Impacts of Climate on the Canberra Nature Park : Risks and Responses

Report for the ACT Office of the Commissioner for Sustainability and the Environment

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Executive Summary

This report was commissioned by the ACT Office of the Commissioner for Sustainability and the Environment (OCSE) to provide advice to the current Investigation into a number of the ACT Nature Reserves, in particular on the implications of climate variability and change. It synthesises conclusions from currently available studies and makes a number of recommendations.

A. Conclusions

Section 1 - Values and Outcomes: Five desired outcome areas (OA) have been identified for the Nature Reserves against which climate impacts can be assessed:

- (OA1): Conservation and rehabilitation of the natural environment
- (OA2): Contribution to climate regulation (including carbon storage), and water and air regulation and quality
- (OA3): Biodiversity conservation and resilience
- (OA4): Protection of both on- and off-reserve assets from natural hazards (especially fires and to some extent excessive water runoff/ floods)
- (OA5): Public uses and associated values (including visual amenity, public use recreational activities, cultural heritage, education and research)

Not all of these are fully articulated in the current policy documents and management plans for the Reserves.

Section 2 – Climate Direction: Continuing global warming with anthropogenic causes was judged to be extremely likely by the most recent IPCC assessment in 2007, and evidence since then is tracking at the upper end of the range of scenarios. The trends are also evident in SE Australia and the ACT, and views are firming that changes to the climate drivers for the region are also consistent with global warming.

A number of recent studies have included climate analysis and projections relevant to the ACT and region. There is little or no consistency in underlying assumptions and approaches adopted, making detailed comparison of the projections difficult. The greatest uncertainty of projections is for rainfall where current climate models are deficient especially at the regional and local level. However, across these studies there is some consistency in the projected directions of climate change including continuing increases in temperatures, and a high probability of changes in the pattern of rainfall from that observed in the period of instrumental records, with some risk of a decline in long-term average rainfall. This and increased evaporation would mean increasing dryness of soil and landscapes. The analyses also suggest increased frequency and intensity of extreme weather events (heatwaves, fire weather, storms).

Therefore, notwithstanding the significant uncertainties in absolute projections, it has been possible to articulate a consistent set of climate *directions* for the purposes of assessing future climate impacts on the Nature Reserves. Proposed climate adaptation decisions should be tested for consistency with these directional changes and, especially if dependent on rainfall, for robustness to a range of possible climate outcomes.

Section 3 – Risks and Impacts: The eucalypt grassy woodlands and grasslands typical of the ACT Nature Reserves are already amongst the most threatened ecological communities in Australia. Analysing the impacts of the future climate directions on the desired Nature Reserve outcomes identifies a number of increased risk areas, especially as the landscape function of the Reserves is already reduced. The climate impacts and other disturbance pressures and stressors (e.g. land use, invasive species, grazing, prescribed burning) have a mutually reinforcing impact.

There is a significant climate risk to natural ecosystem function and processes (Outcome Area 1), with further reduction to already disturbed landscape function through increased erosion and reductions in soil moisture, vegetation growth and renewal and biological/ nutrient processes. This in turn presents a risk (though somewhat less significant compared with other risks) to the natural regulatory functions of the Reserves on climate, water and air (OA2). The most significant risk is to the Reserves' significant biodiversity values (OA3) which face a multiple 'climate whammy' from the increased loss of habitat, the threat from invasive species more resilient to climate, and the increased risk from changing bushfire frequency and intensity and prescribed burning; all in addition to the direct climate physiological impact on local species (though little is know about the latter for individual species most relevant to the Reserves). The complexity of impacts and interdependencies make precise predictions impossible, especially with the likelihood of dynamic and novel ecosystems, and unknown tipping points.

There is a significant climate risk in natural hazards (OA4) mostly related to increased bushfire risk in the Reserves which would also present an increased threat to nearby human and urban assets especially as many of the Reserves have adjacent housing.

To the extent that the above threats continue to increase, there is also a significant risk to public use values of the Reserves (OA5), accentuated by the potential for greater usage restrictions with growing tension between conflicting objectives.

The extent to which these risks and associated impacts increase actual vulnerability depends on the adequacy of adaptation responses.

Section 4 - Adaptation Responses: The good news on adaptation is that most potential responses will mitigate both climate and non-climate threats. Furthermore many can be progressed with some confidence that they will have value notwithstanding the uncertainties in both absolute climate projections and the extent of specific impacts. The main challenges are to better understand areas of potential conflict between competing values, to choose investment priorities in the context of limited resources, and to have effective research and monitoring, and adaptive management processes that respond to new information as it becomes available.

Key strategies include

- Maintaining and enhancing fundamental ecosystems processes and services, including improvement in landscape function, vegetation and habitats, through facilitating natural regeneration (e.g. by removal of stressors) and active restoration (e.g. revegetation and land erosion mitigation)
- Enhancing the resilience of ecosystems and species through maintaining diversified habitats and refugia and improving connectivity on a 'whole of landscape' basis

- Facilitating ecosystems and species development in dynamic, novel and often unpredictable ways – aiming to maintain the status quo is not an adequate response
- Land use planning and fire management that balances human and natural assets protection, backed up by progressive monitoring and learning
- Effective and integrated governance and adaptive management approaches for the reserves, backed up by greater understanding of community values and enhanced community communication and engagement, underpinned by restated values and objectives for the Reserves more appropriate to a changing and to some extent unpredictable environment.

Section 5 - Knowledge Gaps: There are many knowledge gaps identifiable at all stages of the assessment. They do not prevent response strategies and actions taking place right now, but future effectiveness would be enhanced by the most significant information gaps being prioritised and addressed.

Section 6 - Broader ACT and region integration: The climate issues and responses that have been identified in this report have implications for all of the sectors that have been suggested for more general climate change vulnerability assessment for the ACT (natural resource management, water, natural hazards management, human settlements, infrastructure, human health and tourism/ recreation). This reflects the special characteristic of the Reserves being at the interface of the human and environment systems. It also points to the inevitability of some conflict and trade offs when addressing climate change (and other) responses; and to the importance of adopting an integrated cross-sector and cross-agency approach to planning and decisions.

There are many areas of operational cooperation across agencies within the ACT and across jurisdictions with NSW. However, at the level of overall policy and planning, integration and collaboration could usefully be enhanced. There are a number of current climate-related initiatives in both the ACT and NSW that provide opportunities to do so. Overall there is an opportunity to demonstrate the ACT and region as a prototype of cross jurisdictional, coordinated and cost-effective regional climate change response, through development of a truly integrated and regional approach.

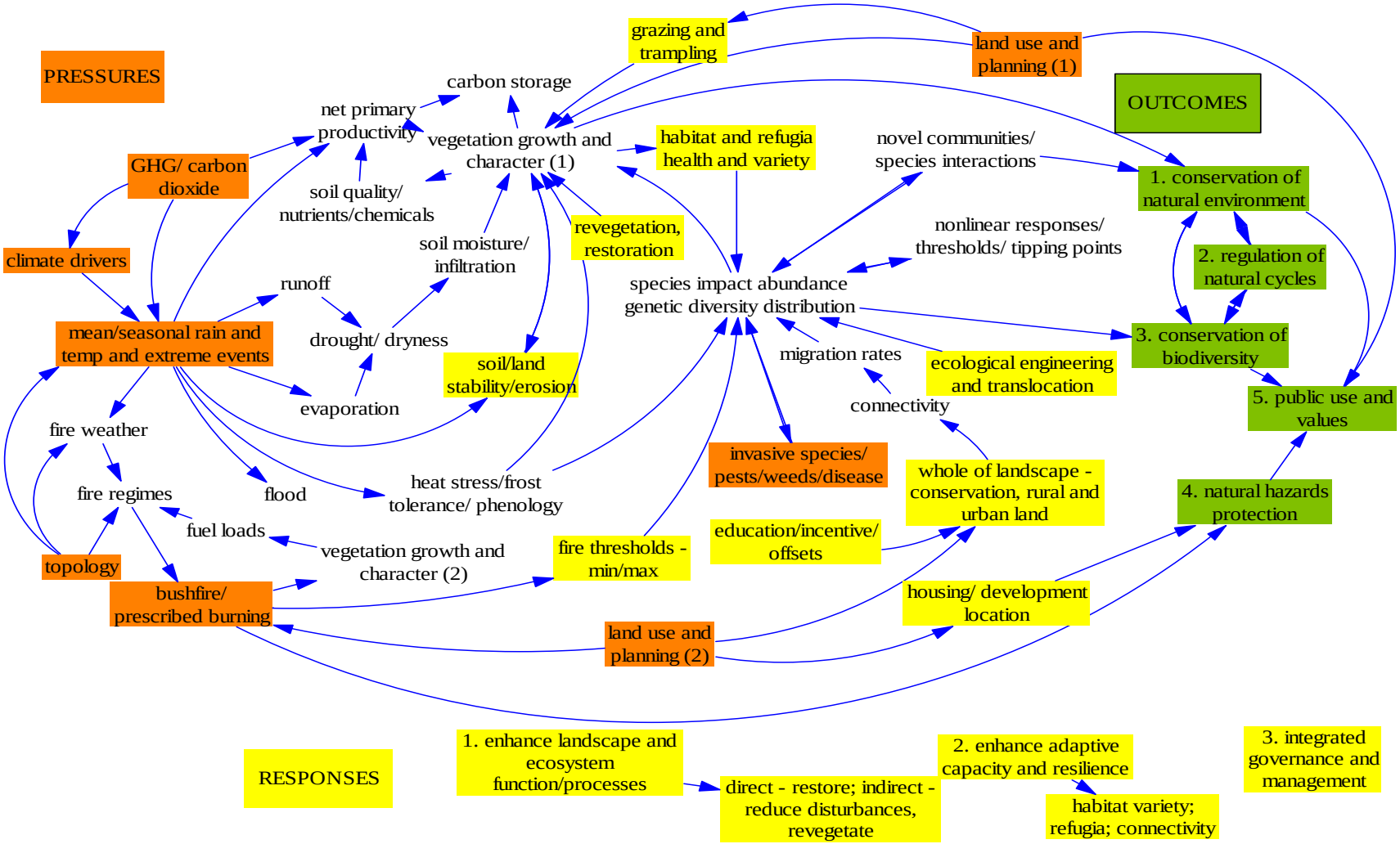
Taking a systems view of the Nature Reserves

Good practice in addressing complex human-environment issues suggests taking a systems based view of the issues. The following influence diagram was used as a device to assist the analysis in this report. It demonstrates a number of features

- The pervasive impacts of climate throughout the entire Nature Reserves 'system', thus affecting all of the outcome areas
- The significance of other (non-climate) pressures and disturbances and their interaction with climate change impacts
- Some of the key response strategies and how they can leverage improvement in the performance of the overall Nature Reserves 'system'
- How human actions, behaviours and responses influence the entire system.

Such analyses are sometimes criticised as being overly-complex and 'spaghetti-like'. In fact the reality is if anything more complex than shown. Policy prescriptions and responses need to be aware of at least the main features and interdependencies if they are to have the desired impact.

Nature Reserves Influence Diagram - a Systems View



B. Recommendations

Recommendation 1: That the publicly stated values and outcomes for the Nature Reserves be reviewed for consistency and completeness, to provide an agreed basis for future risk, strategy and performance assessment, including for the impacts of climate variability and change. The outcomes summarised and used in this report provide one input to such a review.

Recommendation 2.1: The ACT Government, in collaboration with relevant research institutions (and if possible the NSW Government) develop an ACT and region climate risk information system, which includes all types of relevant and currently available climate information, including uncertainties; and based on this adopt and communicate consistent approaches to the use of this information by agencies for various sector or issue-based vulnerability assessments, planning and decision making.

Recommendation 2.2: The ACT Government drive for, and participate with other spheres of government (especially NSW and the Commonwealth) in, progressive enhancement of the regional climate information base, drawing on improvements in climate analysis, modelling and projections as they become available, including downscaling techniques. This is consistent with the national climate science framework and agenda, and also recognises that the ACT Government has limited resources to commission its own basic research.

Recommendation 2.3: In the meantime, for the ACT Nature Reserves, analysis of impacts and planning responses and decisions should be based on the following climate directions

- the strong likelihood of mean temperatures continuing to increase, along with more frequent and severe heatwaves for the ACT and region
- a high probability of changes in observed long-term rainfall patterns (e.g. a potential continuation of significantly lower autumn rainfall), and an increase in rainfall intensity with more extreme rainfall events
- increased evaporation, leading to (all else being equal) reduced runoff and stream flows and
- more severe drought periods, changing bushfire regimes, and flood events.

Recommendation 3: The risk areas and vulnerabilities of the Nature Reserves as identified in this report should be more explicitly analysed at a further level of detail in the next round of planning for the Reserves (see also Recommendation 4.3), using a standard risk and vulnerability assessment tool and a range of expert inputs. This would include establishing at least the relative significance of vulnerabilities and the priority knowledge gaps (see also Recommendation 5). This is important to optimise use of scarce resources to respond to the priority issues.

Recommendation 4.1: Adopt the adaptation response principles and strategies summarised in this report (see Section 4.5) to guide the specific risk mitigation actions proposed for the Nature Reserves. Test specific proposals for alignment with these, and prioritise based on current information.

Recommendations 4.2: Do not wait for improved climate and impact information before taking the further actions that will enhance the resilience of the Nature Reserves.

Recommendation 4.3: Progressively review and update the various strategic and management plans relevant to the Nature Reserves, taking the opportunity to more explicitly incorporate the climate change risk assessments and responses, and to enhance and rationalise the planning process and framework for greater ongoing flexibility. Monitoring and adaptive management approaches should be built in up front so that strategies and activities can respond flexibly as new climate information and impact knowledge becomes available.

Recommendation 5: Address the knowledge gaps on climate, impacts and responses, including those identified in this report, through a prioritised, intentional and coordinated approach across key government agency, researcher and community stakeholders.

Recommendation 6: Ensure the climate change vulnerability assessment and adaptation responses for the Nature Reserves both inform and reflect broader climate change assessments and strategies for the ACT and region as they become available, in an iterative process that recognises over time the many interdependencies across sectors, policy areas and jurisdictions.

The above recommendations are elaborated on in the corresponding section of the report.

Section 1. Context, Values and Outcomes

1.1 The OCSE Investigation into the Nature Reserves

In October 2009 the Australian Capital Territory (ACT) Minister for the Environment Climate Change Energy and Water directed that the Commissioner for Sustainability and the Environment undertake an Investigation into the Canberra Nature Park (nature reserves), Molonglo River Corridor (nature reserves) and Googong Foreshores. A map of the relevant reserves is at Appendix 1.1.

The Terms of Reference (Appendix 1.2) requires at Item 5 that the Investigation *identifies knowledge gaps, research or survey needs, and compliance and monitoring requirements that may be necessary to support improved management programs and practices while taking into account the context of the areas and effects of climate variability'*. A number of submissions to the investigation have also indicated that climate change impacts should be considered.

This report is a response to the requirement to take into account climate variability and change. For convenience it refers to the above reserves collectively as the 'Nature Reserves' or just 'Reserves'.

1.2 Approach taken in this report

The findings of this report are based primarily on a synthesis and interpretation of information and research currently available. The approach taken is as follows

- Identify the Nature Reserve values and outcomes which climate may impact (Section 1)
- Summarise currently available historical and projected climate information relevant to the ACT and surrounding region (Section 2)
- Identify, based on the desired Nature Reserves outcomes and potential future climate directions, the key risk areas and impacts on the Nature Reserves (Section 3)
- Identify potential responses to these risks and impacts, noting that in many cases such responses will also address non-climate pressures (Section 4)
- Identify knowledge gaps based on the above (Section 5)
- Identify linkages to other ACT and regional initiatives to facilitate a more integrated response (Section 6)
- Make recommendations based on the above (included in each section).

The findings are necessarily generic across the Nature Reserves at this stage given the scale of most information available. Furthermore, in addressing complex issues such as climate adaptation the responses themselves need to be adaptive. The challenge is to identify the next set of priority steps and then be prepared to enhance or modify responses based on further monitoring and research.

This report focuses on those impacts and responses most closely related to climate, but in practice it is neither possible nor useful to totally separate the impacts of climate from those of other pressures (e.g. land use, invasive species, grazing, prescribed burning).

1.3 Values and outcomes for the Nature Reserves

In order to carry out an assessment of climate impacts it is necessary to identify 'impacts on what?' This requires identification of values and desired outcomes for the Nature Reserves.

From the Investigation Terms of Reference (Appendix 1.2) the following outcomes can be inferred

- Conservation and rehabilitation of the natural environment (supported for example by maintenance of soil health)
- Biodiversity conservation and protection of biodiversity values (supported for example by ecological connectivity)
- Maintenance of water quality
- Public uses and associated values (including visual amenity, public use recreational activities, education and research).

More specifically the Investigation objectives include 'assessing the condition of forests, woodlands and grassy woodlands', and the status of 'protected communities and species' in the nature reserves – in effect as indicators of some of the above outcomes.

Various ACT policies and plans provide further insight into the desired outcomes. For example more detailed values are expressed in the current Canberra Nature Park Management Plan (ACT Government 1999); and the Googong Foreshore Draft Management Plan (ACT Government 2007b). Whilst often expressed in different terms, the stated values in these documents are essentially consistent with the outcomes summarised above with the more explicit addition of 'undesirable species control' and 'cultural heritage – aboriginal and European'. They also confirm the priority emphasis on nature conservation for the Canberra Nature Park as opposed to the priority on water supply and quality for the Googong Foreshores.

A further source of possible values and outcomes is the framework for ecosystem services climate impact assessment in the most recent IPCC Assessment Working Group II Report (Fischlin and Midgley, 2007 - in turn based on the Millenium Ecosystem Assessment project (Hassan et al., 2005)). The relevant extract is included at Appendix 1.3. Whilst broadly consistent with the outcomes articulated above, this framework also includes more explicitly

- Net primary production and carbon sequestration
- Climate and water regulation and water and air purification
- Protection from natural hazards.

In respect of natural hazards, as well as posing a risk to natural assets several of the reserves contain service facilities such as water reservoirs, power-line easements and mobile phone towers (Sharp, 2010), and several are also adjacent to significant urban housing areas (AECOM, 2010).

The result of the above analysis is that a complete set of outcome areas for the Nature Reserves would include

1. Conservation and rehabilitation of the natural environment (including net primary production and vegetation and supported for example by maintenance of landscape function including soil health and the nutrient cycle)
2. Contribution to climate regulation (including carbon storage), and water and air regulation and quality

3. Biodiversity conservation and resilience (supported by the other outcomes, and for example by invasive species control, and ecological connectivity)
4. Protection of both on- and off-reserve assets from natural hazards (especially fires and to some extent excessive water runoff/ floods)
5. Public uses and associated values (including visual amenity, public use recreational activities, cultural heritage, education and research).

This outcomes framework will be used as a basis for subsequent climate risk and impacts assessment (see Section 3) and could also be an input to a more general review of the Nature Reserve values and outcomes. The outcomes and related targets should also be relevant to a dynamic rather than static view of the ecosystems represented by the Nature Reserves and surrounding landscapes (see for example Dunlop et al., 2010).

Recommendation 1: That the publicly stated values and outcomes for the Nature Reserves be reviewed for consistency and completeness, to provide an agreed basis for future risk, strategy and performance assessment, including for the impacts of climate variability and change. The outcomes summarised and used in this report provide one input to such a review.

Section 2. Climate for the ACT and region

2.1 Overview

This section summarises the currently available climate information for the ACT and region in order to assess potential impacts on the Nature Reserves.

Continuing global warming with anthropogenic causes is judged to be extremely likely (IPCC, 2007). If anything recent evidence since the IPCC report points to more rather than less climate change and impact (Steffen, 2009).

A review of current knowledge available on climate history and projections for the Australian Capital Region (ACR) was included as part of a regional climate change vulnerability scoping study carried out recently for the ACT Government (Webb, 2009). The ACR comprises the ACT and a number of adjacent and nearby council areas in SE NSW. The supplementary draft Knowledge Status Report on Climate (Whan and Webb, 2009) addressed the current state of SE Australian and ACR climate knowledge based on

- literature search and discussions with policy makers and researchers
- outcomes to date from a number of relevant ACT and regional studies
- some original analysis of long term historical instrumental climate data for certain sites in the ACR.

It made a number of recommendations to support vulnerability assessment and adaptation planning. This included a recommendation that the ACT government, with input from relevant experts, clarify how regional climate information should be used more consistently and to best effect to support policy and planning decisions, both within and across the various sectors relevant to the region, and in particular recognising the significant uncertainties in climate and related projections. For example the detailed information needs may vary depending on

- the relevant climate variables for the sector
- the most appropriate combination of historical experience and future projections
- the sector circumstances (e.g. the potential level of impact; and whether policies involve significant trade-offs and contention as opposed to 'no regrets' activities)
- the nature of the decision (e.g. operating versus capital decisions, the latter especially involving considerations of investment timing, phasing and triggers).

The findings from the ACR study have been further developed and updated for this current report drawing on the analysis of the historical record for the ACT and the sources of climate analysis and projections most relevant to the ACT and region.

The conclusion is that policy and planning should be based on the strong likelihood of temperatures continuing to increase for the ACT and region as is consistently projected by analysis of climate drivers and all Global Climate Models (GCMs). For rainfall, GCM projections are far less certain and not by themselves to be relied on, especially at the regional and local level. However increasing evidence from recent analysis of the historical record and changes to underlying climate drivers relevant to the region, indicate that it would also be prudent to plan for an increased future risk of below long-term average rainfall, along with significant changes in seasonal rainfall patterns (e.g. a continuation of significantly lower autumn rainfall), and an increase in rainfall intensity with more extreme rainfall events.

These directions in turn have implications for a range of related phenomena including increased evaporation, reduced soil moisture, reduced runoff and stream flows, and more frequent and severe drought periods, changing bushfire regimes, and potentially flood events.

2.2 Interpreting the past

The historical analysis (see Appendix 2.1 for more detail) confirms that the well documented global warming trend is also evident across the ACR including the ACT, with temperatures especially over the last 10-15 years having moved well outside the range of normal variability in the historical record.

The relatively low levels of average rainfall over the last decade, whilst very unusual, are not completely outside the range of the historical record of the last 130 years, though a marked reduction in Autumn rainfall is peculiar to the most recent drought. Indeed across SE Australia the recent drought has exhibited some quite different characteristics to the two previous major droughts in the period of record, and shows signs of being related to global warming, especially when combined with emerging analysis of the underlying drivers of change that impact the regional climate. Thus the South Eastern Australian Climate Initiative (SEACI) synthesis report (CSIRO, 2010a) concludes that the recent 13 year drought in the southern Murray Darling Basin 'is unprecedented when compared with other recorded droughts since 1900'

- being largely constrained to the southern Australia region
- having lower year to year rainfall variability
- with substantial (indeed the major) declines in autumn and not just winter and spring
- being accompanied by consistently higher temperatures.

These characteristics have also led to significantly lower runoffs and stream flows than in previous dry periods.

The SEACI report concludes that the changed rainfall characteristics are largely explained statistically (about 80%) by the impacts of anthropogenic sourced global warming and the resulting impacts on large scale atmospheric circulation; and especially by the high correlation with the observed intensification of the subtropical ridge, which is also consistent with autumn rainfall reductions. Natural variability is probably also contributing but is insufficient by itself and does not explain the very significant autumn rainfall reductions. In particular the main drivers of regional variability such as the El Nino Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) and Southern Annular Mode (SAM) cannot by themselves explain the above observed climate changes.

According to SEACI researchers this may indicate a shift in the regional climate and an increasing future risk of below long term average rainfall. The impacts on runoff and stream flow during the recent drought have also been higher than predicted by models raising questions as to the best climate baseline to adopt going forward. A persistent longer term return to wetter conditions 'is considered unlikely by SEACI researchers'.

A significant amount of research on rainfall changes in SE Australia has been implemented outside of the SEACI project, particularly in the universities. This includes palaeo-studies of rainfall changes across Australia for the last 500-1000 years and longer. This research has yet to be synthesised with the SEACI and other research, and may modify our understanding of what is occurring to rainfall in the Southeast, particularly the level of certainty which we

attach to explanations of observed changes. A synthesis of all relevant research on the SE Australian rainfall issue has recently commenced and will be completed in the first quarter of 2011 (W. Steffen, personal communication).

2.3 GCM studies and projections

It should be noted that the above SEACI conclusions on rainfall are independent of the regional projections of Global Climate Models (GCMs). Whilst GCMs are quite robust in modelling the impacts on temperature of greenhouse gas induced radiative forcing, and related changes to large scale atmospheric circulation, they are less capable in modelling the drivers of rainfall especially at regional and local levels. As a result there is still significant uncertainty in GCM rainfall projections, even sometimes in direction across the full range of IPCC scenarios and Global Climate Models (GCMs). In this context the ACT region is a particular challenge for GCM's to represent accurately, partly because of inadequate representation of the regional climate drivers in the current models, and also the relatively rapid change in ACT regional topography over spatial scales much less than the GCM grid sizes (typically some 200km square).

Noting the above caveat on GCM rainfall projections this report has reviewed eight recent studies incorporating climate projections most relevant to the ACT in order to identify (in combination with the above historical analysis) any consistency (at least of direction) of projected climate and related phenomena. The study parameters and outcomes are summarised in tabular form at Appendix 2.2. Further background to each of the studies is at Appendix 2.3.

In terms of approaches taken by the various studies a few features stand out

- The SEACI project represents the most comprehensive effort to analyse the impacts of underlying climate drivers independent of regional GCM projections
- Across the studies there is no consistency of assumptions, including selection of IPCC scenarios or GCMs
- Most have not used a full range of scenarios so are limited to one or two sets of projections
- In only a few studies have GCMs been selected to reflect proven 'skill' in representing regional climate history – and these studies have generally selected different GCMs. Each project has taken a different approach to draw conclusions from the range of GCMs available
- Only the SEACI and ACTEW projects have incorporated formal downscaling towards the scale of the ACT using standard techniques (e.g. dynamic or statistical downscaling), though a few have made use of the ANUSPLIN technique (Hutchinson, 2004) to interpolate GCM outputs according to topology and other local features
- Coverage of climate parameters is highly variable and depends very much on the study purpose. Furthermore most only translate projected climate impacts through to one or a few physical or biophysical variables of most relevance to the study.

This diversity of chosen parameters and approaches to some extent reflects the state of knowledge and available information at the time of each study. However it makes comparison and consistency of planning even more complex. Overdependence on projections of any particular scenario and GCM(s), especially for rainfall, could also be dangerous for reasons mentioned above. For the future increased guidance (supported by relevant levels of

government) on how to use (and just as importantly not use) available climate information, would provide a more useful framework for adaptation planning.

Of the studies the SEACI project is the most comprehensive in terms of both climate analysis and downscaling and has had a particular emphasis on analysing climate drivers and on hydrological impacts (see Appendix 2.3). There may be an opportunity to see if the downscaled information provides additional insights for the ACT and region. The SE NSW Climate Impact Profile/ Integrated Regional Vulnerability Assessment (IRVA) project, whilst being based primarily on only one IPCC scenario (A2 - the second most severe in GHG terms), is the most comprehensive in terms of parameters covered including translation from climate projections to a range of physical and biophysical impacts. The Climate Change and the Public Sphere (deliberative democracy) and AECOM/ CSIRO studies are also of interest as they both include the most severe IPCC scenario (A1FI) and take a more selective approach to use and interpretation of the available GCMs. The deliberative democracy project also put considerable effort into how to make the projections accessible to members of the public.

Notwithstanding that it is difficult to make detailed comparisons across these studies because of the different assumptions used, it is noted that the various analyses and projections are generally consistent at least in direction if not always in magnitude. This includes for the main climate variables

- Increasing maximum, minimum and average temperatures (typically by around 2-3ºC by 2050)
- Increases in hot days and heatwaves and reduction in cold days and frosts
- For rainfall, because of the inadequacy of current GCMs, more weight might be given to the SEACI analysis which indicates an increased future risk of below long term average rainfall based on analysis of climate drivers, rather than to GCM regional projections. As far as they go, the summary features of the GCM studies include reduced annual rainfall with biggest reductions in winter and (in some projections) spring, offset (in some projections) by increase in summer. However as noted this is the area of greatest variance across model projections, and the models also do not appear to be reflecting the observed decreases in autumn rainfall during the recent drought. Furthermore, the synthesis of all relevant research on changes in SE Australia may modify somewhat the insights from the SEACI and GCM studies.
- Increases in frequency of intense rain events/ storms. Again this is quite variable across studies but is consistent with observed trends and understanding of the likely impacts of emerging changes to climate drivers.

2.4 Climate directions and scenario planning

The basic conclusion then is that policy and planning for the ACT and region should be based on

- The strong likelihood of mean temperatures continuing to increase, along with more frequent and severe heatwaves for the ACT and region, as is consistently projected by analysis of climate drivers and all Global Climate Models (GCMs)
- A high probability of changes in the pattern of rainfall from that observed during the period of instrumental records, with some risk of a decline in long term average rainfall; and in addition, the likelihood of an increase in rainfall intensity with more extreme rainfall events.

In terms of the physical impacts this leads to

- Increased evaporation (especially in spring and summer), which combined with potential changes in rainfall, is likely to result in reduction in soil moisture (particularly in winter and spring if autumn rainfalls also remain historically low)
- Changes in run off and stream flows, with higher evaporation in spring and summer tending to reduce run-off during those periods.
- An increase in drought severity due to higher temperatures
- Overall increases in bushfire frequency and intensity, based on higher temperatures, drier conditions and lower humidity, with extension of the fire season into spring; noting changes in fuel availability as a significant uncertainty in projections
- Increases in the intensity of flood producing rainfall events with the impacts depending in part on the prevailing catchment conditions (i.e. soil moisture and levels in major water storages).

It is noted that these directions are also broadly consistent with those included in the ACT Weathering the Change document (ACT Government, 2007a) though this was based on studies that preceded the IPCC 2007 assessment and the more recent regional studies referred to above.

The above synthesis of future climate directions will be used in Section 3 to assess risks and impacts, as a precursor to considering potential adaptation responses in Section 4.

It will be important that more specific adaptation decisions are tested for consistency with these directional changes and in some cases for robustness to a range of scenarios around these overall directions, especially if contingent on rainfall and not just temperature. Such an approach has also been suggested in some national studies. For example Steffen et al. (2009) indicate that biodiversity strategies can be usefully tested against a range of alternative global warming scenarios (i.e. runaway, stabilisation and recovery scenarios) whilst noting that leading indicators are currently tracking on the runaway scenario.

This ‘directional’ and ‘scenario testing’ approach will be necessary for the foreseeable future as climate research will not soon reduce uncertainties to the extent that single projections can be relied on. Progressive enhancement of GCMs should however be encouraged, including improved rainfall modelling and incorporation of downscaling from those improved GCMs.

2.5 Future climate research agendas

In this last respect the Commonwealth Government report *Australian Climate Change Science – A National Framework* (Commonwealth of Australia, 2009) has been reviewed to assess how future regional needs align with the longer term national climate science agenda. Whilst the framework is pitched primarily at the overall national priorities and capabilities it does refer to several directions that will provide a context for future regional climate research and assessments including for the ACT and region

- Further research on climate drivers, natural availability and hydrology issues especially for SE Australia (as per the SEACI program, and through paleo-hydrological research)
- The further development from physical to full climate system modelling capturing the feedbacks between the physical, chemical and biological systems (i.e. earth system modelling capability for Australia e.g. ACCESS); and Integrated Assessment Models

- In particular improved capability to predict in the 10-30 years out period, and the need for regional downscaling including for better insights into extreme event projections
- More research into a range of issues that support earth system modelling including (relevant to regions such as the ACT and region) the carbon cycle, vegetation dynamics and growth characteristics, and the links between land cover and climate
- Enhanced climate observations capability and data platforms, and improved cooperation between Australia's research institutions (consistent with the proposed approach to addressing some of the knowledge gap themes identified later in this report).

2.6 Recommendations

Recommendation 2.1: The ACT Government, in collaboration with relevant research institutions (and if possible the NSW Government), develop an ACT and region climate risk information system, which includes all types of relevant and currently available climate information, including uncertainties; and based on this adopt and communicate consistent approaches to the use of this information by agencies for various sector or issue-based vulnerability assessments, planning and decision making.

This is to assist consistent planning approaches and avoid 'everyone doing their own thing', as well as to help future studies make the most appropriate use of available information. It would include

- Shared interpretation of historical information, and of recent and projected changes to climate drivers for the ACT & Region, and especially the potential impacts on rainfall projections
- Shared understanding of how to best use climate and related scenarios and projections to support specific types of decision-making under uncertainty, recognising that this has to be tailored to need and circumstance.
- Collaboration on the above with the NSW Government and key research institutions as many of the insights are regional, and to avoid duplication of effort
- Development of a climate storyline based on the historical data and a number of future scenarios for the region, to be used for both communications and planning purposes; and a readily accessible information package based on the above for use in subsequent community awareness, communication and engagement activities

This recommendation is relevant to the Nature Reserves Investigation as it would provide a more coherent regional and local set of climate analysis approaches, assumptions and parameters, and a shared understanding within which individual issues and recommendations can be assessed and responded to.

Recommendation 2.2: The ACT Government drive for, and participate with other spheres of government (especially NSW and the Commonwealth) in, progressive enhancement of the regional climate information base, drawing on improvements in climate analysis, modelling and projections as they become available, including

downscaling techniques. This is consistent with the national climate science framework and agenda, and also recognises that the ACT Government has limited resources to commission its own basic research.

Recommendation 2.3: In the meantime, for the ACT Nature Reserves, analysis of impacts and planning responses and decisions should be based on the following climate directions

- **the strong likelihood of mean temperatures continuing to increase, along with more frequent and severe heatwaves for the ACT and region**
- **a high probability of changes in observed long-term rainfall patterns (e.g. a potential continuation of significantly lower autumn rainfall), and an increase in rainfall intensity with more extreme rainfall events**
- **increased evaporation, leading to (all else being equal) reduced run-off and stream flows and**
- **more severe drought periods, changing bushfire regimes, and flood events.**

Section 3. Impacts on the Nature Reserves

3.1 Key climate risk areas

This section addresses the risks and potential impacts to the Nature Reserve outcomes identified in Section 1, based on the climate directions identified in Section 2.

In summary the climate directions include higher CO2 levels, higher temperatures, changed seasonal rainfall patterns and potentially increased dryness overall, more extreme weather events (both temperature and rainfall) and increased fire weather risk.

Based on such climate directions the risk and potential impacts have been considered against each of the groupings of Nature Reserve outcomes developed in Section 1 i.e.

- Outcome/ Risk Area 1: Conservation and rehabilitation of the natural environment (including net primary production and vegetation, supported for example by maintenance of landscape function including soil health and the nutrient cycle)
- Outcome/ Risk Area 2: Contribution to climate regulation (including carbon storage), and water and air regulation and quality
- Outcome/ Risk Area 3: Biodiversity conservation and resilience (supported by the other outcomes, and by invasive species control, and ecological connectivity)
- Outcome/ Risk Area 4: Protection of both on-reserve and off-reserve assets from natural hazards (especially fires and to some extent excessive water runoff/ floods)
- Outcome/ Risk Area 5: Public uses and associated values (including visual amenity, public use recreational activities, cultural heritage, education and research).

3.2. Risk Area 1: Conservation and rehabilitation of the natural environment

Climate change adds to the risk of further reduction in landscape function with evidence that a significant proportion of the Reserves already have reduced or severely reduced function (Sharp, 2010). The SE NSW Climate Impact Assessment (NSW Government, 2010) provides insights into impacts on land and soil characteristics based on a typical climate scenario. Together these indicate that there is significant potential impact from the combination of exposure of the natural environment and sensitivity to future climate change.

Whilst net primary productivity has not been specifically identified for the Reserves, recent high resolution work on mapping and modelling ecosystem services for the region (Porfirio et al., 2009) provides the potential to provide a baseline measure as well as future impacts from alternative climate projections.

The climate related conclusions from each of these reports is summarised below.

3.2.1 Landscape function in Canberra Nature Park and impacts of threatening processes on landscape function (Sharp, 2010)

This report has been commissioned by the OCSE as an input to the Investigation. In brief it is assessing the relative health of each of the reserves using a landscape function analysis. This is based on a cost-effective Soil Surface Assessment technique to measure three key aspects

of landscape function: soil stability against water and wind erosion; infiltration – the ability to absorb incident rain and flowing water; and nutrient cycling through the return of vegetative material to the soil to support future plant growth.

The measurements indicate a significant degree of reduced landscape function in parts of most of the reserves. Major disturbance factors include grazing and soil disturbance especially by kangaroos and rabbits; past tree and vegetation clearance; increased gullying and sheet erosion; recent wildfire and/ or prescribed burns; increased weed and pest intrusion; and visitor use and built asset management impacts. These disturbance factors have all been exacerbated by the prolonged drought.

From a climate impact perspective the most significant issues referred to in the report are

- Landscape function changes with normal seasonal conditions, prolonged climatic conditions such as drought, or extended warm and wet periods in spring and autumn. The climate impacts are augmented by other non-climate disturbances. The lower the levels of pre-existing landscape function the greater the effect of a small quantum of disturbance. For example, whilst there was significant growth of vegetation after the recent rainfall, in sites with persistent grazing pressure there was little growth evident by the time the surveys were undertaken (Autumn 2010).
- Drought and increased dryness progressively reduce landscape function through lack of renewal of vegetation, reduction in biological processes maintenance, and reduced soil moisture
- In areas with reduced function, more extreme rainfall events result in further erosion, excessive run off and at least initial further loss of landscape function especially after very dry periods, as evidenced by the rain events since January 2010
- The differential strength of many invasive species to tougher climate conditions, and the differential characteristics of annual and perennial plants when rain does come (e.g. weeds , especially short lived annuals, become likely colonisers, competing with perennial native species)
- The impact of likely increased wildfire disturbance and the increased emphasis and frequency of prescribed burning as a management response (noting that houses or other buildings back on to 16 of the reserves). If fire frequency is too great then litter does not have an opportunity to re-form, the soil crust is destroyed and soil processes are compromised.

It can be concluded from this that for the Nature Reserves there is a significant risk that the extent of already reduced landscape function will be increased by the climate directions summarised in Section 2, even if the magnitude of change is currently uncertain.

3.2.2 Implications of climate change for land based on the SE NSW Climate Impact Assessment (NSW Government, 2010)

Land and soil responses to the climate and physical changes were identified in this study as follows, with increased temperatures and a shift from winter to summer rainfalls (as projected in this and several other studies)

- Likely increases in sheet, rill and gully erosion especially from increased heavy downpours (gully erosion offset to some extent in winter by likely good groundcover and lower soil moisture); with increased risk of mass movement of soils in some areas

- Decreased soil acidification due to shift from winter to summer rainfall, and increased sodic soil erosion
- Soil nutrient levels likely to decrease in some areas (e.g. where lower winter rainfall is likely to engender the concentration of salts)
- Declines in the organic content of alpine humus soils due to higher temperatures and reduced winter rainfalls; however offsetting factors on plant growth, nutrient levels, soil micro organisms and erosion make it difficult to predict elsewhere
- Dryland salinity risk is more likely than not to be exacerbated with the shift in rainfall patterns concentrating salts through watertable fluctuations.

Some of these more general regional changes would need to be assessed for potential significance for the specific land and soil structures of the Reserves, but they point to the additional risk of climate change impacting these structures and characteristics, and therefore dependent vegetation.

3.2.3 Ecosystem services mapping project for the ACR including the ACT (Porfirio et al., 2009)

This project provides mapping of various ecosystem services for the ACR including carbon storage, food production, water provision, biodiversity conservation and recreation.

For example (Porfirio et al., 2009) values for vegetation growth and carbon storage (based on net primary productivity, total carbon in soil and biomass, and carbon turnover) have been mapped to 250m spatial resolution.

There is therefore the potential through the GIS models developed to assess the sensitivity of this and some other services to climate change parameters at quite high spatial resolution, contributing to understanding of both the natural landscape function for the Nature Reserves and some of the other values referred to below (e.g. carbon storage, biodiversity).

3.3 Risk Area 2: Contribution to climate, water and air regulation and quality

Through natural ecological cycles the Reserves contribute to climate regulation (e.g. through carbon storage), water regulation (e.g. through retaining water from rainfall) and air quality. The climate risks to vegetation growth and primary productivity, and to water infiltration are referred to under Risk Area 1 above, as is the potential to model carbon storage impacts. Whilst some of the trends suggest adverse impacts on the 'regulation' potential of the Reserves, the cycles are complex and some factors (e.g. increased CO2 on vegetation growth) can have offsetting impacts.

Water quality is most relevant for only a few of the Reserves (i.e. primarily Googong Foreshores and to a lesser extent the Molonglo River Corridor).

For the latter the main issues would be any impact on the related riverine and riparian ecosystems. From a water quality perspective the short section of the Molonglo River downstream of the Molonglo sewage treatments works (Lower Molonglo Water Quality Control Centre), which flows into the Murrumbidgee is not at material risk from climate change impacts on the adjacent reserves (though the treatment plant could be impacted by the

separate climate risk to water infrastructure under extreme drought or flooding events in the region).

The Googong Foreshore (GF) is more significant from an urban water supply perspective. A vegetation assessment for GF was commissioned (Eddy, 2009) as a contribution to the finalisation of the GF Management Plan, and ACTEW also carried out an environmental impact assessment for the Murrumbidgee to Googong Pipeline proposal (ACTEW, 2010).

These studies were not oriented towards impacts of climate change on the GF, and indeed there is no prima facie reason to believe that any direct climate change impacts on Googong Foreshores would pose a significant risk to water supply and quality.

The overall conclusion is that climate change will have some impact on carbon storage and water regulation functions within the Reserves themselves, but there is not a significant risk from the Nature Reserves to the ACT and region water supply and quality (though of course climate impacts in other areas upstream of the ACT and the GF, including the Murrumbidgee River corridor, can significantly impact these outcomes).

3.4. Risk Area 3: Biodiversity

From a combination of recent national, regional and local studies on the impacts of climate change on biodiversity, and the evidence of significant biodiversity values and issues in the ACT and region, it is clear that this represents one of the major risk areas for the Reserves given the key role they have both in their own right and in relation to the surrounding landscapes.

3.4.1 National Climate and Biodiversity Assessments

(a) Overall impacts on biodiversity

Whilst biodiversity impact assessments ultimately need to be location specific, useful principles and approaches can be drawn from national studies. National policy and processes have been informed by recent expert reports on climate change impacts (Steffen et al., 2009; Dunlop and Brown, 2008; Dunlop et al., 2010).

Conclusions on climate change impacts from these reports (also reflected in more local studies e.g. Manning et al., 2010; Sharp et al., 2008) can be summarised as follows

- Australia's biodiversity is facing an unprecedented challenge from the direct impact of rapid climate change in conjunction with other indirect pressures. The latter includes other threats that are themselves aggravated by climate change i.e. water availability and use, invasive species, land use changes and changed fire regimes.
- Such impacts are clearly showing up in a growing number of extinctions, functional extinctions and threatened species; changes in relative abundance, diversity, distribution and range of species; and in the level of introduced species. The changes are discernable at genetic, species, community and ecosystem levels. In many cases the impacts of change in climate extremes may be more significant than change in the averages.
- Climate change has direct impacts on ecosystems and biodiversity through several physiological and other mechanisms (e.g. through heat stress; changed growth and

water use in plants; changed concentration of nutrients and toxins in leaves; changed phenology including dates of seed germination and flowering, and in egg laying and hatching in birds, reptiles and insects)

- These impacts interact in complex ways with the other existing and increasing stressors (e.g. water availability and use impacts especially on aquatic species; new species to a region outcompeting for food, water and habitat; land use changes impacting vegetation and soils; fire regime impacting especially on species that do not recover rapidly as well as causing progressive changes to type of ecosystem, habitats, nutrient and water balances). Collectively they lead to increasingly fragmented habitat. The potential rate, scale and geographic extent of climate change would make this even more significant than other threats.
- Additional complexity arises from different species migration rates and the formation of novel ecosystems (i.e. species compositions and abundances quite new to the local landscape). These novel ecosystems are also characterised by changing inter-species interactions (e.g. pollination, seed dispersal, competition, predation and diseases) and these consequential impacts can be greater than the initial direct impacts. The novel ecosystems will also continue to evolve over time. Manning et al (2009) propose 'landscape fluidity' as a perspective for analysing change, and use scattered tree landscapes in south-east Australia as an example.
- Changes are often non linear and thresholds may be hard to predict; and the rate of climate change is likely to prove critical on the capacity to adapt
- The complexity of these impacts and interactions makes it is impossible to predict exactly how each species and ecosystem will be affected. There may be limited opportunity to learn from other locations as it is happening everywhere at once, but it does emphasise that responses need to be dynamic rather than static, looking for early signs wherever possible.

(b) Impacts for temperate grassy and woodland ecosystems

Most recently the Dunlop and Brown (2008) report on climate change and the National Reserve System has been extended (Dunlop et al., 2010 – overall synthesis report) to analysis of climate change implications for four different biomes within Australia including (relevant to the ACT) sclerophyll forests of south-eastern Australia, and temperate grassy ecosystems (TGE, including grasslands and grassy woodlands).

The report on TGE (Prober et al., 2010) is of most relevance to the ACT Nature Reserve system. The TGE biome covers a wide geographical area of south-eastern Australia in an arc from South Australia to Southern Queensland. The ACT Nature Reserves are in effect at the south–eastern 'edge' of this biome. The biome includes a few major vegetation subgroups, but in particular of relevance to the ACT 'eucalypt woodlands with grassy understory'. Much of the biome outside reserves has undergone more intensive agricultural development than the ACT but it is still possible to translate most of the conclusions. In summary from the overall synthesis and TGE reports these are that

- This biome represents some of the most threatened ecological communities in Australia, and under projected climate change there is significantly increased vegetation structure stress (or propensity to change) to the extent that this already reduced biome could undergo further very significant reductions in its current locations by 2070. Distribution of eucalypt woodlands is primarily related to moisture (eg soil moisture, rainfall seasonality). Examples of vegetation structural change

could include declining trees from moisture stress and altered shrub-grass balance potentially in favour of shrubs, with consequent fauna impacts. The modelling indicates limited potential for similar woodlands to develop in new areas. The analysis also indicates shifts in herbaceous ground cover functional composition (e.g. cool season C3/ warm season C4 and perennial/ annual ratios) under a complex mix of drivers.

- Analysis of impacts on composition of various biological groups indicates potentially higher stress (or change in biological composition) for reptiles, snails and plants, and relatively lower to moderate stress for mammals, birds and frogs. In this respect though, the report cautions that the full complexities of change and interdependencies under quite new environmental characteristics and drivers, and related novel ecosystems, are not able to be captured in the current models; and that these are likely to significantly accentuate and modify the actual outcomes. Examples of 'cascading changes' in ecological interactions include altered invertebrate dynamics; decoupling of mutual species-species interdependencies from changed phenologies or migration rates of interacting species; changing patterns of disease outbreaks; and other complex changes to current interdependencies within the local ecosystem especially for fauna. Within the biome there is also some regional variation in these conclusions which would need to be taken into account.
- It is possible that structure and composition could change independently of each other. For example vegetation structure could be more sensitive to water and moisture change and some species composition may be more sensitive to temperature. In temperate grassy woodlands the determinants of structure are complex but finely balanced so that small changes in productivity and disturbances could lead to rapid changes in structure e.g. a decline in trees and increase in shrubs as mentioned above.
- Historically this biome had widespread 'biological buffering' from the impacts of change, through high species richness (genetic diversity and redundancy), environmental heterogeneity, widespread distributions and connectivity. This is now greatly reduced by habitat fragmentation and degradation, though it is strongest on the more varied relief areas near the Great Dividing Range. The natural resilience factors are now being further reduced by climate and other impacts (i.e. changes to temporal connectivity of resources, degradation of site-scale ecosystem processes (e.g. soil water infiltration and habitat structure), disturbance from exotics and changed fire regimes, as well as continuing land use changes). The synthesis report (Dunlop et al., 2010 at Figure12, and Table 5) refers to a framework that integrates the processes acting on biodiversity, and especially identifies those that enable biodiversity to persist under disturbance (through resistance and resilience) for the temperate grassy ecosystems. This framework can be used help characterise different management opportunities for specific regions (such as the ACT and surrounding region).

Thus, as summarised in the above section, both the overall characteristics of climate change impacts, and those of the TGE biome closest to the ACT Nature Reserves ecosystems, have relevance for the ACT Nature Reserves and significant implications for appropriate responses (Section 4).

3.4.2 ACT and region studies

The ACT and surrounding region is thus important as part of a key biome under significant threat, but is also intrinsically important from a biodiversity perspective.

Fallding (2002) provides a useful summary of the regional (NSW Southern Tablelands and ACT) ecosystems and biodiversity characteristics including the range of native vegetation types within the region. Grasslands, Grassland-Woodland Mosaic and Box-Gum Woodland are the most important for conservation planning, with a large proportion of these on private land. The report notes that 'over 1200 native plant species occur within the region … which occur nowhere else', 'the bushland surrounding Canberra forms an integral part of the habitat of the urban bird population…suggested as the reason for the relatively high diversity of birdlife in Canberra compared with other cities', 'a range of threatened species…occur within Canberra's urban areas' and that a number of species are already believed to have become extinct as a result of land use or habitat changes.

More generally it notes that 'The NSW Southern Tablelands and ACT region retains important natural ecological and biodiversity assets. The bio-geographical context for the region makes it a relatively diverse area and it also represents the limit of distribution for many plant and animal species. For example, the ACT contains many organisms at the fringe of their normal distribution range, which accounts for their locally uncommon status.'

Sharp et al. (2008) note more specific ACT ecosystem biodiversity impacts from climate change, and that whilst alpine and subalpine species are perhaps most vulnerable there are also risks relevant to lowland areas and to river corridors with reduced environmental flows e.g.

- Natural temperate grassland and snowgum/ candlebark tableland woodland are vulnerable lowland ecosystems dependent on low temperature conditions for their distribution; and higher temperatures could also lead to the invasion of other species
- Reduced water availability will impact fish (migration and spawning), other aquatic vertebrates, macro invertebrates and macrophytes as well as adjacent riparian systems
- Riparian systems with less flows and flooding are vulnerable to non riparian weed invasion.

Sharp (2010) notes that the majority of the Nature Reserves have significant biodiversity values including the presence of threatened species or endangered ecological communities, a high diversity of native plants, a diversity of habitat and connectivity corridor potential.

Indeed many plant and animal species have become extinct in the area since European settlement. Two ecological communities (Yellow Box/Blakely's Red Gum Grassy Woodland and Natural Temperate Grassland) and 17 species have been declared endangered and 15 species declared vulnerable. There are also concerns about declining presence of several species of birds such as the Brown Treecreeper and the Hooded Robin.

The recent discussion paper for review of the ACT Nature Conservation Act (ACT Government, 2010) notes that 'monitoring of ACT lowland birds, reptiles and mammals has revealed a dramatic decline in both wildlife abundance and species diversity' and that 'much of the lowland vegetation and several of the species for which it is habitat are listed by the Commonwealth as matters of national environmental significance' with the majority of the lowland vegetation being listed as 'endangered or critically endangered at both local and national levels'. It also notes that much of this vegetation is on rocky and steep hills and slopes rather than the potentially more productive valley flats.

At a regional level the SE NSW Climate Impact Profile (NSW Government, 2010) based on a typical future climate projection includes the following biophysical impacts, several of which are relevant to the Reserves

- Many alpine ecosystems and species are very likely to become extinct
- Increased overall bushfire frequency and intensity are very likely to cause major changes to ecosystems (especially but not only alpine and subalpine)
- Lower primary productivity is likely to change many ecosystem processes e.g. through lower plant growth due to lower spring soil moisture following lower winter rain; water stress killing vulnerable trees; and flow on effects of lower plant growth, survival and overall productivity to some resident fauna with reduced flowering, foliage and seed
- Climate change is likely to increase stress on already fragmented and degraded ecosystems and threatened species, these being already disturbed by other factors such as land clearance and fragmentation, conflicting land uses, pest and weeds
- Changes in rainfall patterns are likely to intensify seasonality, increase grazing pressure from native herbivores, and alter plant communities eg increased weed incursion

The above studies confirm the importance of the ACT ecosystems, and point to a range of exposures and pressures, increasingly including climate change, on local biological communities. There are however few studies on direct climate change impacts on individual species relevant to the Nature Reserves. As covered later, much of the management response needs to be at the whole of landscape and biological community level, but it would be helpful to complement this with a better understanding of how some of the most vulnerable and significant individual species are likely to respond to changes in climate parameters. Williams et al. (2008) provide a useful framework for analysing vulnerability of individual species to climate change and their adaptive capacity.

3.4.3 Overall conclusion on climate change and biodiversity risk

The above studies – at national, biome, regional and local levels - collectively confirm the significance of the Nature Reserves and surrounding landscapes as biodiversity assets, both in their own right, and from a regional and national perspective. It also confirms that the risk from and vulnerability to climate change for the Reserves' biological communities and biodiversity values is very significant. They are *exposed* as evidenced by the existence of many drivers of change including climate and the high biodiversity values; they are *sensitive* to projected climate change as indicated by the many studies summarised above; and factors affecting their *resilience and adaptive capacity* are already significantly compromised.

3.5 Risk Area 4: Protection of on- and off-reserve assets from natural hazards (especially bushfires)

Bushfire is one of the major natural hazards and risk areas for Nature Reserves. A secondary risk area is the potential for some increased water run-off and minor flooding off-reserves from the combination of reduced landscape function and increased rain intensity. It is considered that floods do not represent the most threatening risk in the ACT (AECOM, 2010). Whilst recent events nationally and locally point to the need to continue to plan for potential flash flooding in the region, there is not a strong nexus with the roles and

management of the Nature Reserves. If anything, compared with the more impervious built-up areas, the Reserves represent a valuable buffer against the risk of flash flooding.

By comparison the potential for increased frequency and intensity of bushfires under future climate projections increases the risk to both on-reserve assets (natural and man-made) and adjacent assets including housing. AECOM and Sharp (2010) note that the proximity of housing and other developments to many of the Nature Reserves increases the risk profile. The management responses to these risks, and in particular prescribed burning in the Reserves, can present an additional risk especially to biodiversity values.

3.5.1. Changing bushfire regimes and ecosystems

The interdependencies between ecosystems and fire regimes are complex. Changes to fire regimes can change species distribution and assemblages. Vegetation forms the fuel for bushfires, so changes in vegetation will in turn impact on bushfire regimes. Detailed fire regime modelling needs to reflect the characteristics of particular ecosystems and locations. Such modelling has been carried out for the ACT using the FIRESCAPE modelling approach (Cary, 2002) and (using the same modelling tool) for alpine and subalpine areas including those in the ACT (King et al., 2009).

At the national level a project for the Department of Climate Change and Energy Efficiency on the interactions between climate change, fire regimes and biodiversity in Australia (Williams et al., 2009) also analyses several biomes including

- temperate/ cool sclerophyll forests of south-eastern Australia (similar to south-west of the ACT such as Namadgi)
- temperate grassy woodlands of inland eastern Australia (similar to the north-east area of the ACT including the Nature Reserves); and
- four regional case studies (which do not however include an example directly analogous to the ACT Nature Reserves)

The analysis illustrates the diversity of climate impacts on fire depending on the specific biome/ regional characteristics. It uses a ‘four switch’ model to analyse the differential impacts of climate on fire regimes for different biomes. Each of the four switches (rate of vegetation/ biomass growth as potential fuel; fuel moisture/ rate of drying reflecting availability to burn; fire weather and the potential for fire spread; and ignition) need to be ‘on’ for landscape fire to occur. Which of these is the ‘limiting switch’ depends on the ecosystem characteristics, and each of the switches is differentially impacted by climate.

There are several conclusions of interest in the ACT context

- There is evidence that fire danger increased in south-eastern Australia in the period 2000-2007 compared with the previous two decades, and modelling (eg Lucas et al. 2007, which included Canberra) suggests a further increase in the future. There has been significant inter-decadal variability in fire weather and danger which appears to be superimposed on an underlying upswing, the latter potentially climate change induced.
- Modelling of the impacts of climate change on fire regimes (including sequence over time and intervals, seasonality, intensity and spread) was available for the ACT (Cary 2002), and predicted that a 2°C increase in mean annual temperature would increase

the landscape measure of fire intensity by 25%, increase the area burnt and reduce intervals between fires

- There may be increased risks to both interval and intensity-sensitive species from climate and fire regime change with the most significant impact in sclerophyll dominated vegetation as in south-eastern Australia
- Climate change will affect fire regimes through the impacts on both fire weather (temperatures, rainfall, humidity and wind) and fuel availability (through increased CO2 and changes in moisture). The climate impact is more significant and direct where weather drivers are the dominant 'switch' (e.g. sclerophyll dominated vegetation such as the temperate forests of south-eastern Australia; including the forest areas in the ACT) than places driven more by fuel or ignition 'switches' (e.g. northern tropical savannahs). In temperate grassy woodlands (such as the ACT Nature Reserves), whilst fire weather is still relevant, the impact of rainfall patterns and moisture on biomass growth is also very significant. For example reduced plant growth (fuel) under a reduced winter rainfall scenario could be offset by reduced fuel moisture content, and/or increased grassland productivity from increasing summer rainfall, winter temperatures and CO2 (Prober et al. 2010). The trend in the net impact is not obvious, and the 'limiting switches' are more in balance.
- Further research is needed on the offsetting effects of elevated CO2 and increased drought on vegetation growth and therefore fuel loads; and on the extent to which reduced soil moisture may increase potential rates of fire spread
- More research is needed on the complex interactions between fire, biodiversity, people, fuel management and land use change. In particular Australian and overseas studies have not yet provided clear evidence on the effectiveness of prescribed burning in various environments. A better understanding of the effectiveness, and relative costs and benefits of prescribed burning is necessary, given the multiple land management goals, and especially under probable pressures to increase its level. These and other uncertainties also emphasise the importance of an 'adaptive management' approach with effective monitoring

In summary the climate impacts on bushfire risk may be greater in forested areas in the ACT and region but are still significant (but with quite different characteristics) for the grassy woodland and grassland more typical of the Nature Reserves, where impacts on fuel (vis a vis fire weather) are relatively more important.

3.5.2 The Nature Reserve/ urban interface

There is a strong nexus between the impacts of climate change and land use planning. This has been recognised in the current update of the ACT Spatial Plan for which ACTPLA commissioned a 'Human Settlement Climate Change Vulnerability and Adaptive Capacity Assessment' (AECOM, 2010).

The report focuses on four risk areas: bushfire, extreme heat and public health, flooding and water resources. In respect of bushfires relevant findings include

- The large number of hills and bushland reserves in the vicinity of urban areas in the ACT increases the exposure of some suburbs to bushfire risks, especially as urban developments are typically situated on vegetated mid slopes and valley bottoms

- The hill slopes and aspect of the valley in relation to prevailing wind directions are vital critical factors influencing fire speed and direction
- Climate change is likely to increase the frequency of fires and reduce the windows for safe controlled burns
- Improvements could be made to the resolution of the fire danger index across the ACT, particularly with a likely increase in bushfire weather (there is currently only one FFDI and GFDI calculated for the entire ACT region based on data from Canberra Airport weather monitoring station)
- ACTPLA and ESA have been upgrading adaptive capacity and risk mitigation through dwelling standards, guidelines on surrounding bush and upgrade of emergency services, especially in terms of access for fire fighting units.

Prescribed burning and improved planning and development practices can mitigate but not remove the risk to off-reserve assets including housing.

3.5.3 Prescribed burns and ecosystems

The ACT Strategic Bushfire Management Plan (SBMP) (ACT Government 2009a - Supporting Information Part 2) includes impact assessment of both bushfire and management mitigation responses (especially prescribed burning) on biodiversity values, as well as on water catchments and cultural heritage.

It identifies the spatial distribution in the ACT of fire thresholds (i.e. the minimum and maximum time periods within which fire should occur to maintain species diversity and minimise species loss (Kitchin, 2008)). It also outlines some of the potential detrimental impacts to both flora and fauna if fire recurs in an area before the minimum threshold is reached. It notes that there are significant knowledge gaps for many individual species. There is a range of thresholds depending on vegetation community. Climate change increases the risk of more frequent and more intense bushfires and so increases this potential threat to ecosystems and species.

The risks from both wildfire and prescribed burning are very actively managed for the ACT. However the risks cannot be completely mitigated. Not peculiar to the ACT, there is considerable uncertainty and in some cases contention as to the relative value and optimum balance of prescribed burning activities (eg King et al., 2009, Williams et al., 2009).

3.5.4 Overall conclusion on climate change and natural hazards risk

In summary the risks from climate change impacts on Nature Reserves through changing and potentially increased fire frequency and intensity are significant and include

- increased threat to a range of ecosystems and species; and to other on-and off-reserve assets
- pressure for more extensive prescribed burning to protect assets; climate change will also reduce the available number of days suitable for prescribed burning activity possibly leading to more intense activity during the narrower windows available
- other pressures on ecosystems means that they are increasingly vulnerable to the addition of bushfire and prescribed burning impacts.

3.6 Risk Area 5: Public uses and associated values (including visual amenity, public use recreational activities, cultural heritage, education and research)

This final set of Nature Reserves outcomes is mostly impacted as a consequence of the other risks. Further diminished landscape function and general reduction in environmental health for the reserves will directly impact these outcomes. Combined with the potential for additional usage restrictions to mitigate the increasingly severe risks, this will place the public use and associated values at increasing risk.

3.7 Variability and risk

It might be asked whether Australia's history of relatively high climate (and especially rainfall) variability has made our ecosystems (in terms of habitat and/ or species) more resilient to climate change relative to less variable climates. This may well be so in some cases, though in others high variability superimposed on a relatively low mean rainfall can mean that many ecosystems are already marginal so that climate change can be 'the last straw'. Furthermore there is some evidence for the most recent 13 year drought in south-eastern Australia that rainfall variability has been much less than in previous droughts (CSIRO, 2010a). In any event, the current and likely extent and speed of climate change, combined with the impact of other pressures, means that the risks identified in this section are significant and increasing.

3.8 Summary and Recommendations

Based on the synthesis of evidence carried out in this section it can be concluded that the risks and potential vulnerabilities are

- *Most significant* for biodiversity with multiple impacts reinforced by both current and future climate and non-climate pressures (Risk Area 3)
- *Significant* for the state of the natural landscape and environment including landscape function (Risk Area 1) and for the exposure to natural hazards (and especially fire) (Risk Area 4)
- *Less significant* for contribution to climate, water and air regulation (Risk Area 2)
- *Significan*t for public use and associated values, reflecting that this is primarily a consequence of the other risks (Risk Area 5).

However a full vulnerability assessment of each risk area for the Nature Reserves is beyond the scope of this report. The standard vulnerability assessment framework is shown at Appendix 3.1. Based on this framework a vulnerability assessment matrix such as that at Appendix 3.2 could be used for the next level assessment referred to in the following recommendation. It would need to be differentiated by reserve or at least major groupings of 'like' reserves. An expert review/ workshop could be the most efficient means of carrying out this analysis in the first instance with an intention of progressive enhancement over time.

Recommendation 3: The risk areas and vulnerabilities of the Nature Reserves as identified in this report should be more explicitly analysed at a further level of detail in the next round of planning for the Reserves (see also Recommendation 4.3), using a standard risk and vulnerability assessment tool and a range of expert inputs. This would include establishing at least the relative significance of vulnerabilities and the priority knowledge gaps (see also Recommendation 5). This is important to optimise use of scarce resources to respond to the priority issues.

Section 4: Adaptation Responses

This section identifies the potential responses to mitigate the five climate risk areas and potential impacts identified in Section 3. The main response opportunities focus around the first four of those risk areas

- Risk Area 1: Conservation and rehabilitation of the natural environment (noting that successful response here is a significant foundation for other areas).
- Risk Area 2: Contribution to climate, water and air regulation and quality
- Risk Area 3: Biodiversity conservation and resilience
- Risk Area 4: Protection from natural hazards (especially bushfires)

The risk to the fifth area (Public uses and associated values) is largely a consequence of the other risks and will be substantially mitigated if the other responses are effective.

Because of their interconnectedness the responses to Risk Areas 1-3 are combined in Section 4.1 below. Risk Area 4 is addressed in Section 4.2. These direct responses need to be complemented by a number of supporting governance and management processes which are covered in Sections 4.3 and 4.4.

In this section the available responses are synthesised from recent studies which either directly or indirectly address climate risks. Many of the studies are not specific to the Nature Reserves but the underlying principles and strategies are still relevant. Several of the responses simultaneously address other (non-climate) pressures and disturbances.

4.1 Maintaining and enhancing ecosystem processes and services (Risk Areas 1-3)

The overall conclusion is that, notwithstanding the uncertainty in the nature and magnitude of climate change impacts, there are a number of tangible strategies and actions that can increase the resilience of ecosystems to change; and that the most fundamental activities are those that preserve landscape function and diversified habitats. Enhancing connectivity is a necessary and complementary strategy that needs to be developed however on a ‘whole of landscape’ basis. This raises a number of policy options and issues.

4.1.1 Overall strategies

The primary strategy is to maintain and enhance fundamental ecosystem processes, which in turn support the ongoing ecosystem services provided by the Reserves; and to do this in a way that responds to the dynamic and to some extent unpredictable environment that characterises climate change. For biodiversity values the related strategy is to enhance the resilience of ecosystems and species to give them the best chance to self-adapt via multiple pathways (Steffen et al., 2009).

With significant climate change some modification to current ecosystems is inevitable, and the impacts will vary significantly between species and be hard to predict. In this context the challenge is to manage change to minimise undesired loss rather than to attempt to preserve the status quo, and to do this under conditions of significant uncertainty. The best overall strategy in these circumstances (Dunlop and Brown, 2008; Dunlop et al., 2010) is to

- ensure different types of habitat are protected to maximise ecosystem and habitat diversity
- recognise that at the local level, managers will need to overtly balance the tension that will often exist between two alternative strategic objectives (i.e. facilitating natural change as opposed to protecting the most threatened and valued species); that previous experience and practice may become less relevant under climate change; and that systematic management responses to climate risks are needed rather than 'patches' to existing conservation strategies
- especially as there will be some inevitable trade-offs, more clearly articulate the various values associated with biodiversity, assess which are most feasible to protect, and which are more fundamental (higher value). A potential categorisation of different biodiversity properties and values, and how persistent they may be under climate change, is provided (Dunlop et al., 2010 Table 3) with the caveat that this does not consider how they might be valued by society.
- the growing knowledge base required to refocus conservation objectives needs both this clearer articulation of biodiversity values, and a good ecological understanding of specific landscapes.

The extension of the Dunlop and Brown (2008) study to various biomes (Dunlop et al., 2010) includes a report (Prober et al., 2010) on Temperate Grassy Ecosystems (TGE) which included grassy woodlands. Conservation options canvassed in the report for this biome (and with some relevance for the landscapes of which the ACT Nature Reserves are a part) include

- Protection of a diversity of on- and off-reserve sites representing natural environments across the biome, with protection of remnant vegetation a high priority, and especially sites with natural (non enriched) soil environments and refugia. (The Canberra Nature Reserves clearly provide a base for this within ACT and surrounding region)
- Tailoring of restoration and revegetation efforts and carbon plantings toward climate resilient outcomes, including (particularly relevant to some of the lands adjacent to the ACT Nature Reserves)
    - a broad mix of local species, and preparedness to experiment with new species where few local species are expected to persist as in more fragmented landscapes
    - targeting development of high and low permeability directions to favour native over exotic species
- Favour land-use changes with potential for positive rather than negative biodiversity outcomes (e.g. revegetation, appropriate carbon sequestration, abandonment and reversion as opposed to high intensity agriculture such as irrigated vineyards or bio-fuel crops)
- Strengthening current approaches to exotic management including weed and ferals control
- Manage disturbance, particularly fire, to maintain open grassy ecosystems.

Mackey (2010) notes the critical role of vegetation based resources to preserve and enhance habitats; and the strong relationship between enhanced ecosystem resilience and adaptive capacity. He also notes that, while rare species are important for many reasons, it is the large common species and the 'cryptic small stuff' (including invertebrates, fungi and bacteria) that perform most of the ecological work in ecosystems, so that more attention should be paid to the potential impacts of climate change on these 'foundation' species.

The recommendations coming forward recently for the ACT in areas such as landscape function (Sharp, 2010) and connectivity and 'whole of landscape' planning (Lane, 2010; Manning et al., 2010) are consistent with the above broader principles of managing natural landscape ecosystems under climate change.

An essential starting point is the maintenance and improvement of landscape function and processes. Strategies include (Sharp, 2010 and ACT TAMS, 2010 specific to the Reserves; Steffen et al., 2009 and Patmore, 2010 more generally)

- facilitating regeneration (natural recovery) of vegetation and habitats through changed management practices that remove or reduce the impact of a range of non climate stressors (e.g. control of invasive species including weed and pests; reducing grazing pressure; and controlled impacts of land use including by visitors and for built assets),
- active restoration by repairing degradation (e.g. planting appropriate species; removal of introduced species; targeted land erosion mitigation measures) with some additional rehabilitation of key habitats.
- careful and targeted disturbance management regimes (e.g. application of bushfire control measures).

Facilitating natural regeneration would generally be the preferred strategy for areas with good quality remnants, being both cheaper and more effective. However some level of active restoration is likely to be necessary for more degraded areas, and can be very effective as already evidenced in some of the Reserves (ACT Government, 2010 p18).

Success in improving landscape function, vegetation and habitats will also support the natural climate, water and air regulation outcomes (Risk Area 2) and the preservation of biodiversity values (Risk Area 3).

Additional strategies more specifically targeted at biodiversity include (Steffen et al., 2009, Whitehead, 2006; Sharp et al., 2008)

- Protecting key habitats and refugia, including local and regional habitat heterogeneity
- Developing improved connectivity between ecological communities through corridors and stepping stones, including integration with off reserves conservation. This can be at continental scale such as the Great Eastern Ranges corridor (Mackey et al., 2010) of which the ACT and region is a component; landscape or regional scale connecting national parks and reserves; and local scale e.g. connecting riparian and adjacent habitats
- Ecological engineering where necessary (e.g. establishing keystone or structuring species)
- Ex situ conservation/ translocation of species
- In implementing the above, following where possible the three 'CAR' principles that have been adopted nationally for reserves (NRMMC, 2009), appropriately downscaled to the local region i.e. comprehensiveness (full range of sub-ecosystems), adequacy (sufficient levels of each ecosystem to provide ecological viability and resilience) and representation (finer scale diversity including habitat).

4.1.2 Connectivity

As mentioned above, addressing connectivity is an important complementary strategy to those more directly aimed at enhancing the health of the Reserves themselves.

This topic has been covered recently for the ACT in a paper (Manning et al., 2010) prepared for TAMS in order to address Action 34 of the ACT Weathering the Change Strategy (ACT Government, 2007a). For the purposes of this report the main principles and strategies from that paper have been distilled with an emphasis on those most relevant to climate change

- The maintenance and expansion of reserve networks is widely recognised as vital to ensuring climate change adaptation
- Mitigation of negative impacts of climate change and of expansion of urban and rural developments, requires land planning and management that recognises the need for wildlife to move across the 'whole landscape'
- Connectivity is an important consideration in land use planning because of the interaction between climate change and land use change impacts. Therefore conservation, rural and urban land uses should be integrated and be mutually supportive as far as possible.
- This implies systematic management of 'off reserve' land, irrespective of land use and tenure, coordinated with the nature conservation estate. The patch-corridor-matrix model of connectivity should be used as part of an integrated and ecologically networked 'whole of landscape' approach.
- Connectivity can therefore be enhanced through a range of approaches
    - Strategic assessment of nature reserves in key locations
    - Strategic establishment of biodiversity corridors
    - Restoration of key connectivity elements on 'off reserve' land i.e. developing an ecological network including protected areas, corridors
- Connectivity for biodiversity is a long term process that addresses climate change even as land-use changes, recognising that the importance of a particular part of the landscape for an organism can change through time, and also that responses to climate change are generally species specific. Connectivity should not be seen as a static property of a landscape; rather it will change through time and for different species.
- It is necessary to plan for all three forms of connectivity (habitat, landscape and ecological)
- Some options for habitat restoration measures within these ecological networks include
    - Maintain and enhance scattered trees
    - Anticipatory restoration
    - Assisted translocations
- In some cases, existing urban development in the ACT means that enhancing connectivity may only be possible in neighbouring areas of NSW, requiring cooperation on planning and landscape management.

The paper then uses techniques to map and value the location of links across the ACT, in order to assess habitat arrangement in the landscape for six 'model' animals that inhabit and move through the ACT's natural reserves system and the surrounding region.

This analysis is suggestive of the areas and directions of most 'connectivity value' for each species. However the paper recommends more detailed assessment to support future connectivity decisions across the ACT including

- Modelling of 'real' species of concern using existing and new data from connectivity related monitoring

- Modelling of neighbourhood connectivity and link value under different climate change and/ or land use scenarios, requiring the ability to model future vegetation and habitat distribution under each scenario and its suitability and permeability for each model animal.

The emphasis on 'whole of landscape' strategy requires consideration of the best policy instruments to support private and leased land ecological improvements (eg education and information provision; partnerships, stewardship and incentive options; and potentially well thought out biodiversity offset and related market-based schemes, provided they reflect the other principles and strategies identified in this report). Close links to catchment and natural resource management authorities and activities will also be important.

It should be noted that the above study focussed very much on the ACT and adjacent region as this is likely to be the most effective immediate 'connectivity' step to support threatened species within the ACT and region. Broader regional and continental scale connectivity may well have an important role from a national and regional perspective, though it needs to be recognised that the net impacts on local species is less certain with some potential risks as well as benefits.

4.2 Protection of on- and off-reserve assets from natural hazards (Risk Area 4)

Response strategies to bushfire risk for the Reserves include improvements to planning the reserve/ urban development interface, and a continuing focus on well-balanced and targeted prescribed burning.

On the former ACTPLA and ESA have been upgrading adaptive capacity and risk mitigation through dwelling standards and guidelines on surrounding bush (AECOM, 2010). A report on how modifications to the ACT Spatial Plan might assist climate change mitigation and adaptation, whilst focussed more on urban form options than the natural environment, also refers to options to reduce bushfire risks at the 'urban edge' e.g. by reducing the extent of the urban edge exposed to bushfire and improving emergency access (SGS, 2010).

Comprehensive bushfire management practices are included in the recently revised ACT Strategic Bushfire Management Plan (SBMP) (ACT Government, 2009a). The Plan has a 10 year horizon and addresses risks to a range of assets including built, environmental (ecological, hydrological and physical), agricultural and cultural.

It summarises the approach to prescribed burning, including the development of a number or Regional Fire Management Plans (RFMPs) for the ACT. The aim of these plans is to 'integrate fuel management strategies with other considerations such as the conservation of declared endangered species and communities, protection of riparian areas, and recreational opportunities' and is based on 'two fundamental concepts: addressing fire risk and conserving natural assets. The natural assets are the ACT declared threatened species and communities, biodiversity values, ecological condition and water catchment values'. This is done at a significant level of detail and includes some site specific considerations such as rare or threatened species.

The RFMPs identify a mosaic of burning across the ACT implemented at the landscape level through a range of prescribed burns at varying time intervals, and at the patch level through burns of varying intensity and unburnt areas within each burn block. Further background to

the more detailed fire management and recovery planning and activities is included in Kitchin et al. (2010) and Kitchin (2008).

With climate change the trade offs between conflicting objectives could be become more difficult and contentious. Kitchin et al. (2010) notes that the fire management approaches will be 'underpinned by monitoring of the objectives of the burns, fire severity monitoring and some quantitative ecological monitoring so that future planning can continue to adapt and improve'. Williams et al. (2009) point out in the overall Australian context that more research is needed on the effectiveness, costs and benefits of prescribed burning, and that an adaptive management approach is even more crucial under increasing climate change pressures.

4.3 Enhanced and integrated governance and management responses

The above direct responses need to be complemented by enhanced and more integrated governance and management processes. These fall into a number of categories summarised below (synthesised from Steffen et al., 2009, Dunlop et al., 2010, Sharp, 2010, Patmore, 2010, Ingamells, 2010, Lembit, 2010, Sharp et al., 2008).

(1) Strategic and management practices including

- clear articulation of strategic outcomes and values in terms that facilitate decisions (including trade offs) and reflect a dynamic rather than static environment
- prepare and implement strategic, management and site operational planning; increasingly framing park management in terms of the above outcomes and values, including ecosystem services and associated outcomes; incorporating a small number of measurable assessment criteria and indicators; and implemented consistently with adaptive management principles
- carry out climate and related risk assessments at landscape and ecosystem as well as individual species levels, coupled with risk spreading strategies and adaptive and iterative management to deal with climate uncertainty. The risk assessments would be incorporated in the above planning process.
- protection and management of core conservation areas, noting that it is important to act on the best qualitative and quantitative information available at the time, rather than wait for 'perfect' information that will never be realised
- monitoring and research programs built into strategies and plans from the outset, in order to support adaptive management, and with monitoring to include landscape function; vegetation, plant and animal communities and populations including threatened species; and supported by spatial modelling
- optimise cost-effective use of resources, with clear management targets and accountabilities, and working actively with the community and other stakeholders.

(2) Institutional, governance and partnership approaches

- reform of institutional, governance and partnership approaches including more integrated regional and cross jurisdictional approaches tailored to each region (e.g. Great Eastern Ranges and its component connectivity initiatives)
- look at landscape scale partnerships working with managers of private land and other public natural resources (e.g. partnerships, stewardship and incentive programs)
- build community partnerships in monitoring, research and ecological restoration
- include key partners in the above strategic and management planning.

(3) Community engagement

- Build greater community awareness and consensus on the values of functioning ecosystems and biodiversity – not least of all their being our life support system – and on the need for greater and more coherent investment and monitoring

(4) Knowledge development and management

- Understand why changes occur (ecological requirements, species interrelationships and dynamics)
- Increase knowledge and expertise in ecological management (e.g. fire ecology and the roles of fungi, invertebrates and soil micro-organisms)

(5) Carbon mitigation and offsets schemes

- Keep the pressure on climate change mitigation strategies, and take advantage of well thought out and tailored carbon and biodiversity offset schemes to enhance both biomass and biodiversity

The above approaches are also quite consistent with the 2009-2030 strategy for the National Reserve System (NRMMC, 2009), which includes a conceptual framework for assessing reserve management effectiveness, and an expectation that all jurisdictions will develop their approaches at least consistent with the national strategy.

Each of the above directions needs to be translated through to the most immediate actions for the ACT based on an understanding of the current issues and status.

For example in respect of item (1) above, in the ACT context current strategies and plans most relevant to the Nature Reserves (e.g. the various Conservation Strategies at ACT Government, 2004b, 2005, 2007c; and Management Plans at ACT Government, 1999, 2007b) will need to be progressively updated to incorporate (amongst other things) increasing climate change risks and responses. This would also be the opportunity to review the most effective overall planning framework including layering of strategies and plans to

- clarify intent, desired outcomes, and priorities reflecting risk assessments
- incorporate performance target and measurement mechanisms at the appropriate level.
- rethink documentation to maximise flexibility to necessary change and enhancement over time, and minimise any duplication and administrative rework.

A recommendation and framework for climate change risk assessments was covered in Section 3 of this report. In respect of performance measurement, the ACT NRM Council's recent Plan (ACT NRM Council, 2009) is an example of embedding Outcomes/ Targets into formal plans in an area with substantial synergy with the Nature Reserves.

In respect of broader regional strategies for the ACT and region (part of item (2) above)

- There are previously documented joint ACT/ NSW approaches (Fallding, 2002) which included a planning framework to support both regional and local planning decisions; supported by GIS mapping at regional, local and site levels with the intent to develop finer scale information on rare or poorly reserved vegetation associations, and important habitats and corridors for assemblages of rare or threatened fauna. However there does not seem to be a current documented version of this more integrated approach.

- There is however cooperation across the border at the operational level and on major initiatives such as the large-scale connectivity corridors (Atherton to Alps, Kosciusko to the Coast etc)
- The ACT State of the Environment (SOE) Reports provide a basis for assessing health of the Nature Reserves on a periodic basis, as well as connection to regional perspectives. For example the OCSE prepares similar SOE reports for each of the local government areas in the ACR and in the most recent report also prepared an overall regional perspective (ACT Government, 2009b).

4.4 Mainstreaming with other relevant policies and strategies

A key strategy for climate change adaptation is to mainstream responses into related policies, strategies and management activities rather than treat as a stand alone issue. Within the ACT there are several current government directions within which the response to climate change adaptation could be integrated (Webb, 2009).

Some of the ACT policies, strategies and plans most relevant to climate change and the Reserves have already been mentioned and include

- Weathering the Change (ACT Government, 2007a) – the overall response to climate change. A strategy update and the next action plan are currently under development
- The Canberra Spatial Plan (ACT Government, 2004a) - currently being updated including specific analysis of climate change issues and responses
- The Strategic Bushfire Management Plan (ACT Government, 2009a) – an example where climate change has been explicitly addressed
- The ACT NRM Council Plan (The Bush Capital Legacy) (2009).

Others of potential relevance include

- Think Water Act Water Strategy (2005) – currently under review
- Nature Conservation Act (1980) and Strategy (1998) – currently under review
- Biodiversity Offsets Policy - currently under development
- ACT Weeds Strategy 2009-19 (2009)
- ACT Vertebrate Pests Strategy
- ACT Conservation Action Plans 27 (in 2004 – covering Lowland Woodlands), 28 (in 2005 - covering Lowland Grasslands), and 29 (in 2007 – covering Aquatic Species and Riparian Zones).

Some of these are not currently explicit or consistent in addressing climate change responses though overall it is becoming an increasing theme. However several are under active review which gives an opportunity to address this (e.g. the current review of the Nature Conservation Act (ACT Government, 2010).

4.5 Summary and Recommendations

Recommendation 4.1: Adopt the adaptation response principles and strategies summarised in this report (see also below) to guide the specific risk mitigation actions

proposed for the Nature Reserves. Test specific proposals for alignment with these, and prioritise based on current information.

Summary of response principles and strategies

- The primary strategy is to maintain and enhance fundamental ecosystem processes which in turn support the ongoing ecosystem services provided by the reserves. This includes maintaining effective landscape function, vegetation and habitats within the reserves, and can involve both facilitating regeneration (natural recovery through removal or reduction of stressors such as exotics, fires, incompatible land use) and where necessary active restoration by repairing degradation (e.g. revegetation and land erosion mitigation)
- A complementary strategy is to enhance the resilience of ecosystems and species to give them the best chance to self-adapt via multiple pathways. This includes maintaining diversified habitats and key refugia, as well as enhancing connectivity, within and beyond the reserves on a 'whole of landscape' basis. Some ecological engineering and species translocation may also be necessary.
- Recognise that strategies will need to respond dynamically through time and for different species in response to continuing climate (and other) changes and to improved understanding. Facilitating natural change and novel ecosystems will often need to be balanced with attempting to preserve existing ecosystems and (in some cases) most threatened species.
- Land use and development planning needs to address the specific risks on-reserve, at the reserve/ urban development interface, and off-reserve across different land uses and tenures
- Fire management approaches including prescribed burning and effective planning at the reserve/ urban interface need to reflect a balance across the range of values and risks, and be underpinned by monitoring so that future planning can continue to adapt and improve
- The above direct responses need to be complemented by effective and integrated governance and adaptive management responses, including newly stated objectives, outcomes and values; strategic and operational planning and performance measurement and monitoring; institutional development and partnerships; mainstreaming responses into related policies and strategies; community engagement; and cumulative and accessible knowledge development and management feeding into future strategies and activities.

Recommendations 4.2: Do not wait for improved climate and impact information before taking the further actions that will enhance the resilience of the Nature Reserves.

Recommendation 4.3: Progressively review and update the various strategic and management plans relevant to the Nature Reserves, taking the opportunity to more explicitly incorporate the climate change risk assessments and responses, and to enhance and rationalise the planning process and framework for greater ongoing flexibility. Monitoring and adaptive management approaches should be built in up front so that strategies and activities can respond flexibly as new climate information and impact knowledge becomes available.

Section 5. Knowledge gaps

Drawing on the previous sections of this report the following are key knowledge gaps that could be addressed if the impacts of climate change on the Nature Reserves are to be better understood and responded to. This Section is also informed by the outcomes of an ACT Climate Change and NRM Knowledge Management workshop in March 2010 co-sponsored by the ACT NRM Council, the ANU Climate Change Institute and DECCEW. The reality is that these need to be prioritised to make best use of the scarce resources.

Section 2 – Climate:

- Whilst the instrumental climate records for the ACT and region have been well analysed there is potential to strengthen the interpretation of variability and trends through more research on the underlying regional climate drivers and potentially paleoclimatological/ dendrochronological techniques

- The currently available projections have a high degree of uncertainty, especially around rainfall, are at too broad a spatial scale, and there is no consensus as to the approach to making the best use of the information and projections available, in the ACT context.

Section 3 - Impacts:

- Whilst general directions can be projected, the extent and specifics of physical and biophysical impacts of climate are not well understood or documented for the Nature Reserves and surrounding landscapes (eg on runoff, fire regimes, land erosion and soil movement, soil quality (nutrients/ organic content/ acidification/ salinity), soil moisture, ecosystems (primary productivity and plant growth, bushfire impact, flow on impacts to threatened and invasive species (pests and weeds), species movement)). However Sharp (2010) has provided useful baseline analysis for soil stability, soil infiltration and nutrient cycling in the Reserves.

- In particular the differential impacts of climate change on specific ecosystems and species of importance, and likely species-specific responses, are not well understood or documented. This could include
    - identifying and understanding thresholds/ tipping points and controlling variables, species to species interaction; dynamic and evolving systems based models and related decision making tools; supported by better baseline information, spatial mapping, and longer term environmental monitoring processes/ programs; with the potential to develop workable decision rules for effective and devolved implementation of policy intent
    - more comprehensive and integrated spatially relevant data and representation; including vegetation and land cover (not just composition) maps for ACT and the region; rare, threatened and vulnerable species/ communities mapping; supported by use of citizen/ community science resources
    - better understanding of the other threatening processes and how they interact with climate change for each major ecosystem (ie pests, weeds, fire regimes and management, land use)
- Climate change impacts on the riverine and riparian ecosystems (e.g. Googong Foreshores and the Molonglo River Corridor) have not been assessed. This could include understanding multiple drivers of water quality (climate, rainfall, fire, weed management, sewerage etc)

- The relative roles and importance of the Nature Reserves vis a vis the surrounding NSW landscapes, in preserving key ecosystem values, are not well documented.

- The weighting placed by the community on the various and sometimes competing values ascribed to the Nature Reserves are not well understood, yet climate change is likely to exacerbate tensions between some of those values.

Section 4 – Adaptation responses:

- The options and relative cost-benefit of potential responses to climate change (and other drivers) are not well understood and could include
    - evaluating alternative and complementary adaptation response options for likely cost-effectiveness (e.g. restoring landscape function and ecosystem health for the Reserves; connectivity at regional and local scale; land use and planning taking account of the Reserve/ urban interface and urban form; biodiversity offsets policy; environmental water flows)
    - better understanding of economic and non-economic costs, values and trade offs; and approaches to public/ private cost-sharing
    - understanding how much investment to make in maintaining current environmental assets versus assisting change to novel ecosystems
- Developing approaches to adaptive management under uncertainty, including
    - testing robustness and resilience of proposals to a range of scenarios;
    - adaptive institutions, planning systems, rules and people
    - regional governance options including respective roles of institutions and the community
    - developing a small number of agreed and relevant key performance indicators supporting overall outcomes
- How to best influence community, private sector and political support, and decision making; including education and youth, and media.

Recommendation 5: Address the knowledge gaps on climate, impacts and responses, including those identified in this report, through a prioritised, intentional and coordinated approach across key government agency, researcher and community stakeholders.

This would include

- developing a prioritised knowledge gap/ research agenda for climate change and related issues for the ACT (and if possible adjacent region) with at least annual workshop review by policy, research and community stakeholders
- fostering development of research alliances, across institutions and with the community, encouraging focus on policy and community priorities
- developing an accessible Knowledge Management System for the ACT and region at least for key sustainability subsystems – for the Nature Reserves this would need to leverage off other broader initiatives (in particular the current Canberra Urban and Region Forum (CURF) initiative; complemented by follow up to the recent ACT NRM Knowledge Management workshop proposal)
- identifying and confirming ownership and access to key data sets, including GIS and related mappings, as these and associated modelling techniques could provide an increasingly useful input

- clarifying the appropriate coordinating and contributing institutional roles and responsibilities that would best support the above improved knowledge development and management.

Section 6. Broader ACT and regional integration

The outcomes for the Nature Reserves are inextricably linked with other policy and community objectives, and can be best addressed in an integrated way across sectors and with the surrounding region. An integrated approach to carrying out climate vulnerability assessment and adaptation has been recommended in a recent climate change vulnerability and adaptation scoping study prepared for the ACT Government (Webb, 2009). This was commissioned by ACT DECCEW and covered the Australian Capital Region (ACR). The recommendations included integrated vulnerability assessments across a number of sectors; building on the close collaboration established through the scoping study with the SE NSW Integrated Regional Vulnerability Assessment (IRVA) project; and progressively expanding stakeholder and community engagement. The scoping project also provided a number of draft Climate Change Knowledge Status Reports for selected sectors.

It is understood the ACT Government is still considering its approach to the above adaptation scoping proposals in the context of its review of the overall 'Weathering the Change' Strategy. There are already some useful building blocks. Relevant work that includes climate change implications has been under way for some time in key sectors including water (ACTEW investment planning and the current DECCEW review of the Think Water Act Water Strategy); fire (as reflected in the climate change components of the ACT Strategic Bushfire Management Plan 2009); and more recently for human settlements with climate change a significant focus in the current update of the ACT Spatial Plan.

Community engagement on these issues varies. The recent ACT Government 'Canberra 2030 - Time to Talk' initiative could provide a foundation for more specific consultations. The Regional Leaders Forum provides one opportunity to engage at the broader regional decision-maker level.

The climate issues and responses that have been identified in this report for the Nature Reserves have implications for all of the sectors that have been proposed for more general vulnerability assessment for the ACT (natural resource management, water, natural hazards management, human settlements, infrastructure, human health and tourism/ recreation). This reflects the special characteristic of the Reserves being at the interface of the human and environment systems. It also points to the inevitability of some potential conflict and trade offs when addressing climate change (and other) responses; and to the importance of adopting an integrated and cross-agency approach to planning and decisions.

Recommendation 6: Ensure the climate change vulnerability assessment and adaptation responses for the Nature Reserves both inform and reflect broader climate change assessments and strategies for the ACT and region as they become available, in an iterative process that recognises over time the many interdependencies across sectors, policy areas and jurisdictions.

There is a window of opportunity to address this over the coming year based on related initiatives including review and update of the ACT Weathering the Change Strategy and Action Plan, and of the ACT Spatial Plan; building on the collaboration that has been established with the current SE NSW IRVA project; and further development of community engagement following on the Canberra Time to Talk consultations. These provide the potential to establish a clear adaptation and sustainability vision for the ACT and region,

complementary to the carbon neutral vision. The future of the Nature Reserves would be an integral part of that vision.

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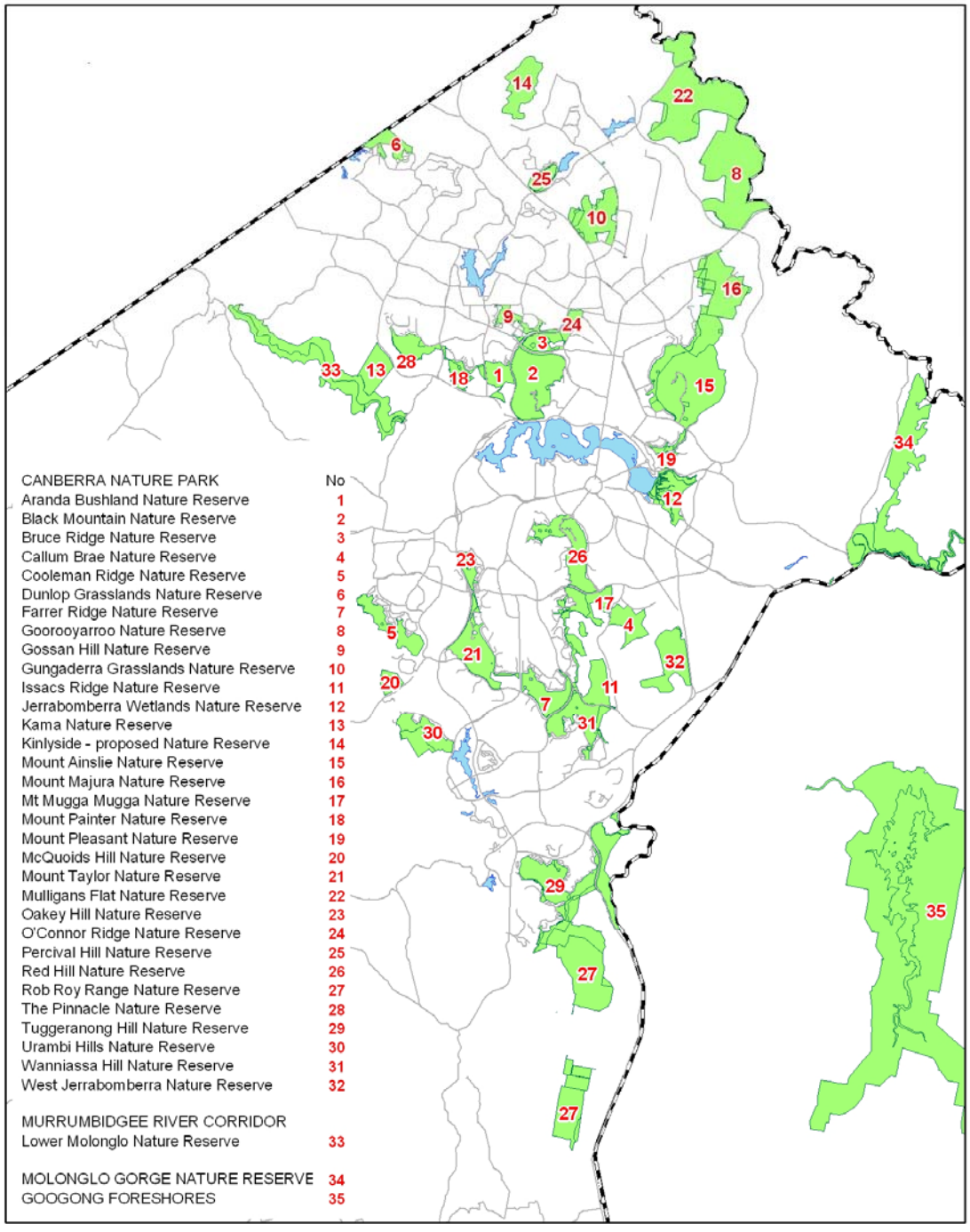
Appendix 1.1 Map of the Nature Reserves



Appendix 1.2 OCSE Investigation Terms of Reference

Terms of Reference

An investigation will be undertaken into Canberra Nature Park (nature reserves); Molonglo River Corridor (nature reserves) and Googong Foreshores that:

1. assesses the condition of the forests, woodlands and grassy woodlands in these areas, including the effects of grazing by stock and/or kangaroos, vertebrate, pests and weeds;

2. identifies actions to protect and enhance these areas, including land use or boundary changes while taking into account their purpose, values, and location and the status of indigenous species and communities protected in the nature reserve system;

3. reviews existing land management programs and practices for these areas and areas that adjoin them. This is to include but not be limited to agistment, leasing, culling arrangements, Land Management Agreements or plans of management which may apply;

4. identifies any urgent actions and longer-term changes that are needed to improve the management of these areas. This is to include identifying successful management measures that should be retained;

5. identifies knowledge gaps, research or survey needs, and compliance and monitoring requirements that may be necessary to support improved management programs and practices while taking into account the context of the areas and effects of climate variability;

6. identifies ways for ensuring effective communication and involvement of stakeholders, including Aboriginal people, whose actions potentially, indirectly or directly, affect these areas;

7. identifies potential biodiversity offset management actions or sites; and

8. identifies the evidence justifying the need for managing grazing pressure in the context of sound reserve management practices.

In undertaking the investigation, the Commissioner is to consult with all relevant experts and key stakeholders, including staff in TAMS and in the Department of the Environment, Climate Change, Energy and water.

Note: The management of grassland nature reserves in Canberra Nature Park was recently reviewed as pert of the Commissioners inquiry into Lowland Grasslands of the ACT and will not be included in this study.

Appendix 1.3 – Sources of Nature Reserve Values and Outcomes

This Appendix includes extracts from 3 potential sources to help confirm the most appropriate values and outcomes against which climate impacts on the Nature Reserves should be assessed.

(1) Canberra Nature Park Management Plan (ACT Government, 1999)

The CNP plan includes the following values at the headline level

- Ecological/ Nature Conservation (including biodiversity, protection of sensitive populations, communities and ecosystems, undesirable species control)
- Landscape Aesthetic (as urban backdrop)
- Scientific Research
- Educational
- Cultural Appreciation (aboriginal and European)
- Recreational

(2) Googong Foreshores Draft Management Plan (ACT Government, 2007)

The Googong Foreshores draft plan includes the following values at the headline level

- Water Supply including Quality
- Natural Heritage including biodiversity and landscape values
- Cultural Heritage (Aboriginal and European)
- Recreation

(3) IPCC Assessment Working Group II – Chapter 4 on Ecosystems, their properties, goods and services (Fischlin et al., 2007)

In the context of the ACT Nature Reserves the following values are especially relevant from the IPCC framework (see full framework below):

i. Supporting services:

- primary production
- biodiversity

iii. Regulating services:

- carbon sequestration
- climate and water regulation
- water and air purification
- protection from natural hazards
- disease and pest regulation

iv. Cultural services: human spiritual and aesthetic appreciation

Extract from IPCC Assessment Working Group II – Chapter 4 on Ecosystems, their properties, goods and services (Fischlin et al., 2007)

"4.1.1 Ecosystem goods and services

Ecosystems provide many goods and services that are of vital importance for the functioning of the biosphere, and provide the basis for the delivery of tangible benefits to human society. Hassan et al. (2005) define these to include supporting,

provisioning, regulating and cultural services. In this chapter we divide services into four categories.

i. *Supporting services*, such as primary and secondary production, and biodiversity, a resource that is increasingly recognised to sustain many of the goods and services that humans enjoy from ecosystems. These provide a basis for three higher-level categories of services.

ii. *Provisioning services*, such as products (cf. Gitay et al., 2001), i.e., food (including game, roots, seeds, nuts and other fruit, spices, fodder), fibre (including wood, textiles) and medicinal and cosmetic products (including aromatic plants,
pigments; see Chapter 5).

iii. *Regulating services*, which are of paramount importance for human society such as (a) carbon sequestration, (b) climate and water regulation, (c) protection from natural hazards such as floods, avalanches or rock-fall, (d) water and air purification, and (e) disease and pest regulation.

iv. *Cultural services*, which satisfy human spiritual and aesthetic appreciation of ecosystems and their components."

Appendix 2.1 ACT and region historical climate analysis

This Appendix summarises the sources of information and conclusions for the ACT and region

(1) From the instrumental record

The ACR Knowledge Status Report on Climate (Whan and Webb, 2009) included an analysis of ACT and regional climate historical records prepared by Clem Davis from the ANU. The information for the ACT is being updated to include another year of data (i.e. for 2009) and further analysis of ACT and regional trends and drivers is in preparation (Davis and Lindesay, in prep).

Interpretation of trends is sensitive to the length of period reviewed – hence the value of reviewing the longer term records as well as more recent features. The period used for a climate baseline (at least 30 years is generally considered necessary for longer term trends) is important in considering future potential climate change and therefore in future adaptation decision making.

There is a good selection of instrumented sites within the ACR though more limited in number and commencement date for temperature than for rainfall. The ANU analysis identified a few key sites representative of the ACR subregions with data back to the 1880s for rainfall and around 1910 for temperature.

The evidence for the ACR includes (in addition to the ACT) long term data from other representative sites (Goulburn - tablelands, Cabramurra - alpine, Moruya - coastal). Across the region there are similar overall trends but with some local characteristics in the detail (e.g. ocean influences for the coastal regions) which points to the value of understanding local evidence within the context of broader trends. The overall trends and interpretations include (Whan and Webb, 2009)

- Maximum and minimum mean temperatures have been on an increasing trend over the last 100 years but have been particularly high in the last decade, especially maximum temperatures in summer
- Rainfall trends are harder to pick with significant periods of drought around 1895-1910, the 1940s and the last decade
- The current drought has seen most consistent rainfall declines across the region in Autumn, exacerbated by increased temperatures, and with some seasonal and spatial variation across the region
- Whilst the recent rainfall declines are still within the long term historical range of variability, the increasing understanding of climate change drivers likely to impact on the region (in particular sea level pressure increases associated with the southward extent and intensification of the subtropical ridge, which impacts the intensity and timing of autumn through spring cold fronts across the region) is consistent with the significant Autumn declines. Therefore decision makers need to allow for the possibility that rainfall in SE Australia has permanently shifted to lower levels (as happened in SW Australia from the 1970s onwards).
- Other regional drivers of climate (El Nino Southern Oscillation - ENSO, Indian Ocean Dipole - IOD, Southern Annular Mode - SAM) are also showing changing characteristics consistent with climate change, and can explain some of the observed

regional climate features including some contribution to reduced rainfall of the last decade. For example (drier, hotter) El Nino periods have tended to be more prevalent that La Nina periods, and there is some evidence of the SAM contracting polewards potentially reducing winter rainfalls from cold fronts.

More specifically from the long term data for the ACT (and Queanbeyan) trends include (Davis and Lindesay, in prep; Whan and Webb, 2009)

- The same increasing temperature and declining rainfall patterns as the region, with winters getting shorter and warmer, and summers getting hotter but not necessarily longer; and changes in seasonal rainfall with autumn in particular getting drier, summer somewhat wetter and more marginal changes in winter and spring; and a reduction in the number of long term rainfall events
- A significant increase in days of 35°C or more and in numbers of heat waves especially in the last two decades
- An increase in sunshine
- A slight reduction in frost days
- A decrease in strong winds and fogs
- Reduced soil moisture
- No evident trend in thunderstorms or evaporation.

There is also some evidence that historical trends in ACT bushfire frequency and intensity are at least consistent directionally with the predictions of climate change (ACT Government, 2009a).

The above analysis expands on, but is consistent with that presented for SE Australia at a 2008 NPA ACT conference (Lindesay, 2008). It is also consistent with the recent Phase 1 synthesis from the SEACI project (CSIRO, 2010a – see also Section 2 of the main report and Appendix 2.3).

(2) Paleo-climatological and dendrochronological research

The evidence from the historical record can be augmented by paleoclimatological research (e.g. Pillans, 2010) and through techniques such as dendrochronology based on tree ring growth analysis (Brookhouse, 2010).

Pillans (2010), noting that interrogation of the geologic record to reconstruct past global climates 'is a complicated business', discusses the history of, and evidence for, global climate changes on two timescales – the last 65 million years and the last 2.6 million years - and how they have impacted on the Australian continent, in order to identify the major drivers (causes) of long-term climate change and their potential relevance to present and future climate changes. The very long term paleo-climatology is at too broad a level to directly interpret local trends, but can be important to counter claims that climate change is not a serious future risk.

Brookhouse (2010) notes that 'dendrochronology … has revealed the sensitivity of plant species to climatic variability and change as well as the nature of natural disturbance regimes. These issues are of particular relevance in Australia, where knowledge on the sensitivity of

plant species to climate variability is limited, long records of climate are sparse and disturbance by wildfire is common.'

He cites studies that evidence the potential for certain tree species growing at or above the timberline 'to create chronologies that exceed the span of European inhabitance' and states that 'climate reconstructions based on these chronologies may reveal whether the current temperature, snowfall and river flow trends have precedence' and that 'cross-dated ring counts will also allow investigation of fire regimes in the ACT and throughout the remainder of the alps.'

Whilst this work, currently based on certain tree species in the alpine areas of NSW and Victoria, is most relevant for the alpine and montane ecosystems, its proximity to the ACT (including work in Namadgi) could provide some indication as to the longer term regional weather patterns back to around 1800, including comparison with the instrumental record in equivalent climatic sites. Whilst it is early days it has potential to confirm and identify longer term climate trends and variability in the region.

Appendix 2.2 -Table 1: Comparison of climate studies relevant to the ACT and region (see Appendix 2.3 for more context)

Climate Parameter	**ACT Historical Record (Appx 2.1)**	**SEACI (CSIRO, 2010a) Multiple Projects**	**SE NSW Climate Impact Profile (NSW Govt, 2010) and IRVA**	**AECOM (2010) for ACT Spatial Plan**	**CCPS Project (Niemeyer, 2010)**	**IACCIUS Project (Hutchinson et al., 2008)**	**ACTEW (2007a) from Bates et al. (2003)**	**Lucas et al. (2007) SE Aust fire; ACT Govt (2009a)**	**King et al. (2009) Alpine fire**
Assumptions:					2050/2100 A1B **or** A1FI				
Periods	Rain 1871-Temp1912-	Various	2050	2050	2050/2100	2030	2030	2020/2050	2030/2070
IPCC scenarios	N/A	Mostly A2	A2 (but runoff A1B; SLR-A1FI)	A1FI (some A2)	A1B **or** A1FI	A1B		All	B1/ A1FI
GCMs	N/A	Various: (eg Mean over 22 GCMs; Best 5 GCMs etc depending on projects)	4 GCMs: (CSIRO3; ECHO-G;MRI;MIROC-m)	19 GCMs: (8 Most Likely inc GFDL2; 5 Worst Case inc ECHAM5; 6: other)	1 GCM: (ECHAM5)	CSIRO (2007) median	13 GCMs	CSIRO CCAM Mark 2/3	23 GCMs: CSIRO (2007) 50%ile
Spatial/ Downscaling	Qbyn/ Cba airport; Fairlight	Statistical: (NHMM method /A2/ 4GCMs); (ASDM method /15 GCMs) Dynamical: (CCAM/ RAMS/ A2)			ANUSPLIN	ANUSPLIN	Statistical		ANUSPLIN
Temperature:									
Daily Max Daily Min Daily Ave Hot days Heatwaves	Increase Increase Increase Increase Increase	Increase Increase Increase Increase Increase	+1-3C +1.5-3C +1-3C Increase Increase	+2-3C Increase	Increase Increase Inc 1.7/3.2C **or** 2.6/6C Increase	+1C +1C +1C Increase Increase	+0.4-1.6C		

Frost days	Decrease				Inc 4x/7.5x **or** 6x/20x Dec 29%/48% **or** 40%/75%	Decrease			
Rainfall:									
Overall		Decrease	Decrease	ML -5 to +4% WC -13 to -5%	-7%/13% **or** -11%/25%		-9 to +2%		
Autumn Winter Spring Summer	Decrease	Decrease Decrease Decrease	-5-20% -20-50% No change +20-50%		Aut 0% **or** 0% Win -11% **or** -17% Spr -13% **or** -20% Sum -3% **or** -4%		-5 to +5% -11 to +2% -11 to 0% -9 to +12%		
Relative Humidity						Dec summer			
Potential Evaporation						Inc summer	+1.4 to +9.1% annual		
Rain Storm freq/ intensity		Increase		Increase		Inc winter	Increase		
Drought freq/ intensity	Increase?	Increase			Increase	Increase			
Bushfire freq/ intensity	Increase (ACTGovt 2009a)	Increase		Increase	Increase	Increase		Increase	Inc
Other: Water flows Soil moisture Wind Fogs	 Decrease Decrease Decrease	 Decrease Decrease			Dec 25% **or** 38%				

Appendix 2.3 Sources of ACT and region climate projections

A number of climate studies with projections relevant to the ACT and surrounding region have been identified. These are summarised in Table 1 at Appendix 2.2 of this report. The following provides some brief additional context for each study.

(1) SEACI (CSIRO, 2010a)

The South Eastern Australian Climate Initiative (SEACI) is being carried out by CSIRO and the Bureau of Meteorology, and differs from the other studies in that it is a long term program with multiple phases and a number of complementary projects aiming to

- enhance understanding of the historical and current climate for SE Australia, and the main climate controls or drivers, including global warming
- assess future regional climate change, and associated longer term projections including downscaling, with an emphasis on hydrology and runoff/ stream flow implications
- improve shorter term seasonal climate forecasts 3-12 months ahead

The Phase I (2006-2009) synthesis report (CSIRO, 2010a) concludes that the recent 13 year drought in the southern Murray Darling Basin 'is unprecedented when compared with other recorded droughts since 1900'

- being largely constrained to the southern Australia region
- having lower year to year rainfall variability
- with substantial (indeed the major) declines in autumn and not just winter and spring
- being accompanied by consistently higher temperatures.

These characteristics have led to much lower runoffs and stream flows than in previous dry periods.

It also concludes that the changed rainfall characteristics are statistically explained (about 80%) by the impacts of anthropogenic sourced global warming and the resulting impacts on large scale atmospheric circulation and especially intensification of the subtropical ridge. Natural variability is probably also contributing but is insufficient by itself and does not explain the very significant autumn rainfall reductions. This may indicate a shift in the regional climate and an increasing future risk of below long term average rainfall. The impacts on runoff and stream flow during the recent drought have been higher than predicted by models raising questions as to the best climate baseline to adopt going forward. A persistent longer term return to wetter conditions 'is considered unlikely by SEACI researchers'.

The program has also further developed both statistical and dynamical downscaling approaches for the region, noting however that climate variability and uncertainty increases with decreasing space and time scales. However they are important in order to relate to local experience and issues, as well as to project extreme events which tend to be more localised.

The program has adopted various approaches to selection of GCMs for particular projects but as yet there is no clear finding as to the relative benefits of (for example) selecting one or a few 'better skilled GCMs' as opposed to the mean of all or most of the GCMs.

The above has led to several priority issues to be addressed in Phase II of the SEACI program which has now commenced

(2) NSW Climate Impact Profile (NSW Government, 2010)

This report is based on work commissioned by NSW DECCW over the last few years and covers the projected impacts of climate change for each of the NSW Planning Regions. This includes SE NSW which is adjacent to the ACT (to the north, east and south) and is similar though not identical in extent to the Australian Capital Region (ACR). It includes considerable physical and biophysical impact assessment as well as the climate analysis. It is based primarily on only one possible scenario and so should not by itself be the basis for significant decisions. However it provides a good starting basis for vulnerability assessment and development of a range of alternative 'what ifs' under different assumed scenarios and projections.

It was based on climate work commissioned by the NSW Government of Andy Pitman (UNSW) in 2008, which in turn was based on 4 GCMs and the A2 IPCC scenario; and on a number of expert input processes to translate climate changes to various physical and biophysical parameters, including impacts on land and ecosystems. The latter are referred to in the Impacts assessment (Section 3) of this ACT Nature Reserves report.

The SE NSW Impact Profile is also the basis of the current SE NSW Integrated Regional Vulnerability Assessment (IRVA) project.

(3) AECOM report for the ACTPLA Spatial Plan Update (AECOM, 2010)

ACTPLA commissioned consultants AECOM to carry out a 'Human Settlement Vulnerability and Adaptive Capacity Assessment' (AECOM, 2010) as part of the current ACT Spatial Plan update. In this project locally relevant climate projections were used to underpin the vulnerability assessment of four key risks for the ACT (bushfire, extreme heat and public health, flooding and water resources).

The climate projections were provided by CSIRO for AECOM and indicate that 'the ACT is on track to go beyond a 2°C warming by 2050'. The projections were based on the A1FI IPCC emission scenario which is 'in the higher end of the emissions scenario family' and a set of 19 GCMs. It uses groupings of GCM projections to establish 'most likely' and 'worst case' selections of GCMs.

The draft report concludes that

- 'The most likely future climate in the Canberra region (8 of the 19 models) is hotter with little rainfall changes … The Climate model considered the most representative of this climate future in the Canberra region is GFDL 2'. Annual air temperatures are 1.8° – 2.9°C warmer than current values, and mean rainfall changes are between -4.6% and + 4.4%.
- 'The suggested worst case scenario for a likely future climate in the Canberra region (5 of 19 models) is hotter with drier conditions … The climate model considered the most representative of this climate future in the Canberra region is ECHAM 5'. Annual air temperatures are 1.9° – 2.7°C warmer than current values, and mean rainfall decrease between -13% and -5.2%.

The projections show significantly more days above 35°C temperatures (approximately fourfold increase 2050 over current). They also indicate changes to extreme rainfall events, (though in this case only A2 IPCC scenario information was available). The extreme rainfall changes show a less consistent trend with a mixture of increases and decreases though with a tendency for an increased frequency of '10 and 50 year return' 1 day rainfall events for the worst case climate future.

(4) Climate Change and the Public Sphere (ACT and Goulburn-Mulwarree) project (Niemeyer, 2010)

Climate projections were prepared for this recent project, in this case using the A1B and A1FI scenarios and projections drawn from OzClim. It also used the ANUSPLIN technique (Hutchinson, 2004) to interpolate climate projections at a finer scale for the ACT and surrounding region. The climate projections were based on one GCM model (ECHAM 5) selected on a number of criteria. Consequential implications for a small number of issues were also developed (i.e. changes in area suitable for Blakely's Redgum, and for regional wine growing).

These projections were prepared to elicit a response from research participants from the ACT and Goulburn-Mulwarree, and as a prelude to deliberation about how the potential changes should be managed. Although the potential reactions of participants and their recommendations are policy relevant, no specific claim can be made in relation to the use of the scenarios for decision making. However they do demonstrate an interesting approach to defining a range of possible scenarios at the local level and in particular explored various ways to present climate and related information to facilitate engagement and discussion. This work is in preparation for publication, with the report due in December 2010.

(5) IACCIUS project (Hutchinson et al., 2008)

The Integrated Assessment of Climate Change Impacts on Urban Settlements (IACCIUS) project carried out impact assessments for a number of specific locations in SE Australia and Darwin. It included some climate projections for the ACT and region. They were based on CSIRO (2007) median projections under the A1B IPCC scenario and were used more to facilitate participative stakeholder discussion rather than for management decisions. However through use of the ANUSPLIN interpolation technique they did simulate greater spatial resolution of climate parameters within the region including within the ACT.

(6) ACTEW projects for ACT water planning and investment decisions (ACTEW, 2007a)

In recent years ACTEW has had to address the potential impacts of climate change in order to assess major capital investment decisions (eg the Cotter dam enlargement and the Murrumbidgee to Googong pipeline) (ACTEW, 2007a, b).

Climate assumptions underpinning the investment proposals were based in part on work commissioned from the CSIRO (Bates et al., 2003). From this study the '2030 climate' adopted reflected the most pessimistic in the range of rainfall projections for the ACT for the year 2030. These projections were in turn based on 13 GCMs. ACTEW and ACTEW/ AGL

also took a ‘prudent planning approach’ in assessing water supply options on three alternative assumptions (noting that they should not be taken a an opinion on whether such permanent shifts had in fact occurred)

- that the ACT had already (in 2007) undergone an abrupt change to the lower ‘2030 climate’ projections for rainfall
- repetition of the previous 6 years of the then current drought (ie rainfall somewhat lower than the ‘2030 climate’ level)
- repetition of the previous 12 months (significantly lower even than the previous 6 years) of the then current drought

all implying new reduced baselines for potential use in decision making.

Whilst this led to what could be viewed in the overall spectrum of scenarios/ GCM outputs as the more conservative end of low rainfall and runoff assumptions, this was justified by ACTEW in terms of a prudent response to the risk profile considered relevant to such an essential service as water supply security (i.e. the proposition that the financial and non-financial costs of severe limitations on water availability have greater consequence than the costs of over-investing should rainfall be significantly greater than projected). This study indicates the importance of relating the approach to use of climate assumptions and models to the nature of the decisions under consideration.

It is understood (ACTEW, 2010) that the next round of water planning for the ACT is likely to extend the above approach through more formal use of scenario planning in order to address the inevitable degree of uncertainty around projections. In this approach a number of possible scenarios are used to establish the robustness of proposed decisions to alternative outcomes under a range of probabilistic assumptions, and to identify ‘trigger points’ at which interventions would need to be made in the future, in order to protect an explicitly stated risk profile.

(7) Bushfire related climate studies - Lucas et al. (2007) and Hennessy et al. (2005)

Hennessy et al. (2005) assessed the potential impact of climate change on bushfire weather in a number of sites in SE Australia. A key finding was that an increase in fire-weather risk is likely at most sites in 2020 and 2050, including the average number of days when the Fire Danger Index (FDI) rating is very high or extreme. The study also indicated that the window available for prescribed burning may shift and narrow (ie higher fire-weather risk in spring, summer and autumn will increasingly shift periods suitable for prescribed burning toward winter).

Lucas et al. (2007) updated this earlier study using climate change projections from two CSIRO climate models CCAM (Mark2) and CCAM (Mark3) for 2020 and 2050, and covering the full range of IPCC scenarios (IPCC, 2000). This study is referred to by the ACT Strategic Bushfire Management Plan (SBMP) (ACT Government, 2009a) noting (SBMP Supplementary Information 1 p21ff) that “it is predicted that days >50 FDI will increase in southern Australia, with a possible increase of the frequency of >70FDI events to once every five years by 2020 and to more than once every two years by 2050”. The SBMP also refers to research under way into the impact on fire behaviour of a range of discrete climatological conditions (e.g. thunderstorms and wind changes); and to assessment, modelling and modification of bushfire fuels.

The Lucas et al. (2007) study comments that ‘the results of the projects could be vastly improved if climate-vegetation interactions were taken into account’ and that ‘fire impact

assessments are needed at finer spatial scales (10-100m) allowing for differing terrain and vegetation, property types and fire management techniques'.

(8) Bushfire related climate studies - fire regime studies by King et al. (2009)

Studies at the ANU using the FIRESCAPE model (Cary, 2002) have taken finer scale regime modelling approaches including for the alpine region (King et al., 2009).

King et al (2009) modelled fire regimes in the NSW/ ACT/ Victorian alpine areas based on IPCC B1 (least change) and A1FI (most change) scenarios and 50th percentile values from CSIRO and BOM (2007), which in turn was based on 23 GCMs. Spatial and temporal variations in weather parameters were developed using the ANUSPLIN model (Hutchinson, 2004) with weather data for 1975-2005.

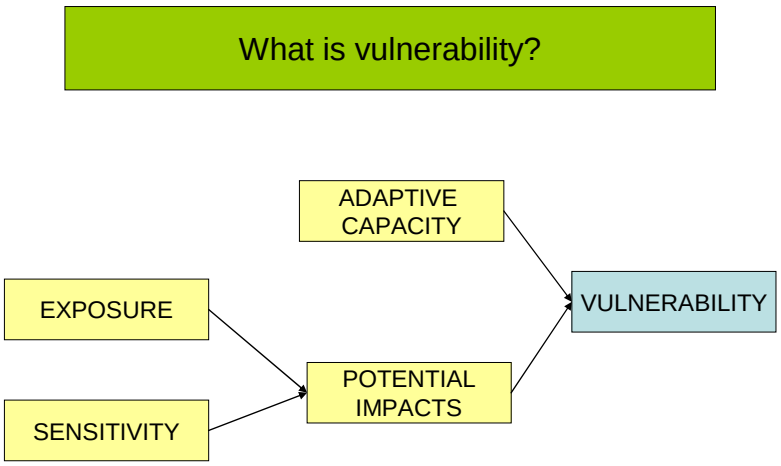
This study showed that climate change is likely to produce changes in fire regimes over a 30 year simulation period

- Greater number of unplanned fires
- Shorter time intervals between fires
- Greater fire intensities and area burned by unplanned fires
- Earlier start to the fire season every year
- Increased carbon emissions and reduced biomass and carbon stocks.

The modelling did not include changes to vegetation dynamics and growth (from changes in CO2 fertilization, heat and water stress) or predicted increases in lightning occurrence.

Appendix 3.1 Climate Change Vulnerability Framework

The components of climate change vulnerability are shown in the chart below (following the framework in Commonwealth of Australia, 2005, 2006).



1

In this framework vulnerability is assessed as a function of exposure to climate change effects, the sensitivity of that which is exposed to the change, and the capacity of that which is exposed to adapt to that change. Systems or groups that are highly exposed, sensitive and less able to adapt are more vulnerable. Alternatively a community may be both exposed and sensitive to the change but less vulnerable than others due to a higher adaptive capacity. It is the combination that determines overall vulnerability.

Appendix 3.2 Risk Area and Vulnerability Template for the Nature Reserves

Risk Area	Exposure	Sensitivity	Impact	Adaptive capacity	Vulnerability
1. Natural environment					
Soils					
Vegetation					
2. Regulation services					
Carbon storage/ climate					
Water supply/ quality					
Air quality					
3. Biodiversity					
Flora					
Fauna					
4. Natural hazards					
Fire					
Floods					
5. Public use/ values					

The climate change risk areas for the Nature Reserves are those identified in Section 3 of the main report.

As indicated in Appendix 3.1, Impact is combined from Exposure and Sensitivity; and Vulnerability is combined from Impact and Adaptive Capacity

At an overall level each cell can for example be summarised as High, Medium or Low in order to provide a rough guide to relative significance. In a first pass these can be based on collective expert judgement (supported by evidence including data where available).