecosystem-based approach.

Environmental flows are being used to reinstitute more natural patterns of wetting and drying in the river systems, aiming to ‘run the system to create the right conditions for the system to respond’ (Lachlan OEH Respondent). However, environmental water obtained through the buyback program is still governed by irrigation rules, which can prevent it being used at ecologically appropriate times or to create overbank flooding (Lachlan OEH Respondent).

Riparian restoration and the conservation of more resilient habitats have been shown in our assessments to have significant climate change benefits (see Tables 17–19 in Appendix 1). We proposed in this project that more resilient habitats include free-flowing or undisturbed rivers as well as rivers with favourable physical characteristics, such as a north–south orientation, topographic shading and a gradual habitat gradient. These habitats could potentially conserve freshwater biodiversity under climate change because they may remain cooler, retain natural variability in ecosystem processes like flows, and enable migration of species and ecosystems. However, such characteristics are not assessed when planning conservation and restoration efforts because they are undertaken with a focus on conserving existing biodiversity rather than adaptation to future climate impacts. For example, the Murray CMA focuses riparian restoration efforts on sites with remnant vegetation because funding for it is from a: “protect and restore” bucket of money rather than “start from scratch and completely rehabilitate” bucket of money’ (Murray CMA Respondent 1). Funding is thus not targeting some characteristics for selecting sites that would be resilient in respect to climate change.

Our assessments show that although a system-wide approach is contemplated, existing environmental flow rules and funding arrangements constrain the full implementation of a climate-change focused system approach.

7.4 *Considering the triple-bottom line*

Community expectations and attitudes can both aid and constrain an ecosystem-based approach, and it is important to acknowledge that the magnitude of maladaptation potential depends on one's point of view. While potential maladaptation may be negligible for a regional management body as an organisation, it may have greater negative impacts on other parties, such as individual landholders. For example, the creation of small and medium floods is limited by community concerns over the flooding of private lands, causing loss of access, and damage to crops and irrigation equipment (Murray CMA Respondent 1; Lachlan OEH Respondent).

Government and regional bodies have limited ability to act on private land, so the full benefits of an ecosystem-based approach may not be realised. For example, the restoration of riparian vegetation on both sides of the riverbank improves downstream water quality; however, so far the goal of restoring enough riparian vegetation on both sides of the bank has not yet been achieved in the Goulburn Broken Catchment (GB CMA Respondent 4). Private landholders are often unwilling to undertake actions such as riparian restoration if the financial costs of undertaking the action (not to mention maintenance) are judged to outweigh the financial benefits (Murray Respondent 3; GB CMA Respondent 2); some landholders have an aversion to perceived government intervention and community 'interference' (GB CMA Respondent 4) and there exist persistent misperceptions about the land being 'locked up', as well as increased fire and weed risks (Murray Landholder Respondent).

Consideration of the triple-bottom line is important not just to understand landholder motivations in refusing financial incentives, but also to highlight positive socio-economic consequences of freshwater biodiversity actions. For example, CMAs have instituted diverse programs aimed at providing natural resource management training for Aboriginal communities, enabling the protection of important cultural sites and access to country (Murray CMA Respondent 3; Lachlan CMA Respondent 2; GB CMA Respondent 2). These programs provide employment opportunities, skills training and cultural recognition. However, this training does not cover business management skills, and employment is dependent on continued funding. As a result ongoing, permanent employment is often unrealised through these programs.

One of the benefits of the CCA CAF is its explicit assessment of constraints to implementation as well as socio-economic considerations of ecological actions. Including social and economic outcomes is consistent with a focus on resilience. The concept of resilience adopted by CMAs is not limited to the ecological and therefore it is necessary to include triple-bottom line (ecological, social and economic) consideration in action assessments.

7.5 *Implementing adaptive management*

Adaptive management is a key to an ecosystem-based approach to climate change. Adaptive management involves learning from past actions and active experimentation (Allan 2007). Experimentation implies that sometimes management actions may not achieve desired ends and be perceived as failures and recommended best practice may change. For example, willows originally were planted to control erosion, but have been found to actually cause it instead (GB CMA Respondent 4).

The CCA CAF explores maladaptive potential of various actions, but assessments rely on limited available knowledge. Maladaptive potential can be minimised but not totally eliminated; therefore, community expectations must make allowance for learning on the job. For example the release of stock and domestic water in the Edward Wakool system in the Murray Catchment caused an unintended blackwater event in 2009 that led to massive fish kills of the Murray Cod (Murray-Darling Freshwater Research Centre 2009) and widespread community anger towards water managers (Murray CMA Respondent 2). The knowledge necessary to prevent the blackwater event from forming was absent at the time, but has been gained as a result of the event (NOW Respondent).

Our CMA partners repeatedly highlighted the need for consistent, ongoing monitoring programs to measure the effectiveness of undertaking actions. For example, if a monitoring program was put in place to quantify the environmental benefits of addressing cold-water pollution, the widely held perception that thermal pollution control is too expensive might change, but establishing such monitoring programs is in itself expensive (GB CMA Respondent 4). The main constraint in establishing monitoring programs is the lack of long-term, ongoing funding, as well as a lack of expertise and time (both of which could be solved with funding). However, while monitoring is seen as an essential part of adaptive management, it is supported in rhetoric rather than in dollars ‘they like to hear the words [adaptive management]; they don’t like to pay for them ... Convincing people to pay for monitoring is staggeringly difficult.’ (Murray CMA Respondent 1)

Because of the ecological complexity of the river system, we acknowledge that maladaptive potential of any action cannot be totally eliminated (only minimised), and therefore adaptive management is a key strategy in an ecosystem-based approach. We believe that adequate funding should be allocated to ongoing, long-term monitoring programs, and community expectations should be managed to allow experimentation within adaptive management.

7.6 The CCA Catchment Assessment Framework

The CCA CAF offers a ‘holistic’ look at the feasibility of different climate change adaptation options. The aim of the CCA CAF is to highlight those actions that present the maximum benefits along with the least risk. As such, it is divided into six sections.

- *Catchment relevance:* This section establishes specific projects that are either undertaken or considered by the managing body. Specifying actual projects or programs allows the evaluation to be more practical.
- *Climate change adaptation:* This section is further divided into three aspects:
 - Consideration of whether the NRM action contributes to reducing non-climate change stressors or to increasing resilience to climate change shocks.
 - Assessment of the effectiveness of NRM actions under different climate change scenarios.
 - Consideration of the potential for maladaptation (unintended consequences).
- *Ecosystem services benefits:* This section looks at the ecosystem benefits provided by the NRM actions. The ecosystem-based approach to climate change adaptation highlights the need to have healthy, functioning ecosystems to build resilience to climate change impacts, sequester carbon (in itself a climate change mitigation strategy), attenuate natural disasters and meet other human needs.

- *Constraints to implementation:* Constraints can either prevent or limit the adoption of individual adaptation actions. These can be physical, financial, social and institutional.
- *Socio-economic considerations:* Assesses the positive and negative socio-economic implications of individual projects.
- *Risk of failure:* This looks at the risk (probability x consequences) of the option failing to achieve its goals under different climate change scenarios. While similar to the assessment of option effectiveness under different climate change scenarios, the risk of failure considers not just the bio-physical risks but the added institutional or socio-economic risks that may be overlooked in assessments.

7.7 Limitations of the Framework

There are some limitations to the CCA CAF, which were briefly outlined in Section 1.3. In this project, workshop participants were all CMA staff engaged in water-related projects. Despite the significant differences between catchments, the three CMAs reported similar institutional issues and struggled with the same social constraints. In this chapter, we have outlined issues that affect all catchments (such as addressing institutional complexity and implementing adaptive management), irrespective of states or physical characteristics, so we believe that some results can be generalised to other catchments. However, the results could have been different if non CMA stakeholders (such as representatives of environmental groups and community interests) were present during discussions. CMA staff were chosen to participate in the workshops for their expert opinion but we are aware that in doing so other types of expert opinions were not directly included.

Tables 17–19 in Appendix 1 have very different results in the risk-assessment section because participants talked in very abstract terms and there was no detailed local-level modelling or scenarios that could focus discussions (hence this is one of our suggestions for further research). The hypothetical nature of discussions in the future scenarios and risk-assessment sections does represent a significant limitation to the CCA CAF in the absence of reliable, standardised studies of future impacts at a local level.

7.8 Conclusion

The CCA CAF is designed to help managers to systematically assess the risks, costs and benefits of different adaptation options to identify low-risk, no-regret measures. It has been developed in a project that examined an ecosystem-based approach to climate change adaptation. Often, one particular measure is perceived to be the answer for adaptation. The value of this framework is in helping decision-makers consider whether it has perverse impacts that have not been considered, to ask whether an intervention that may work in the next decade could fail after that with a changing climate, and whether there are better alternatives. There are no entirely quantitative answers, only better informed qualitative judgements to be made.

REFERENCES

- ADAMSON, D, MALLAWAARACHCHI, T and QUIGGIN, J 2009, Declining inflows and more frequent droughts in the Murray–Darling Basin: Climate change, impacts and adaptation, *The Australian Journal of Agricultural and Resource Economics*, 53, 345–66.
- ALDOUS, A, FITZSIMONS, J, RICHTER, B and BACH, L 2011, Droughts, floods and freshwater ecosystems: evaluating climate change impacts and developing adaptation strategies, *Marine and Freshwater Research*, 62, 223–31.
- ALLAN, C 2007. Adaptive management of natural resources, in AL WILSON, RL DEEHAN, RJ WATTS, KJ PAGE, K BOWMER and A CURTIS (eds), *Australian rivers: making a difference, Proceedings of the 5th Australian Stream Management Conference*, Institute for Land, Water and Society, Charles Sturt University, Albury.
- ARNAIZ, OL, WILSON, AL, WATTS, RJ and STEVENS, MM 2011, Influence of riparian condition on aquatic macroinvertebrate communities in an agricultural catchment in south-eastern Australia, *Ecological Resilience*, 26, 123–31.
- ARNELL, NW and CHARLTON, MB 2009, Adapting to the effects of climate change on water supply reliability, in WN ADGER, KL O'BRIEN and I LORENZONI (eds), *Adapting to climate change: thresholds, values, governance*, Cambridge University Press, Cambridge.
- ARTHUR, L 2010, The impacts of water trading in the southern Murray-Darling Basin: an economic, social and environmental assessment, paper presented to Irrigation Australia Conference and Exhibition: One Water, Many Futures conference, Sydney, 8–10 June.
- ASTLES, K 2001, Overview and knowledge gaps of cold water pollution in New South Wales, in B PHILLIPS (ed.), *Thermal pollution of the Murray-Darling Basin waterways, Lake Hume, Inland Rivers Network and World Wide Fund for Nature Australia*, 18–19 June.
- BALCOMBE, SR, SHELDON, F, CAPON, SJ, BOND, NR, HADWEN, WL, MARSH, N and BERNAYS, SJ 2011, Climate-change threats to native fish in degraded rivers and floodplains of the Murray-Darling Basin, Australia. *Marine and Freshwater Research*, 62, 1099–114.
- BALDWIN, DS, CAMPBELL, B, FRANKENBERG, J, HILLMAN, T, KING, A, KOEHN, JD and WARD, K 2003, *Living Murray Regional Evaluation Group B (Hume Dam to Yarrawonga Weir): Final Report*, Attachment 2 – REG B Report Regional Evaluation Group Assessment of reference point flow scenarios for zone B of the River Murray System (Hume Dam to Yarrawonga Weir), Murray-Darling Basin Commission, Australia.
- BARNETT, J, DOVERS, S, HATFIELD-DODDS, S, MCDONALD, J, NELSON, R and WALLER, S 2011, *National Climate Change Adaptation Research Plan: Social, Economic and Institutional Dimensions*, National Climate Change Adaptation Research Facility, Gold Coast.
- BARNETT, J and O'NEILL, S 2010, Editorial: Maladaptation. *Global Environmental Change*, 20, 211–13.

- BARRETT, J and MALLEN-COOPER, M 2006, The Murray River's 'Sea to Hume Dam' fish passage program: progress to date and lessons learned. *Ecological Management and Restoration*, 7, 173–83.
- BATES, B, BUNN, S, BAKER, PJ, COX, M, HOPKINS, A, HUMPHREYS, B, LAKE, S, WILLGOOSE, G and YOUNG, B 2010, *National Climate Change Adaptation Research Plan: Freshwater Biodiversity*, National Climate Change Adaptation Research Facility, Gold Coast.
- BAZELEY, P 2009. Analysing qualitative data: More than 'identifying themes'. *Malaysian Journal of Qualitative Research*, 2, 6–22.
- BELSKI, JM and WILLIAMS, DR 2012, Introduction from the new Editors-in-Chief (2012–2015). *Society and Natural Resources*, 25, 1–2.
- BOM 2011, *Special Climate Statement 24*. Bureau of Meteorology, Melbourne.
- BOND, NR and LAKE, PS 2005, Ecological restoration and large-scale ecological disturbance: the effects of drought on the response by fish to a habitat restoration experiment. *Restoration Ecology*, 13, 39–48.
- BOND, NR and LAKE, PS 2008, Local habitat restoration in streams: constraints on the effectiveness of restoration for stream biota. *Ecological Management & Restoration*, 4, 193–8.
- BOND, NR, LAKE, PS and ARTHINGTON, AH 2008, The impacts of drought on freshwater ecosystems: an Australian perspective, *Hydrobiologia*, 600, 3–16.
- BOON, HJ, COTTRELL, A, KING, D, STEVENSON, RB and MILLAR, J 2012, Bronfenbrenner's bioecological theory for modelling community resilience to natural disasters, *Natural Hazards*, 60, 381–408.
- BOOTH, DJ, BOND, NR and MACREADIE, P 2011, Detecting range shifts among Australian fishes in response to climate change, *Marine and Freshwater Research*, 62, 1027–42.
- The Brisbane Declaration, 10th International Riversymposium and International Environmental Flows Conference, 2007 Brisbane, 3–6 September.
- BURKE, T 2013, Gillard government supports irrigators, media release from Minister for Sustainability, Water, Population and Communities, viewed 13 February 2013, <<http://www.environment.gov.au/minister/burke/2013/mr20130213.html>>.CATFORD, JA, NAIMAN, RJ, CHAMBERS, LE, ROBERTS, J, DOUGLAS, M and DAVIES, P 2012, Predicting Novel Riparian Ecosystems in a Changing Climate. *Ecosystems*, doi: 10.1007/s10021-012-9566-7
- CHEESMAN, J and WHEELER, S 2011, *Survey of water entitlement sellers under the Restoring the Balance in the Murray-Darling Basin Program: final report prepared for the Department of Sustainability, Environment, Water, Population and Communities*, Marsden Jacob Associates, Financial and Economic Consultants.
- CHESSMAN, BC 2009, Climatic changes and 13-year trends in stream macroinvertebrate assemblages in New South Wales, Australia, *Global Change Biology*, 15, 2791–802.

- COMMONWEALTH OF AUSTRALIA 2011a, *Murray-Darling Basin*, Department of Sustainability, Environment, Water, Population and Communities, Canberra, viewed 25 October 2011, <<http://www.environment.gov.au/water/locations/murray-darling-basin/index.html>>.
- COMMONWEALTH OF AUSTRALIA 2011b, *Of drought and flooding rains: Inquiry into the Impact of the Guide to the Murray-Darling Basin Plan*, House of Representatives Standing Committee on Regional Australia, Canberra.
- COTTINGHAM, P, BOND, NR, LAKE, PS and OUTHET, D 2005, *Recent lessons on river rehabilitation in eastern Australia*, Cooperative Research Centre for Freshwater Ecology, Canberra.
- CSIRO 2007, *Climate change in the Murray Catchment*, prepared for the New South Wales Government by the CSIRO, Canberra.
- CSIRO 2008a, *Water availability in the Goulburn-Broken: a report to the Australian government from the CSIRO Murray-Darling Basin Sustainable Yields Project*, CSIRO, Canberra.
- CSIRO 2008b, *Water availability in the Lachlan: a report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project*, CSIRO, Canberra.
- CSIRO 2008c, *Water availability in the Murray-Darling Basin: summary of a report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project*, CSIRO, Canberra.
- CSIRO 2008d, *Water availability in the Murray: a report to the Australian government from the CSIRO Murray-Darling Basin Sustainable Yields Project*, CSIRO, Canberra.
- CSIRO 2012, *Assessment of the ecological and economic benefits of environmental water in the Murray–Darling Basin*, CSIRO Water for a Healthy Country National Research Flagship, Canberra.
- CSIRO and BUREAU OF METEOROLOGY 2007, *Climate change in Australia*, Technical Report, CSIRO, Canberra.
- DAVIES, PE 2010, Climate change implications for river restoration in global biodiversity hotspots, *Restoration Ecology*, 18, 261–8.
- DEMARRAIS, K 2004, Qualitative interview studies: learning through experience, in K DEMARRAIS and SD LAPAN (eds), *Foundations for research: methods of inquiry in education and the social sciences*, Lawrence Erlbaum, Mahwah, NJ.
- DOVERS, SR and HEZRI, AA 2010, Institutions and policy processes: the means to the ends of adaptation, *Wiley Interdisciplinary Reviews: Climate Change*, 1, 212–31.
- DSE 2008, *Climate change in the Goulburn Broken*, Department of Sustainability and Environment, Melbourne.
- DSE 2009, *Northern Region Sustainable Water Strategy*, Department of Sustainability and Environment, Melbourne.
- DUDLEY, N, STOLTON, S, BELOKUROV, A, KRUEGER, L, LOPOUKHINE, N, MACKINNON, K, SANDWITH, T and SEKHRAN, N (eds) 2010, *Natural solutions: protected areas helping people cope with climate change*, IUCN-WCPA, TNC, UNDP, WCS, The World Bank and WWF, New York.

- ECKERSLEY, N 2010, SunRice to reopen Deniliquin rice mill, *Aus Food News*, 4 November.
- EISENACK, K and STECKER, R 2012, A framework for analyzing climate change adaptations as actions, *Mitigation and Adaptation Strategies for Global Change*, 17, 243–60.
- FERRARO, PJ 2008, Asymmetric information and contract design for payments for environmental services, *Ecological Economics*, 65, 810–21.
- GILLIGAN, D, JESS, L, MCLEAN, G, ASMUS, M, WOODEN, I, HARTWELL, D, MCGREGOR, C, STUART, I, VEY, A, JEFFERIES, M, LEWIS, B and BELL, K 2010, *Identifying and implementing targeted carp control options for the Lower Lachlan Catchment*, Department of Industry and Investment, Batemans Bay, NSW.
- GITAY, H, FINLAYSON, M and DAVIDSON, N 2011, *A framework for assessing the vulnerability of wetlands to climate change*, Ramsar Technical Report No. 5, Ramsar Convention Secretariat, Gland, Switzerland.
- GLOBAL LEADERSHIP FOR CLIMATE ACTION 2009, *Facilitating an International Agreement on Climate Change: Adaptation to Climate Change*, UN Foundation, Geneva.
- GOULBURN BROKEN CMA 2005. Goulburn Broken Regional River Health Strategy: 2005-2015. Shepparton, Victoria: Goulburn Broken Catchment Management Authority.
- GOULBURN BROKEN CMA 2012a, *Climate Change Integration Strategy 2012–2015*, Goulburn Broken Catchment Management Authority, Benalla, Vic.
- GOULBURN BROKEN CMA 2012b, *Who we are and what we do*. Viewed 30 March 2012, <http://www.gbcma.vic.gov.au/default.asp?ID=who_we_are_what_we_do>.
- GOVERNMENT OF SOUTH AUSTRALIA 2012, *South Australian Government Submission on the Murray-Darling Basin Authority's Draft Basin Plan – April 2012*, South Australian Government, Adelaide.
- GROSS, C, PITTOCK, J, FINLAYSON, M and GEDDES, MC 2011, *Limits to adaptation: climate change adaptation in the Coorong, Murray Mouth and Lakes Alexandrina and Albert*, National Climate Change Adaptation Research Facility, Gold Coast.
- HALLEGATTEA, S 2009, Strategies to adapt to an uncertain climate change, *Global Environmental Change*, 19, 240–7.
- HLADYZ, S, WATKINS, SC and BALDWIN, DS 2009, Current understanding of blackwater events relating to the Edward-Wakool River System, Murray-Darling Freshwater Research Centre, Wodonga, Vic.
- HULME, PE 2005, Adapting to climate change: is there scope for ecological management in the face of a global threat? *Journal of Applied Ecology*, 42, 784–94.
- IPCC 2007a, Climate change 2007: the physical science basis. *Contribution of Working Group I to the Fourth Assessment Report of the IPCC*, Cambridge University Press, Cambridge.

- IPCC 2007b, Summary for policymakers, in ML PARRY, OF CANZIANI, JP PALUTIKOF, PJ VAN DER LINDEN and CE HANSON (eds), *Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge.
- IPCC 2007c, Technical summary, in ML PARRY, OF CANZIANI, JP PALUTIKOF, PJ VAN DER LINDEN and CE HANSON (eds), *Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge.
- IPCC 2012, Summary for policymakers, in CB FIELD, V BARROS, TF STOCKER, D QIN, DJ DOKKEN, KL EBI, MD MASTRANDREA, KJ MACH, GK PLATTNER, SK ALLEN, M TIGNOR and PM MIDGLEY (eds), *Managing the risks of extreme events and disasters to advance climate change adaptation*, Cambridge University Press, Cambridge.
- JACKSON, P 2009, Carp harvest and disposal at Murray River Fishways, in J PRITCHARD (ed.), *Proceedings of the Murray-Darling Basin Authority Native Fish Forum 2009*, Murray-Darling Basin Authority, Albury, 129–33.
- JENKINS, KM, KINGSFORD, R, WOLFENDEN, BJ, WHITTEN, S, PARRIS, H, SIVES, C, ROLLS, R and HAY, S 2011, *Limits to climate change adaptation in floodplain wetlands: the Macquarie Marshes*. National Climate Change Adaptation Research Facility, Gold Coast.
- JONES, RN, DETTMANN, P, PARK, G, ROGERS, M and WHITE, T 2007, The relationship between adaptation and mitigation in managing climate change risks: a regional response from North Central Victoria, Australia, *Mitigation and Adaptation Strategies for Global Change*, 12, 685–712.
- KING, N and HORROCKS, C 2010, An introduction to interview data analysis, in *Interviews in qualitative research*, Sage, London.
- KINGSFORD, RT 2000, Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia, *Australian Ecology*, 25, 109–27.
- KINGSFORD, RT 2011, Conservation management of rivers and wetlands under climate change: a synthesis, *Marine and Freshwater Research*, 62, 217–22.
- KINGSFORD, RT and THOMAS, RF 2001, *Changing water regimes and wetland habitat on the Lower Murrumbidgee floodplain of the Murrumbidgee in arid Australia*, Report to Environment Australia, NSW Parks and Wildlife Service, Sydney.
- KOEHN, JD 2001, Ecological impacts of cold water releases on fish and ecosystem processes, in B PHILLIPS (ed.), *Thermal pollution of the Murray-Darling Basin waterways*, Inland Rivers Network and World Wide Fund for Nature Australia, Lake Hume, 18–19 June.
- LACHLAN CMA 2012a, *About Us*, viewed 30 March 2012, <<http://www.lachlan.cma.nsw.gov.au/about.aspx>>.
- LACHLAN CMA 2012b, *Carbon sequestration, Lachlan CMA*, viewed 29 June 2012, <<http://www.lachlan.cma.nsw.gov.au/ourprojects/pages/carbseq.aspx>>.

- LACHLAN CMA 2012c, *Climate Change*, viewed 30 March 2012, <<http://www.lachlan.cma.nsw.gov.au/whatwedo/climatechange.aspx>>.
- LACHLAN CMA 2012d, *Water & Aquatic Ecosystems*, viewed 30 March 2012, <<http://www.lachlan.cma.nsw.gov.au/whatwedo/water.aspx>>.
- LACHLAN CMA n.d., *Lachlan Environmental Water Management Plan Summary*, Lachlan CMA, Forbes, NSW.
- LAKE, PS 2003, Ecological effects of perturbation by drought in flowing waters, *Freshwater Biology*, 48, 1161–72.
- LEE, H 2008. Protected areas and climate change, *Annals of the New York Academy of Sciences*, 1134, 301–12.
- LEE, H, MIDGLEY, G, ANDELMAN, S, ARAÚJO, M, HUGHES, G, MARTINEZ-MEYER, E, PEARSON, R and WILLIAMS, P 2007, Protected area needs in a changing climate, *Frontiers in Ecology and the Environment*, 5, 131–8.
- LINDENMAYER, DB, STEFFEN, W, BURBIDGE, AA, HUGHES, L, KITCHING, RL, MUSGRAVE, W, STAFFORD SMITH, M and WERNER, PA 2010, Conservation strategies in response to rapid climate change: Australia as a case study, *Biological Conservation*, 143, 1587–93.
- MAC NALLY, R, CUNNINGHAM, SC, BAKER, PJ, HORNER, GJ and THOMSON, JR 2011, Dynamics of Murray-Darling floodplain forests under multiple stressors: the past, present, and future of an Australian icon, *Water Resources Research*, 47, W00G05, doi:[10.1029/2011WR010383](https://doi.org/10.1029/2011WR010383)
- MARTIN, F 2011, *Position statement – riparian and aquatic health*, Lachlan CMA, Forbes, NSW.
- MCALPINE, CA, SYKTUS, J, RYAN, JG, DEO, RC, MCKEON, GM, MCGOWAN, HA and PHINN, SR 2009, A continent under stress: interactions, feedbacks and risks associated with impact of modified land cover on Australia's climate, *Global Change Biology*, 15, 2206–23.
- MDBC 2008, *SRA report 1: a report on the ecological health of rivers in the Murray–Darling Basin, 2004–2007*, MDBC Publication No. 19/08, Canberra.
- MDFRC 2009, *Understanding blackwater events and managed flows in the Edward-Wakool River system, NSW*, Murray-Darling Freshwater Research Centre, M/BUS/319, Version 1.
- MILLENNIUM ECOSYSTEM ASSESSMENT 2005, *Ecosystems and human well-being: wetlands and water synthesis*, World Resources Institute, Washington, DC.
- MILLER, SW, BUDY, P and SCHMIDT, JC 2010, Quantifying macroinvertebrate responses to in-stream habitat restoration: applications of meta-analysis to river restoration, *Restoration Ecology*, 18, 8–19.
- MORRISON, M, DURANTE, J, GREIG, J, WARD, J and OCZKOWSKI, E 2012, Segmenting landholders for improving the targeting of natural resource management expenditures, *Journal of Environmental Planning and Management*, 55, 17–37.

- MURRAY CMA 2011, *Climate Change Adaptation Policy*, viewed 30 March 2012, <http://www.murray.cma.nsw.gov.au/images/stories/policies/Climate%20Change%20Adaptation%20Policy%202011_12.pdf>.
- MURRAY CMA 2012a, *Catchment Facts*, viewed 30 March 2012, <<http://www.murray.cma.nsw.gov.au/our-catchment/facts.html>>.
- MURRAY CMA 2012b, Deliverability of environmental water in the Murray Valley: report to Murray Group of Concerned Communities, Murray CMA.
- MURRAY CMA 2012c, *Riverine Strategy*, viewed 30 March 2012, viewed 30 March 2012, <<http://www.murray.cma.nsw.gov.au/riverine-strategy.html>>.
- NELSON, DR 2010, Adaptation and resilience: responding to a changing climate, *Wiley Interdisciplinary Reviews: Climate Change*, 2, 113–20.
- NELSON, DR, ADGER, WN and BROWN, K 2007, Adaptation to environmental change: contributions of a resilience framework, *Annual Review of Environment and Resources*, 32, 395–419.
- NEWTON, G 2009, Australia's environmental climate change challenge: overview with reference to water resources, *Australasian Journal of Environmental Management*, 16, 130–9.
- NOSS, RF 2001, Beyond Kyoto: forest management in a time of rapid climate change, *Conservation Biology*, 15, 578–90.
- NSW DPI 2006, *The identification, assessment and prioritisation of threatening processes to the aquatic environment of the Lower Lachlan Catchment*. Report to the Lachlan Catchment Management Authority, NSW Department of Primary Industries, Sydney.
- NSW DPI 2013, *High flow and flood management*, viewed 16 March 2013, <<http://www.water.nsw.gov.au/Water-management/Water-availability/Flood-management/Flood-management>>.
- NSW STATE WATER 2012, *Completed fish passage: Fishways*, viewed 16 March 2013, <<http://www.statewater.com.au/Current+Projects/Environmental+Projects/Completed+fish+passage>>.
- NWC 2012, *Water policy and climate change in Australia*, National Water Commission, Canberra.
- OLDEN, JD and NAIMAN, RJ 2010, Incorporating thermal regimes into environmental flows assessments: modifying dam operations to restore freshwater ecosystem integrity, *Freshwater Biology*, 55, 86–107.
- PATT, AG 2009, Learning to crawl: how to use seasonal climate forecasts to build adaptive capacity, in WN ADGER, KL O'BRIEN and I LORENZONI (eds), *Adapting to climate change: thresholds, values, governance*, Cambridge University Press, Cambridge.
- PITTOCK, J 2009, Lessons for climate change adaptation from better management of rivers, *Climate & Development*, 1, 194–212.
- PITTOCK, J 2011, National climate change policies and sustainable water management: conflicts and synergies, *Ecology & Society*, 16, 25.

- PITTOCK, J and FINLAYSON, M 2011, Australia's Murray-Darling Basin: freshwater ecosystem conservation options in an era of climate change, *Marine and Freshwater Research*, 62, 232–43.
- PITTOCK, J, FINLAYSON, M, GARDNER, A and MCKAY, C 2010, Changing character: the Ramsar Convention on Wetlands and climate change in the Murray-Darling Basin, Australia, *Environmental and Planning Law Journal*, 27, 401–25.
- PITTOCK, J, HANSEN, LJ and ABELL, R 2008, Running dry: freshwater biodiversity, protected areas and climate change, *Biodiversity*, 9, 30–9.
- PRODUCTIVITY COMMISSION 2012, *Barriers to effective climate change adaptation: draft report*, Productivity Commission, Canberra.
- REEDER, T, WICKS, J, LOVELL, L and TARRANT, O 2009, Protecting London from tidal flooding: limits to engineering adaptations, in WN ADGER, KL O'BRIEN and I LORENZONI (eds), *Adapting to climate change: thresholds, values, governance*, Cambridge University Press, Cambridge.
- REID-PIKO, C, CRASE, L, HORWITZ, P and BUTCHER, R 2010, *Ecosystem services and productive base for the Basin Plan*, report prepared for the Murray-Darling Basin Authority by the Murray-Darling Freshwater Research Centre, MDFRC Publication 06/2010, MDFRC, Canberra.
- RYAN, T, WEBB, A, LENNIE, R and LYON, J 2001, *Status of cold water releases from Victorian dams*, report produced for Catchment and Water, Department of Natural Resources and Environment, Arthur Rylah Institute, Melbourne.
- SANGER, A 2009, *Recommendation: degradation of native riparian vegetation along New South Wales water courses*, Fisheries Scientific Committee, Sydney.
- SCANLON, J 2006, A hundred years of negotiations with no end in sight: Where is the Murray Darling Basin Initiative leading us? *Environmental Planning and Law Journal*, 23, 1–26.
- SHELDON, F, BALCOMBE, SR, CAPON, SJ, HADWEN, WL, KENNARD, M, BOND, NR and MARSH, N 2010, *Modelling the impacts of climate change on aquatic ecosystems of the Murray-Darling Basin*, Murray-Darling Basin Authority, Canberra.
- SMOKOROWSKI, KE, WHITHERS, KJ and KELSO, JRM 1998, *Does habitat creation contribute to management goals? An evaluation of literature documenting freshwater habitat rehabilitation or enhancement projects*, Canadian Technical Report of Fisheries and Aquatic Sciences, Marie, Canada.
- STEFFEN, W 2009, *Climate change 2009: faster change and more serious risks*, Department of Climate Change, Canberra.
- THE WORLD BANK 2009, *Convenient solutions to an inconvenient truth: ecosystem-based approaches to climate change*, World Bank, Washington, DC.
- THOMSON, JR, BOND, NR, CUNNINGHAM, SC, METZELING, L, REICH, P, THOMSON, RM and MAC NALLY, R 2012, The influences of climatic variation and vegetation on stream biota: lessons from the Big Dry in southeastern Australia, *Global Change Biology*, 18, 1–15.

- TOMPKINS, EL and ADGER, WN 2003, *Building resilience to climate change through adaptive management of natural resources*, Tyndall Centre for Climate Change Research, London.
- TUCKER, K 2011, *Goulburn Broken Local Government Regional Climate Change Adaptation Plan*, Goulburn Broken Greenhouse Alliance, Camberwell, Vic.
- TURAK, E, MARCHANT, R, BARMUTA, LA., DAVIS, JA, CHOY, S and METZELING, L 2011, River conservation in a changing world: invertebrate diversity and spatial prioritisation in south-eastern coastal Australia, *Marine and Freshwater Research*, 62, 300–11.
- UMWELT 2009, *Preliminary environmental assessment – proposed ammonium nitrate emulsion production facility and continued operation of Orica Mining Services Technology Park, Richmond Vale, NSW*, Umwelt Environmental Consultants, on behalf of Orica Australia Pty Ltd, Toronto, NSW.
- URQUHART, J 2012. *International honour award for fish superhighways*, viewed 1 December 2012, <<http://www.statewater.com.au/About+us/News+and+events/Media+releases+2012/International+honour+award+for+Fish+Superhighways>>.
- URS 2003, *Lake Mokoan study final report: executive summary*, Goulburn Broken Catchment Management Authority, Goulburn.
- VAN DIJK, A, EVANS, R, HAIRSINE, P, KHAN, S, NATHAN, R, PAYDAR, Z, VINEY, N and ZHANG, L 2006, *Risks to the shared water resources of the Murray-Darling Basin*, Murray-Darling Basin Commission, Canberra.
- VANCLAY, F 2004, Social principles for agricultural extension to assist in the promotion of natural resource management, *Australian Journal of Experimental Agriculture*, 44, 213–22.
- WILDLIFE QUEENSLAND 2011, *Environmental Impact of Floods – February 2011*, viewed 16 March 2013, <<http://www.wildlife.org.au/news/2011/flooding5.html>>.
- WILLIAMS, SE, SHOO, LP, ISAAC, J, HOFFMANN, AA and LANGHAM, G 2008, Toward an integrated framework for assessing the vulnerability of species to climate change, *PLoS Biology*, 6, 2621–6.
- WINTON WETLANDS COMMITTEE OF MANAGEMENT 2011, Website, viewed 29 May 2012, <<http://www.wintonwetlands.org.au/index.asp>>.

APPENDIX 1: CCA CATCHMENT ASSESSMENT FRAMEWORKS

Table 17: The Murray CCA CAF

Murray Catchment													
Description of each option			Environmental flows	Environmental works and measures	Thermal pollution control	Restoration of riparian vegetation	Freshwater habitat connectivity	Conservation of more resilient habitats	Conservation of gaining reaches	Geomorphic restoration	Management of exotic species		
Catchment relevance	Extent to which the option exists in the catchment		Currently Implemented	Currently Implemented	Considered & Rejected	Currently Implemented	Currently Implemented	Currently Implemented	Currently Implemented	Not Yet Implemented	Currently Implemented		
Climate change adaptation potential	Climate change adaptation benefit	Reducing vulnerability caused by non-climate change stressors	✓	✓	✓	✓	✓		✓	✓			
		Increasing resilience to climatic shocks/changes	✓	✓		✓		✓	✓	✓	✓	✓	
	Effectiveness under changing climate change scenarios	Extreme Wet											
		Moderate											
		Dry											
		Very Dry											
		Current conditions											
	Potential for maladaptation	Increasing emissions	?	•/•	•/•	•	•	•	•	•	?	•	
		Disproportionate burden on most vulnerable	•/●	•	•	•	•	•	•	•	•	•	
		High opportunity costs	•/•	•/●	●	•/•	•	?	?	•	•	•	
		Reducing incentive to adapt	•	?	•	?	•	?	•	•	•	•	
		Path dependency	•	●	•	•	•	•	•	•	•	•	
		Increasing existing stressors	?/•	•	•	•	•	•	•	•	•	•	
Ecosystem services benefit	Provisioning		✓	✓		✓		✓	✓	✓	✓		
	Regulating		✓/?	✓		✓		✓	✓	✓	✓		
	Supporting		✓	✓		✓	✓	✓	✓	✓	✓		
	Cultural		✓	✓	✓	✓	✓	✓	✓	✓	✓		
Constraints to implementation	Physical		•/•/●	•	●		●		•	•			
	Financial		●	●	●	●	●	•		•	●		
	Socio-political		•/•/●	●	•	•/●	•	•	•	•	•/●		
	Institutional		●	•/●			•	•/●	•/●	•/●	•		
Actual, perceived and hypothetical socio-Economic consequences			✓✓✓	✓✓	✓	✓✓✓		✓			✓✓		
			✕✕✕✕	✕✕		✕		✕✕			✕✕✕✕		
Risk assessment	Extreme wet		L	L	L	L	L	L	L	E	H	H	
	Moderate		M	L	L	L	M	L	L	L	M	M	
	Dry		H	M	M	M	H	M	M	M	M	M	
	Very dry		E*	E*	H	H	E	H	H	H	H	L→	H

Table 18: The Lachlan CCA CAF

Lachlan Catchment											
Description of each option			Environmental flows	Environmental works and measures	Thermal pollution control	Restoration of riparian vegetation	Freshwater habitat connectivity	Conservation of more resilient habitats	Conservation of gaining reaches	Geomorphic restoration	Management of exotic species
Catchment relevance	Extent to which the option exists in the catchment		Currently Implemented	Not Yet Implemented	Considered & Rejected	Currently Implemented	Currently Implemented	Currently Implemented	Currently Implemented	Currently Implemented	Currently Implemented
Climate change adaptation potential	Climate change adaptation benefit	Reducing vulnerability caused by non-climate change stressors	x		✓	✓	✓	✓	✓	✓	✓
		Increasing resilience to climatic shocks/changes	✓	✓		✓		✓	✓	✓	
	Effectiveness under changing climate change scenarios	Extreme Wet									
		Moderate									
		Dry									
		Very Dry									
		Current conditions									
	Potential for maladaptation	Increasing emissions	.	./•	./•	.	.	.	.	.	.
		Disproportionate burden on most vulnerable	•/●	.	.	.	.	.	.	.	.
		High opportunity costs	.	●	●	?	•	.	•	./•	•→●
		Reducing incentive to adapt	•	?	.	.	.	.	?	.	.
		Path dependency	●	●	.	.	.	.	.	.	•
		Increasing existing stressors	•	•	.	.	•	.	.	.	.
Ecosystem services benefit	Provisioning		✓	✓		✓		✓			
	Regulating			✓		✓		✓	✓	✓	
	Supporting		✓	✓		✓	✓	✓	✓	✓	
	Cultural		✓	✓	✓	✓	✓	✓	✓	✓	
Constraints to implementation	Physical		•	./•	•		•/●		•	●	●
	Financial		•	●	●	●	●	●	•	●	●
	Socio-political		•	•	•	./•	●	•	•	•	./•
	Institutional		•	•	•		•		•		•
Actual, perceived and hypothetical socio-economic consequences			✓✓			✓✓✓					✓✓
			x x x x	x		x	x	x x			x x
Risk assessment	Extreme wet		L	L	M	L	L	L	L	H	E
	Moderate		M	L	M	L	L	L	L	E	H
	Dry		E	H	M	H	M	H	H	H	H
	Very dry		E	H	L	H	H	E	H	H	H

Table 19: The Goulburn Broken CCA CAF

Goulburn Broken Catchment													
Description of each option			Environmental Flows	Environmental works and measures	Thermal pollution control	Restoration of riparian vegetation	Freshwater habitat connectivity	Conservation of more resilient habitats	Conservation of gaining reaches	Geomorphic restoration	Management of exotic species		
Catchment relevance	Extent to which the option exists in the catchment		Currently Implemented	Not Yet Implemented	Considered & Rejected	Currently Implemented	Currently Implemented	Currently Implemented	Currently Implemented	Currently Implemented	Currently Implemented		
Climate change adaptation potential	Climate change adaptation benefit	Reducing vulnerability caused by non-climate change stressors	✓	✓	✓	✓	✓ x	✓	✓	✓	✓		
		Increasing resilience to climatic shocks/changes	✓	✓	✓	✓		✓	✓	✓	✓		
	Effectiveness under changing climate change scenarios	Current conditions											
		Wet											
		Moderate											
		Dry											
		Very dry											
	Potential for maladaptation	Increasing emissions	•	•/•	•/•/?	•	•	•	•	•	•	•	
		Disproportionate burden on most vulnerable	•	•	•/●	•	•	•	•	•	•	•	
		High opportunity costs	•	•	●	?	•	•	•/•	?	●	●	
		Reducing incentive to adapt	•	?	•	•	•	•	?	•	•	•	
		Path dependency	•	●	•	•	•	•	•	•	•	•	
		Increasing existing stressors	•	•		•/?	•	•	•	•	•	•	
Ecosystem services benefit	Provisioning			✓		✓	✓	✓	✓		✓		
	Regulating		✓	✓		✓	✓	✓	✓	✓	✓		
	Supporting		✓	✓		✓	✓	✓	✓	✓	✓		
	Cultural		✓	✓		✓	✓	✓	✓	✓	✓		
Constraints to implementation	Physical		●		●				•				
	Financial		●	●	●	●	●	●	●	●	●		
	Social		•/●		•	•/●	●	•		•	●		
	Institutional			•		•	●	●	●	●	●		
Actual, perceived or hypothetical socio-economic consequences						✓✓✓✓	✓✓✓✓✓						
			x x		x	x	x				x		
Risk assessment	Wet		L	L	E	L	L	L	L	L	H	E	
	Moderate		L	L	M	L	M	L	L	L	M		
	Dry		H	M	L	L	H	H	H	L	M		
	Very dry		E	E	L	M	E	H	H	M	L	→ E	

Legend for Tables 17–19

✓	Present & directly beneficial
✗	Present & directly detrimental
·	Negligible impact
•	Medium impact
●	Large impact
?	Impact unknown
	Not present
	Likely to be effective and beneficial
	Less effective or with lower benefits
	Not effective or redundant
L	Low risk of failure
M	Medium risk of failure
H	High risk of failure
E	Extreme risk of failure

National Climate Change Adaptation Research Facility
Griffith University Gold Coast Campus
Parklands Drive, Southport
QLD 4222, Australia
Telephone 07 5552 9333
Facsimile 07 5552 7333
www.nccarf.edu.au



Australian Government
Department of Climate Change
and Energy Efficiency



Queensland
Government



Griffith
UNIVERSITY



Murdoch
UNIVERSITY



UNIVERSITY OF
SOUTHERN QUEENSLAND
fulfilling lives



University of the
Sunshine Coast
Queensland, Australia

MACQUARIE
UNIVERSITY



THE UNIVERSITY OF
NEWCASTLE
AUSTRALIA