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Indicators of community vulnerability and adaptive capacity across the Murray– Darling Basin—a focus on irrigation in agriculture



ABARE–BRS client report
for the Murray–Darling Basin Authority

October 2010



INSTITUTE FOR Rural Futures

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Science and economics for decision-makers

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Australian Bureau of Agricultural and Resource Economics – Bureau of Rural Sciences

Postal address GPO Box 1563 Canberra ACT 2601 Australia

Switchboard +61 2 6272 2010

Facsimile +61 2 6272 2001

Email info@abare-brs.gov.au

Web abare-brs.gov.au

ABARE–BRS project 43099

On 1 July 2010, the Australian Bureau of Agricultural and Resource Economics (ABARE) and the Bureau of Rural Sciences (BRS) merged to form ABARE–BRS.

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The Murray–Darling Basin Authority commissioned this report, amongst a number of consultancy reports, to examine a range of different aspects of the socio-economic implications of reducing current diversion limits. These studies were conducted at specific points in time during the development of the proposed Basin Plan and aimed to analyse the likely implications of a range of potential scenarios for reducing long-term average diversion limits in order to inform the MDBA on options for setting Sustainable Diversion Limits and other aspects of the proposed Basin Plan.

Acknowledgments

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The multi-criteria mapping produced using MCAS-S in this report is intended to assist understanding of patterns of vulnerability and adaptive capacity in the Basin using available data. The mapping process is highly flexible, enabling exploration of spatial relationships. The mapped scenarios presented in this report should be regarded as illustrative rather than definitive.

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Glossary

Definitions of key conceptual terms used in this document are as follows:

Adaptive capacity	Ability or potential of a system (for example, a community) to modify or change its characteristics or behaviour to cope better with change or stresses.
Community	The term community has been applied to three different contexts. Communities of place refer to people living in a given geographical area (for example, Narrabri); community of interest refers to those who share a common interest, such as an industry; community of identity refers to people who take an important part of their identity from some characteristic (for example, the Aboriginal community).
Exposure	The amount of external stress or change a community is likely to be affected by.
Potential impact	Consequences of the change or stressor. Made up of a combination of exposure and sensitivity to change, for example, worse potential impact results from a community that is very dependent on irrigation water facing a large reduction in water availability.
Resilience	An emergent property of an individual or community that is understood in three main ways in the literature: as recovery, as stability and as transformation (see Maguire and Cartwright 2008 review in appendix D).
Sensitivity	A measure of how dependent a community is upon the resource that is changing – for example, irrigation water.
Vulnerability	Potential for susceptibility to harm. The degree to which a system (for example, community) is susceptible to pressures and disturbances, such as climate change or socio-economic processes.

The use of statistical terms in this document is as follows:

A measure	A generic term referring to indicators, sub-indices and indices.
Census Collection District (CCD)	ABS standard geographic unit of collection covering on average around 150–250 dwellings. There are likely to be more dwellings in urban CCDs than those in rural areas which cover a larger area but contain fewer dwellings.
Data item	A single number, such as number of people in the workforce.

Index	A single number representing a complex concept and obtained by combining sub-indices.
Indicator	A single data item or a number derived arithmetically from more than one data item that is taken to indicate the level of simple concept, for example, the proportion of unemployed in the workforce is an indicator of the level of unemployment.
Statistical Local Area (SLA)	A unit of geography used for data aggregation by the Australian Bureau of Statistics. In most cases SLA is identical, or formed from a division of, whole Local Government Areas (LGAs).
Sub-index	A single indicator or a number derived arithmetically from more than one indicator.

Summary

There are many changes occurring in rural and regional communities in the Murray-Darling Basin as a result of climate change, water availability, water trading, global markets, population movements and ongoing social changes. Basin communities will respond to and be affected by a range of these drivers in combination with their adaptive capacity, resilience and vulnerability. This project was commissioned by the Murray-Darling Basin Authority (MDBA) to measure the vulnerability, resilience and adaptive capacity of Basin communities to changes in water availability — due to a range of factors — in order to inform MDBA planning and decision-making.

The aim of the project was to increase understanding of community socio-economic circumstances in the Murray-Darling Basin and to provide a readily accessible metric with which to compare the vulnerability of the many communities across the Basin. A set of measures of community vulnerability to changes in water availability was developed drawing on and adapting the IPCC framework (Allen Consulting 2005). Composite indices were derived to spatially examine differences across regions and communities and these were mapped at the Basin scale. The work applies the concept of sensitivity, which in the context of this report is a measure of the reliance of Basin communities on irrigation water and their dependence on associated agricultural and processing employment. It then develops the composite index of community vulnerability by overlaying this sensitivity with a measure of the adaptive capacity of communities to manage or cope with change.

The results show that community vulnerability to changes in water availability varies widely across the Basin depending on the different adaptive capacities and sensitivities of particular communities. There are two large regions in the Basin with high to very high community vulnerability: in the Border Rivers, Gwydir, Namoi and Macquarie-Castlereagh Basin Plan Regions in the northeast of the Basin and in the Lachlan, Murrumbidgee and Murray Basin Plan Regions in the southern Basin (map 1, appendix B).

Communities in these areas have a combination of higher sensitivity to changes in water availability (that is very high dependence on water for agriculture and high agri-industry employment) and limited levels of adaptive capacity (that is low levels of human capital, social capital and economic diversity) in comparison to other areas in the Basin. This means that communities in these areas are more likely to be impacted by changes in water availability.

A simple sensitivity analysis was undertaken to determine which indicators and sub-indicators have the most influence on the final community vulnerability index. The sensitivity analysis considered the effect on the community vulnerability index of a 10 per cent departure from the mean value of each constituent indicator (table 6). The values are as expected from a consideration of the hierarchy of calculations. The economic diversity index has the most influence on the vulnerability index because it is a single sub-index that enters the calculation relatively high in the hierarchy. Hence its influence is diluted the least by the process of standardising and addition that occurs in the hierarchy of calculations.

The outputs of the project can be used in two ways — to support policy decision-makers in prioritising effective investments and policy settings, and to work with community decision-makers in the Murray-Darling Basin to better understand their circumstances and the factors that contribute to changes in their communities. It is recommended that a process of science communication and community engagement be continued to incorporate community specific knowledge in future analyses. In addition, potential further data items and data sources are identified that could help refine the index of community vulnerability.

1 Introduction

The Murray-Darling Basin Authority (MDBA) has been established by the Water Act 2007 and has responsibility for developing and implementing the Murray-Darling Basin Plan. The Basin Plan is being developed to support the integrated management of the Basin's water resources. It will identify key environmental assets and ecosystem functions of water resources that must be protected. The plan will also identify risks to the condition or continued availability of Basin water resources and provide strategies for managing those risks.

The MDBA is seeking to understand and measure community vulnerability and sensitivity, as well as resilience and adaptive capacity, to reductions in water availability — due to a range of factors — for consumptive purposes across the Basin.

Objectives

The objectives of the project as specified in the brief are to:

- review and synthesise the current state of thinking around the concepts of community resilience, vulnerability and adaptive capacity with an emphasis on understanding the drivers of change in regional and rural communities especially in regard to reduction in water availability for consumptive purposes across the Basin
- identify suitable indicators of community vulnerability, resilience and adaptive capacity across the Basin
- measure and map the relative resilience/vulnerability of communities across the Murray-Darling Basin. This information will assist the MDBA in optimising the economic, social and environmental outcomes of the Basin Plan.

This project will complement other social and economic assessments already underway that aim to optimise the outcomes of the Basin Plan.

Approach

The concept of vulnerability is increasingly popular for describing the socio-economic circumstances of communities undergoing change. It is a complex concept, but at its core it is about identifying the potential strengths and weaknesses of a community. Community vulnerability is used in this report to describe the likelihood of communities in the Murray-Darling Basin (MDB) being susceptible to changes to water availability primarily to agriculture. The approach takes into account the inherent characteristics of the community, such as income, education levels, age structure and housing, as well as the likely sensitivity to changes in the availability of water.

This project uses the best available science in the area of indicator development for social change subject to the constraints imposed by time and resources to complete the project. An indicator approach is a well-known method for tracking changes in socio-economic circumstances of resource dependent communities. British Columbia Statistics for example developed socio-economic indicators for measuring regional hardship (BC Stats 1999). The Canadian Forest Service assessed vulnerability of forest-based communities (Parkins 2007; Johnstone 2007). The United States Department of Agriculture published a number of indicator studies on forest community resilience (USDA Pacific Northwest Research Station 2008; Donoghue and Sturtevant 2007). Indicators of vulnerability have been used successfully in these and other policy contexts to identify where policy interventions are best directed.

The method used to develop the indices of community vulnerability and adaptive capacity was developed in a collaboration between the Australian Bureau of Agricultural and Resource Economics – Bureau of Rural Sciences (ABARE–BRS) in the Australian Government Department of Agriculture, Fisheries and Forestry, and the Institute for Rural Futures (IRF) at the University of New England.

There are a number of issues in developing a single index of vulnerability. A disadvantage is that complex concepts are reduced to a single index that to some extent masks local contextual differences. The advantage lies in the ability to synthesise a large amount of socio-economic information across many diverse Basin communities into a single metric—a form that is easily digestible for decision-makers. Defining measures of community vulnerability is necessarily a balance between describing and representing the concept adequately and finding consistent data sets to populate the measures. This project has reviewed recent theory on vulnerability and indicator development, building on the work of Herreria et al. (2008) and Reeve et al. (2010), and has considered the available data sets.

A workshop was held on 22 February 2010 to discuss and review the methodology and initial outputs from this project. The workshop was attended by a range of stakeholders including MDBA staff, Basin Community Committee members, state jurisdictional representatives and the ABARE–BRS/IRF project team.

Structure of the report

The remainder of this report is organised into five sections. Section 2 reviews some of the key concepts in the literature and evaluates their applicability to this study. This section also draws together a conceptual framework that is used as a basis for developing the index for community vulnerability. Section 3 describes the methodology and computations used to operationalise the key concepts and choose appropriate data items to populate the index of community vulnerability. Mapped outputs of community vulnerability for the Murray-Darling Basin are presented in Section 4 with a short discussion how these outputs are to be understood. Section 5 outlines general ways that the index of community vulnerability could be used to inform policy discussions. Lastly, Section 6 recommends further work that could be done to strengthen the index of community vulnerability, for example incorporating local community knowledge, exploring indicator weightings and identifies useful further indicators and data sources.

2 Community responses to changes in water availability

This section presents a brief review of the literature relating to the concepts of vulnerability, adaptive capacity and resilience and describes a conceptual framework of the way in which the concepts are related. The review is selective rather than comprehensive, and comments on specific sources are relevant only to the current purpose. A more extensive review of a number of documents that are considered to be particularly relevant to the project is contained in appendix D.

The concepts reviewed here are currently the focus of active and fertile development within Australia and elsewhere, not only by researchers but also within government and community practice, so that useful insights and results are continuously emerging. There has been substantial growth in the literature in the past decade, especially as a result of the intense attention that has been given to the impacts of climate change. A feature of the literature, however, as noted by several authors (for example, Preston and Stafford-Smith 2009), has been the inconsistent and therefore confusing use of terminology. Apart from the terms used in this project, the literature refers to community robustness, vitality, viability, sustainability, health, and others. These apparent or near-synonyms have not always been used in ways that clearly convey their meaning. The concepts have, however, gradually been clarified, and the framework we present has general support in the most recent literature.

Communities of place, interest and identity

In this project, the emphasis is on communities of place, although it is acknowledged that communities of interest and identity are also relevant to some extent (refer to 'Communities' in the Glossary).

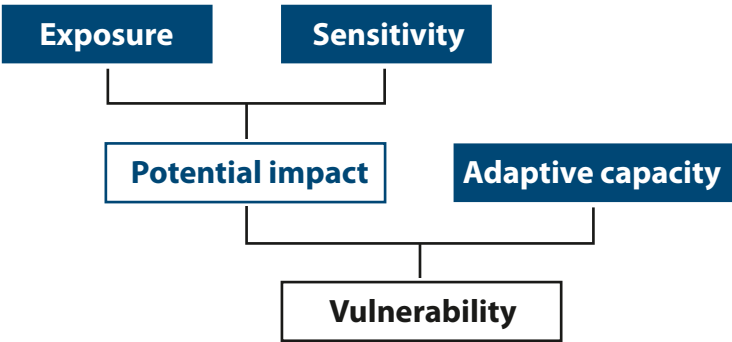
The relationships between individuals, households, businesses, and other organisations in rural areas are spatially diffuse; people interact over often wide areas and long distances. They may live, work, spend, and depend upon services in, a range of different places. Communities are complex, adaptive, socio-economic systems in continuous flux, and have varying capacities to absorb and respond to stress or shock. Therefore, the specification of a particular place-based community should not be taken to imply that the wellbeing of that community is solely determined by the conditions within it. This becomes important when interpreting the maps of sensitivity, adaptive capacity, and vulnerability: the geographic links between cause (factors influencing access to water for irrigation) and effects (impacts on economic and social wellbeing) may not be well captured within a given place-defined community.

Initial conceptual framework

The diagram or schematic we chose to illustrate the key concepts is that used by the Allen Consulting Group (2005), which in turn was based on Schröter (2004). This framework has since been used by other authors (for example, Smit and Wandel 2006), which suggests that it has been found useful and relevant. It relates the concepts of exposure, sensitivity, potential impact, adaptive capacity and vulnerability as depicted in figure 1.

Exposure is the amount of external stress or change a community is likely to be exposed to — for example, a 90 per cent reduction in water availability is a greater stress than a 10 per cent reduction.

1 Initial conceptual framework used in this project
(Allen Consulting Group 2005, based on Schröter 2004)



Sensitivity is a measure of how dependent a community is upon the thing that is changing — for example, a community that makes no use of water in a local river will be relatively unaffected by reductions in water yield/availability compared to a community that uses a lot of water.

Exposure and sensitivity together determine the magnitude of potential impact — for example, worse potential impact results from a community that is very dependent on water availability facing a large reduction in water availability. In the context of this study, where exposure has not been included, potential impact is equivalent to sensitivity.

Whether or not this potential impact will cause lasting loss and harm depends on the adaptive capacity of the community. Some communities may be able to adapt to the impacts by ‘reinventing’ themselves and so avoid loss and harm, whereas others may find it difficult to avoid social and economic damage. Whether a community is vulnerable or not depends on both the size of potential impacts and its adaptive capacity. Communities that are not vulnerable are often described as resilient, that is their adaptive capacity enables them to minimise the social and economic damage that might have resulted from potential impacts.

The literature stresses the fact that potential impacts, adaptive capacity and the resulting vulnerability are dependent both on the specific nature and scale of the impacting event, and on specific local history and conditions. In the MDB, the potential impacts will clearly depend on the scale and local incidence of reduced water availability. They will also depend on, for example, recent climatic conditions: irrigators who have experienced drought in recent years are likely to have reduced financial capacity to adapt to further cuts, unless rainfall returns to more 'normal' patterns. This suggests that the analysis of adaptive capacity and vulnerability should ideally be based on information about specific places.

Resilience

While resilience does not appear in the Schröter schematic, it is the subject of much discussion in the literature, where it has been used in several different ways, sometimes interchangeably with adaptive capacity or sensitivity. Maguire and Cartwright (2008) usefully clarify its meanings and interpretations. They note that it has been used in the psychology, ecology, environmental and human geography literature in three main ways: as recovery, as stability, and as transformation. From our reading of their paper, we believe that the sense that is most applicable to the current project is resilience as transformation. In terms of the Schröter diagram, it could therefore be seen as inversely related to vulnerability; that is, as a judgement made about the condition of a community after it has had the opportunity to adapt to a source of stress or shock.

The relationship between diversity and resilience also attracts attention in the literature. In general, the diversity of the local economic base (as distinct from the spread of employment across industry sectors) and the diversity of the stocks of local resources appear to enhance adaptive capacity and therefore resilience, resulting in lower vulnerability.

Adaptive capacity

There is considerable agreement in the literature that adaptive capacity is positively related to the endowments of resources available to the community. In recent years a common way of describing these resources is to classify them as various forms of capital, namely built, human, natural, social or financial capital (Burnside 2007; Ellis 2000; Nelson et al. 2005; Yohe and Tol 2002). The five capitals are as follows (Ellis 2000):

- *human capital* — labour and influences on the productivity of labour including education, skills and health
- *social capital* — claims on others by virtue of social relationship
- *natural capital* — land, water and biological resources
- *physical capital* — produced by economic activity including infrastructure, equipment and technology
- *financial capital* — savings and credit.

We have already noted that adaptive capacity appears to be positively related to the diversity of the resources (stocks of capital) available to a community. Another desirable characteristic of resources is that they should be mobile between uses, thereby increasing the flexibility with which they can be applied to new or alternative ends, and facilitating the adaptation of communities. In terms of human capital this means, for example, that education and skills should be transferable between jobs. Similarly, the specificity of built capital (harvesting machinery, irrigation infrastructure, buildings) affects its reallocation to other uses.

With respect to the mobility of human capital, however, while the movement of labour to another local job might be seen as a positive adaptation from the perspective of the community, moving to a job elsewhere would presumably not. This illustrates the tension between the adaptive capacity of people, and the adaptive capacity of places. On the other hand, some rural towns are benefiting from the in-migration of new residents who embody desirable human capital characteristics (skills, attitudes, motivations, networks), and who tend to be attracted by a mix of social, cultural and environmental amenities. These amenities could also be seen as forms of capital.

A wide variety of variables have been suggested as indicators of adaptive capacity and resilience (and therefore, inversely, of vulnerability). There has, however, been little testing of their predictive power to explain observed outcomes (that is, vulnerability) using cross-sectional and time series data. An exception to this is a recent paper in 1981 by Alasia, Bollman, Parkins and Reimer (2008), which analysed the power of 'stressor' and asset indicators to predict future vulnerability to declining population and employment in Canadian communities in 2001. More commonly, however, large area studies of adaptive capacity use recent data on proxy variables. One reason for this is that the intangible nature of the components of adaptive capacity makes it difficult to identify variables that might predict the outcomes in each sub-area. A second reason is the high cost of collecting primary data on context-specific variables for each sub-area. Another shortcoming of many studies to date is that the a priori justification for the choice of proxy variables, and of their weights, can be sketchy.

Walcott and Wolfe (2008) noted similar concerns regarding the existing theory and measurement of adaptive capacity. These were that:

- many indicators are based on intuitive assumptions of the attributes underlying adaptive capacity
- the accuracy with which any indicator measures the attribute
- the strength of the relationship between an indicator and its attribute, that is does a change in the indicator relate to a similar change in the attribute?
- some indicators are best gained from local qualitative studies
- matching the (spatial) scale of adaptive capacity to that of the driver of change is difficult
- there is a danger of conveying more precision than is warranted.

Vulnerability

There are several implications of the above issues for estimating adaptive capacity and vulnerability. Given the importance of taking into account both the nature and scale of the impacting event, and the context-specific nature of adaptive capacity and processes, the estimation of vulnerability would ideally involve the scoping of the logical linkages between exposure (in this case, changes in access to water), sensitivity, potential impacts, and adaptive responses, for each sub-area, and the analysis of the relationships between context-specific variables in each. The analysis would also take into account the ways in which Basin communities have been affected by, and responded to, periods of very low water availability over the past ten years.

In relation to the use of consumptive water in irrigated agriculture, the first stage in this scoping and analysis would be modelling the farm-level responses, such as changes in enterprise mix (for example, increased proportion of dry-land cropping), changes in technology (for example, the substitution of built capital for water), reduced debt-servicing capacity, and impacts on financial viability and property sale. Importantly, responses at the farm level will include water trading, which has the potential to have major effects on the scale and geographic distribution of economic and social impacts. That is, the task of adaptation, and the ultimate vulnerability of particular sub-areas, could be intimately affected by the spatial pattern of water trade. ABARE-BRS modelling may generate important information on the spatial pattern of farm-level adaptation, including water trade. While irrigated agriculture accounts for the highest volume of water use, the potential impacts on urban water users, recreational users (for example, fishing and tourism), and 'stock and domestic' use on farms should also be scoped and analysed.

The next stage of such an analysis would involve identification of the potential 'flow-on' effects, both in the local community and in other communities linked by trade and other ways to irrigated agriculture. Next, the analysis would attempt to identify the potential adaptive responses undertaken at several levels: on farm, in associated industries (input suppliers, output processors, transport and handling, providers), in businesses serving farm households, in other industries such as mining, tourism, the service sector, aged care services, and in the community and non-profit sector. The next stage would be to predict, estimate, or (in the absence of such models) make informed judgements about the likely success of the adaptive responses, based on an assessment of the resources (or capitals) available to the community. Finally, judgements would be made regarding the remaining negative impacts not dealt with by the local adaptive responses: the vulnerability of the community. These remaining impacts may be targets for adjustment programs.

3 Developing the index of community vulnerability

It is useful to consider the previously independent development of indices of adaptive capacity, vulnerability and resilience from the IRF and ABARE–BRS.

The IRF has undertaken a number of studies of community vulnerability in recent years, including:

- vulnerability to climate change of the NSW Central Coast and Hunter regions (Brunckhorst et al. 2009), and
- vulnerability of communities in the Condamine-Balonne, Macintyre Brook and Border Rivers regions to reductions in water availability.

These studies have employed, and further refined, a methodology that uses a statistical technique called Principle Component Analysis (PCA). PCA is a means of identifying relatively independent groups of Census indicators so that a reduced number of relatively uncorrelated sub-indices can be derived. The application of PCA to demographic data was first undertaken by the Australian Bureau of Statistics for the 1971 Census, and expanded for the 1986 and subsequent Censuses (for details, see ABS 1998). The method has also been applied successfully to the specific issue of natural resource availability (Fenton 1998) and to develop measures of socio-economic disadvantage (Vinson 1999). The method has subsequently been used in this study to identify a reduced number of composite indicators for community vulnerability to changes in water availability.

The BRS undertook a national assessment of community dependence on water and social resilience in 2007 as part of the Water 2010: National Assessment of Community Dependence on Water and Social Resilience project (Herreria et al. 2008). The project demonstrated how social theory can be used as a guide to help identify a range of national data sets to help unravel the complex relationships between agricultural communities and the resources they depend on to maintain their livelihoods. Indicators of community dependence on water and social resilience were used to develop a composite index of susceptibility to changes in water access which were then spatially mapped at national and regional scales.

These measures provided a useful starting point to help advance our understanding of the intersection between biophysical phenomena and the social circumstances of agriculturally dependent communities. However, it was noted that the selection of indicators would benefit from further empirical and statistical validation of how well the indicators explained the constructs of interest. For this purpose, the measures used in the Water 2010 project have been re-visited and statistically validated through the collaboration with the Institute for Rural Futures.

Choosing measures of community vulnerability

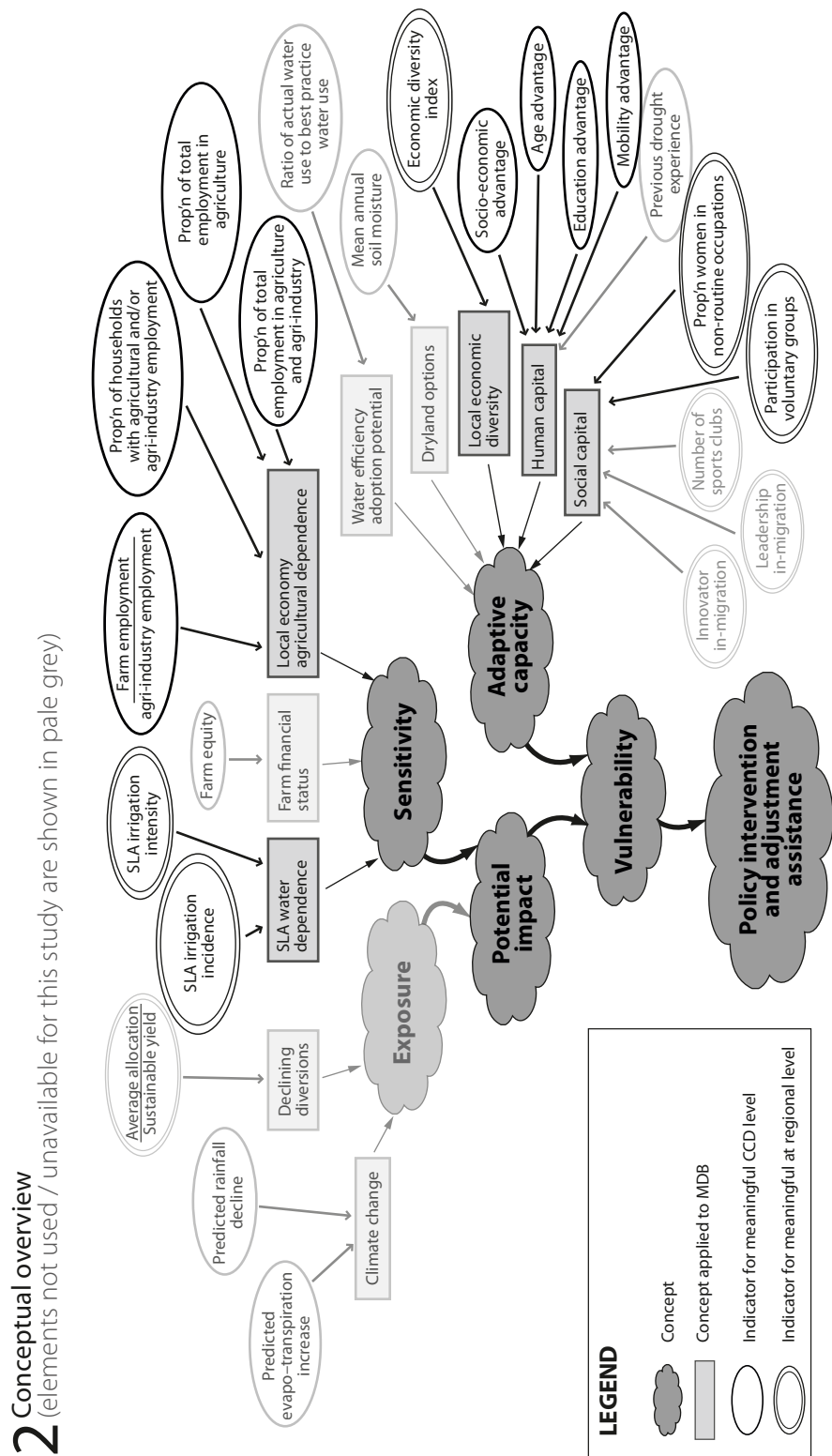
The conceptual framework introduced in the previous section was used to guide indicator selection in studies of vulnerability and adaptation to climate change, depicted in figure 1. These concepts were applied to the specific circumstance of possible reductions in the availability of water for diversion to irrigation in the Murray–Darling Basin (figure 2). Numerical measures were developed of the various concepts that can be mapped at a Basin-wide scale. These numerical measures are linear combinations of particular data items available from the Australian Bureau of Statistics (ABS) Population Census for 2006 and from a 2008 publication by ABS on water use in agriculture in Australia. The conceptual overview is represented diagrammatically in figure 2, and explained further below.

The rectangular boxes outside the concept boxes in figure 2 represent the application of the concept to the specific context of reductions in water availability in the Basin. Subject to the constraints of time and data availability for this study, it has been possible to operationalise five of these as numerical sub-indices: SLA water dependence and local economy agricultural dependence (which jointly determine sensitivity), and local economic diversity (see section below), human capital and social capital, which jointly determine adaptive capacity. Figure 2 also shows in pale grey other potential sub-indices which may be possible with further investigation of secondary data sources, or primary data gathering.

The Economic Diversity Index (EDI; or Hachmann Index) provides an indication of the vulnerability of communities to changes in economic circumstances (Moore 2001; Pembina Institute 2005). In theory, a community with a relatively diverse local economy is better able to adjust to changes that have a significant impact on a particular sector or sectors of employment, as employment is available in a range of sectors. In a less diverse local economy, the community may be especially sensitive to change in certain industry sectors. For example, a community in which a large proportion of the workforce is employed either in agriculture or in related service and processing operations is particularly sensitive to events that will have a negative impact on the quantity of agricultural goods the regions are able to produce (for example, drought, loss of irrigation water, increasing input costs, labour shortages etc).

The elliptical boxes on the far edge of the rectangular boxes in figure 2 refer to the various indicators which have been used to calculate the sub-indices. As before, potential indicators which have not been included due to constraints of time and data availability are shown in pale grey.

For local economy, agricultural dependence and human capital, there were many potential indicators which, according to the literature on community vulnerability and adaptive capacity, might be chosen as appropriate measures. In these two cases, principal components analysis was used to examine the relationships among the potential measures and choose a parsimonious (that is less numerous) set of indicators that were relatively uncorrelated.



Spatial considerations in indicator selection

An issue to be considered when embarking on a study of a specific region, is whether or not to use indices derived previously by analysis of a much larger region. The Australian Bureau of Statistics Socio-Economic Indexes for Areas (SEIFA) and Fenton's (1998) Community Sensitivity Indices for example were derived using PCA with demographic data at the Census Collector District level for the whole of Australia. The study by Vinson (1999) used postcode level data for New South Wales and Victoria. The use of indices derived from larger regions than the region of interest have the advantage of enabling comparison beyond the specific region of interest. While such comparisons may be relevant in some policy circumstances, for water resource management within the Murray–Darling Basin, the ability to draw comparisons outside the Basin is likely to have little policy relevance.

On the other hand, analysis of data drawn only from the region of interest has the advantage of deriving indices that may reflect the unique circumstances of the region. This is a particularly important consideration when Principle Component Analysis (PCA) is the method of analysis. The application of indices derived from the analysis of larger regions assumes that the same correlational relationships between demographic variables occur in the larger region as in the smaller region of interest. To the authors' knowledge, this assumption has not been tested.

Certainly it is possible to point to plausible examples where this assumption will not be met. For example, in mining towns in north-west Western Australia, high incomes may be associated with single households in rented accommodation, whereas these households in some inner city areas and some coastal retirement communities might be more likely to be associated with lower incomes. PCA on data from a combination of such regions could find that income was uncorrelated with household size or tenure, and so allocate income to one component and household size and/or tenure to another component. However, PCA applied to just a single one of the three regional examples would be more likely to place income, household size and tenure in a single component. For these reasons, PCA solutions are likely to be scale-dependent. Components that are uncorrelated in larger regions may well be correlated in small regions.

Given that the aim of using PCA is to identify underlying components or factors that make a unique contribution to community vulnerability, and given that an understanding of these factors contributes to the development of adjustment policies, the considerations above suggest that there is considerable merit in confining the derivation of indices to the analysis of data drawn from within the Basin.

Data sources

The secondary data for this study came from the sources detailed in table 1. A list of Census Collection Districts (CCDs) were obtained from the ABS, based on previous work conducted by the ABS in which CCDs were concorded with the boundary of the MDB. A final list of 4,600 CCDs was included in the data set.

Relevant data items were extracted from the Census DataPack for each CCD in the Basin concordance using the Excel lookup function, and aggregated into a single spreadsheet. Each indicator was then calculated from the data items, and the indicators exported for further analysis in the SPSS software package. Calculation included missing value substitution where appropriate (see Section 5).

1 List of ABS secondary data sources used to construct indicators

data source	catalogue/identifier no.	scale
2006 Census DataPacks	2069.0.30.001	CCD
2006 Community Profile Series—Basic Community Profile	2001.0	CCD
Water Use on Australian Farms, 2005–06	46180DO001_200506	SLA
2006 Census employment and household data relating to employment in ANZSIC Division A Subgroup 01 (Agriculture) and employment in Division C Subdivision 21 (Food Beverage and Tobacco)	N/A—data supplied by ABS direct	CCD

CCD=Census Collection District, SLA=Statistical Local Area.

The 2008 publication by ABS on water use in agriculture in Australia. provided five indicators at the Statistical Local Area (SLA) level:

- the number of agricultural businesses
- the number of agricultural businesses irrigating
- the area of agricultural holdings ('000 hectares)
- the area irrigated ('000 hectares)
- the volume of water applied (megalitres, MI).

This data has a number of shortcomings. Firstly, it comes from a year when drought conditions occurred in many parts of the Basin and, consequently, the amount of irrigation may be less than a 'normal' year. Secondly, where the amount of irrigation in an SLA is not large, estimates are either not given for confidentiality reasons, or have large relative standard errors. Time constraints on the project have precluded investigation or compilation of data from any alternative sources.

Calculation of initial indicators

The data items and indicators initially assembled as potential constituents of a vulnerability index are listed in table 2. This choice of potential indicators was guided by a review of the literature (summarised in Section 1), which identified which phenomena appear to influence community vulnerability and adaptive capacity.

2 List of indicators, the data items from which they were derived and the scale at which data was available

indicator	ABS data used	scale
Adaptive capacity related		
% 65 over	Total persons aged 65 and over / total persons	CCD
% People <5 years old	Total persons aged 0–4 / total persons	CCD
% Population aged 15–24	15–24 year olds as proportion of total population	CCD
% Couple families	Total couples without children + total couples with children / total families	CCD
% Lone households 65+ years old	Total lone householders aged 65+ / total persons in occupied private dwellings	CCD
% Lone person households	Total one persons households / total occupied dwellings	CCD
% One parent	Total single parent families / total families	CCD
% Separated and divorced	Total separated + total divorced / total persons 15+	CCD
% Single parent with children <15 only	Total single parent families with children < 15 years old / total families	CCD
% Single persons 15+	Total persons not married / total persons 15+	CCD
% Single persons 15–64	Persons between 15 and 64 not married as proportion of total persons aged 15–64	CCD
Average no. persons per household	Average household size	CCD
% 'ethnicity' (language spoken at home not English)	Total other language spoken at home / total persons	CCD
% Born overseas	Country of birth outside Australia / total persons	CCD
% Over 15 no qualifications	% of persons 15+ with no qualifications: certificate, diploma, undergraduate degree, postgraduate degree	CCD
% Persons 15+ with management or commerce qualification	Total non-school field of study management, commerce etc / total persons 15+	CCD
% Graduates	Total bachelor degree + total graduate diploma/certificate + total postgraduate degree / total persons 15+	CCD
Left school before Year 10	Total year 9 leavers + total year 8 leavers + total did not attend school / total persons 15+	CCD
Percentage of persons aged 15–24 attending an educational institution	Full or part time technical college or university students as proportion of persons aged 15–24—Water 2010 'Youth educational engagement'	CCD
Household weekly income less than \$349	% of houses with income between \$0 and \$349 per week – 2006 readjustment of Water 2010 indicator 'Low income households'	CCD
Income / mortgage differential	(Median household weekly income * 52 / 12) – median monthly housing loan repayment	CCD

continued...

2 List of indicators, the data items from which they were derived and the scale at which data was available continued

indicator	ABS data used	scale
Median household income as fraction of Australian median	Median household income as proportion of the 2006 Australian median (\$1026.80)	CCD
% 'Need for assistance' Dependency ratio	Total need for assistance (disability) / total persons Persons aged <15 and >64 as a proportion of persons aged between 15 and 64	CCD CCD
% Voluntary work	Total volunteers / total persons 15+	CCD
% Dwellings no vehicle	No. Dwellings with no vehicle / total dwellings	CCD
% Of population indigenous	Total indigenous persons / total persons	CCD
% Visitors	Total visitors / total persons	CCD
% House 'being purchased'	Dwellings being purchased / total occupied private dwellings	CCD
% Dwellings rented	Rented properties / total dwelling structures	CCD
Median monthly housing loan repayment as a fraction of the Australian median	Median monthly house loan repayment as proportion of the 2006 Australian median (\$1300)	CCD
Median weekly rent as a fraction of the Australian median	Median weekly rent as proportion of the 2006 Australian median (\$190)	CCD
% Households using the internet	Total households with internet / total occupied private dwellings	CCD
% Of internet users with broadband	Total households with broadband / total occupied private dwellings	CCD
% Different address to 1 yr ago	Lived at different address 1 year ago / lived at different address 1 year ago + lived at same address 1 year ago	CCD
% Different address to 5 yrs ago	Lived at different address 5 years ago / lived at different address 5 years ago + lived at same address 5 years ago	CCD
% new residents (<= 1 year residing in SLA)	Persons living overseas or in different CCD one year ago / total persons > 1 year old	CCD
% Employed in public sector	Total employed in public admin sector / total employed persons 15+	CCD
% Labourer (employed 15+)	Total labourers / total employed persons 15+	CCD
% 'Tradespersons' (technicians and trades workers)	Total technicians and trade workers / total employed persons	CCD
Women in non-routine occupations	Female managers + female professionals + female technicians + female community and personal / total female employed persons	CCD
Economic Diversity Index	Diversity of local economy relative to Australian/MDB economy, calculated using employment by sector data	CCD
Total unemployment	Total unemployed / total labour force	CCD
Unemployment 15–24	Unemployed persons aged 15–24 / labour force aged 15–24	CCD
Unemployment 20–64	Unemployed persons aged 20–64 / labour force aged 20–64	CCD

continued...

2 List of indicators, the data items from which they were derived and the scale at which data was available continued

indicator	ABS data used	scale
Sensitivity related (local economy agricultural dependence)		
% Persons 15+ with agriculture or env. Qualification	Total non-school field of study agriculture, environmental etc / total persons 15+	CCD
% work in Agriculture	Total working in agriculture/mining/forestry sector / total employed persons 15+	CCD
Proportion of households with agricultural and/or agri-industry employment	Households with at least one member employed in ANZSIC Division A Subgroup 01 (Agriculture) and Division C Subdivision 21 (Food Beverage and Tobacco) as % of all households	CCD
Ratio of agriculture and agri-industry employment to total employment	Ratio of persons employed in ANZSIC Division A Subgroup 01 (Agriculture) and Subgroup 02 Minor subgroup 05 to total employment	CCD
Ratio of employment in agricultural and downstream agri-industries to agricultural establishments	Ratio of persons employed in ANZSIC Division A Subgroup 01 (Agriculture) and Division C Subdivision 21 (Food Beverage and Tobacco) to number of farm establishments with an estimated value of agricultural operation (EVAO) greater than \$5,000	CCD
Ratio of employment in agriculture to downstream agri-industries	Ratio of persons employed in ANZSIC Division A Subgroup 01 (Agriculture) to persons employed in Division C Subdivision 21 (Food Beverage and Tobacco)	CCD
Sensitivity related (Irrigation water dependence)		
SLA irrigation incidence	% of agricultural businesses irrigating	SLA
SLA irrigation intensity	Megalitres of water applied divided by number of irrigated farm establishments	SLA

CCD=Census Collection District, SLA=Statistical Local Area.

All the indicators, with the exception of SLA irrigation incidence and SLA irrigation intensity were available at CCD level. The SLA values for these two water dependence indicators were assigned to the constituent CCDs in each SLA. However ‘SLA’ has been retained in the name of the indicator to emphasise it is a SLA level indicator that applies to a region around and including a CCD, and not just the CCD itself. This approach is less than ideal, but was necessary if the vulnerability index was to take account of water dependence.

Economic Diversity Index (EDI)

The EDI was calculated for each CCD from ‘Industry of Employment’ data available from the ABS Basic Community Profiles. The EDI compares the proportion of the workforce employed in each sector to that of a larger geographic unit (in the case of this project, the entire Murray-Darling Basin). The closer an EDI score for a CCD is to 1.0, the closer its employment distribution is to the Basin as a whole, and the more diverse its economy is assumed to be. Conversely, a lower EDI score suggests a less diverse economy. Further details (including the method by which the index is calculated) are available in Moore (2001).

Data quality checks

Extreme values and distributions

The extreme values of all indicators were checked against the corresponding data items to ensure miscalculations had not occurred. Google Street View was used where available to check that there were plausible explanations for extreme values of indicators. All extreme values were found to have plausible explanations, for example, high values of public sector employment occurred where CCDs were largely taken up by military establishments, high values of the proportion of over 65s occurred where CCDs contained large retirement villages.

The histograms of indicators that were to be used in PCA were also checked for excessive departures from a normal distribution. The distributions of SLA irrigation incidence and SLA irrigation intensity, at SLA level, were found to be too highly skewed and disjointed to consider including in PCA. Given that there are only two available indicators for the SLA water dependence, PCA is not required to choose a smaller set of composite indicators. All other indicator distributions were considered suitable for inclusion in PCA.

Missing values

A number of indicators, by their nature, were prone to creating considerable numbers of missing values. For example, unemployment in the 15 to 24 age group is a missing value for those CCDs where there are no people in this age group. Median weekly rent as a fraction of the Australian median is a missing value for those CCDs where there are no households in rented housing. If the mapping of a vulnerability index across the Basin was restricted to only those CCDs with non-missing values for all indicators, around one half of CCDs would be omitted from the map.

Therefore it is preferable to introduce some missing value substitutions where this can be done without compromising the validity of the vulnerability index. The substitutions made are listed in table 3, together with the justification for the substitution.

In summary, the main reasons for missing values are:

- the CCD or SLA lies largely outside of the Basin boundary, or
- the CCDs are sparsely populated and the ABS did not make the data available.

It should be noted that while every effort has been made with the substitutions and imputations described in table 3 to provide plausible estimates where data is missing, there are two main sources of uncertainty that may affect these estimates. Firstly, many of the numbers provided by ABS have high relative standard errors. Secondly, areas are rounded to the nearest 1000 hectares and water volumes are rounded to the nearest megalitre. Due to this rounding, some zeros in the data may represent true zeros, for example, no land was irrigated or no water applied in the year to which the data applies, and some zeros may represent small areas or volumes rounded down to zero, for example, 499 hectares irrigated would be given as 0 hectares, and 499 kilolitres would be given as 0 megalitres.

While these uncertainties can be noted, it is also the case that they generally apply to SLAs with relatively little irrigation. Consequently, the estimates of SLA water dependence should be more accurate for the SLAs that have a high water dependence. These are the SLAs where reduction in the availability of water is a matter of some importance.

3 Missing value substitutions and justification

indicator	frequency of missing value	substitution	justification
% unemployment in 15–24 age group	3.6% of CCDs had a zero workforce aged 15–24	Mean	It is assumed that, had there been people in this age group in the CCD, the unemployment would be the same as the mean CCDs where there were people in this age group.
Median weekly rent as a fraction of the Australian median	10.4% of CCDs had no households in rented accommodation	0	This indicator is a proxy for disposable income. From this perspective, not renting at all is equivalent to renting for zero rent.
Median monthly housing loan repayment as a fraction of the Australian median	2.2% of CCDs had no households making mortgage repayments	0	This indicator is a proxy for disposable income. From this perspective, owning one's home is equivalent to having a home loan with a zero mortgage repayment.
SLA irrigation incidence (number of farm businesses irrigating as a fraction of the number of farm businesses)	29.7% of SLAs have no agricultural businesses	SLA irrigation incidence is 0%	From the perspective of the number of farm businesses irrigating, zero farm businesses is equivalent to zero farm businesses irrigating. Replace division by zero error with zero.
	2.8% of SLAs have farm businesses, the number irrigating is not given, but the volume of water applied is given	SLA irrigation incidence is 0.001 * volume applied (MI) / number of agricultural businesses	Where both number of irrigating businesses and water volume are non-missing, the r2 for the correlation is 0.53. Use water volume to estimate number of irrigating businesses.
	1.5% of SLAs have only 1 agricultural business, and number of businesses irrigating is not given	SLA irrigation incidence is 100%	Some SLAs with one agricultural business have zero for the number of businesses irrigating. Assume where number irrigating is missing, it is 1, which gives an SLA irrigation incidence of 100%.
	0.9% of SLAs have three or more agricultural businesses and the number of businesses irrigating is not given, but a non-zero irrigated area is given	SLA irrigation incidence is 1.5 / number of agricultural businesses * 100	The smallest number of irrigating businesses in a SLA where ABS has provided a number is 3. If there are zero businesses irrigating ABS provides a zero. Therefore the missing values for number of business irrigating must be a 1 or a 2. Substitute the mean of 1.5

continued...

3 Missing value substitutions and justification

continued

indicator	frequency of missing value	substitution	justification
SLA irrigation intensity (volume of water applied divided by number of irrigating businesses)	11.8% of SLAs have one or more agricultural businesses, all with non-zero agricultural area, but neither the number of businesses irrigating, nor the irrigated area nor the water volume is given	SLA irrigation incidence is $1.5 / \text{number of agricultural businesses} * 100$	The smallest number of irrigating businesses in a SLA where ABS has provided a number is 3. If there are zero businesses irrigating ABS provides a zero. Therefore the missing values for number of business irrigating must be a 1 or a 2. Substitute the mean of 1.5
	29.7% of SLAs have no agricultural businesses	SLA irrigation intensity is 0	From the perspective of irrigation intensity, zero farm businesses is equivalent to zero irrigation intensity. Replace division by zero error with zero.
	4.0% of SLAs for which the number of farm businesses is given by ABS have zero businesses irrigating	SLA irrigation intensity is 0	All the SLAs with zero farm businesses irrigating also have zero volume of water applied. Replace division by zero error with zero.
	2.8% of SLAs have farm businesses, the number irrigating is not given, but the volume of water applied is given	SLA irrigation intensity is 1000	The number of businesses was estimated using the regression relationship with water applied (see six rows above in this table). Use the inverse of the coefficient of 0.001 as the irrigation intensity.
	5.3% of SLAs have farm businesses irrigating but the water volume is not given. However, the area irrigated is given.	SLA irrigation intensity = $4502 * \text{irrigated area ('000ha)} / \text{no of irrigating businesses}$	Where both irrigated area and water volume are non-missing, the r^2 for the correlation is 0.95. Use irrigated area to estimate water volume.
	14.9% of SLAs have farm businesses given or estimated as irrigating, but no irrigated area nor water volume is given.	SLA irrigation intensity = $9 / \text{no of irrigating businesses}$	The smallest water volume in a SLA where ABS has provided a number is 18ML. If there is zero water volume, ABS provides a zero. Therefore the missing values for the water volume must lie between 0.5ML and 17.5ML. Substitute the mean of 9ML.

Multivariate outliers

All principal components analyses carried out were preceded by identification and removal of CCDs that were multivariate outliers, using the criterion: Mahalanobis distance > χ^2 for $p=0.001$, d.f. = number of variables (Taberchnick and Fidell 2007). Having used PCA to identify groups of relatively uncorrelated indicators, that is sub-indices, the outlier CCDs were returned to the data set for calculating the scores of individual CCDs on these sub-indices.

Principal Components Analysis (PCA)

Principal components analysis was used where there were a large number of potential indicators that could be regarded as having an influence on the main conceptual components of vulnerability as shown in figure 1. Of the list shown in table 2 some 39 indicators could be regarded as having an influence on the level of human capital, and five indicators upon the level of agricultural dependence. PCA was used with each of these two sets of indicators.

In all cases, PCA was carried out on the correlation matrix, with orthogonal varimax rotation to aid interpretation of the components. The software used was SPSS.

An initial analysis was undertaken with the number of components set by the criterion that their eigenvalues be less than one. The number of components to interpret was chosen by inspection of the scree plot, the interpretability of the components, and the presence of components with loading on only a small number of variables. Where these criteria permitted the possibility of several different solutions, each with a different number of components, each solution was examined and the solution providing the most readily interpreted components chosen. A conservative loading threshold of 0.7 was set for interpretation of components.

PCA on human capital indicators

Following the procedure and criteria described above, a four component solution was chosen. This suggested that just under 63 per cent of the variance in the 39 Census indicators was represented in the first four components (table 4).

4 Variance and cumulative variance explained by components

component	% of variance	cumulative %
1	31.329	31.329
2	19.431	50.761
3	7.608	58.368
4	4.603	62.971

Using the rotated component matrix (table 5), these components were interpreted as educational advantage, socio-economic advantage, age advantage and mobility advantage.

PCA on the agricultural dependence indicators

PCA applied to the five agricultural dependence indicators suggested a one component solution, with the component representing 84 per cent of the variance in the five indicators. The four indicators loading on the first component all had loadings greater than 0.78, which suggested that agricultural dependence could be represented with a simple unweighted sum of these four indicators. The four indicators were:

- percentage employed in agriculture
- ratio of agriculture and agri-industry employment to total employment
- agricultural and downstream agri- industries households
- ratio of employment in agriculture to downstream agri- industries.

5 Rotated component matrix for human capital Census indicators

	component loadings			
	educational advantage	socio-economic advantage	age advantage	mobility advantage
	1	2	3	4
% Graduates	0.842	-0.264		0.103
Median weekly rent as a fraction of the Australian median	0.835	0.296		
% Employed in the public sector	0.828			
% Over 15 with no qualifications	-0.794	0.319	0.195	
Median household income as % of the Australian median	0.783	-0.248	-0.412	-0.204
Monthly income / mortgage differential	0.749	-0.214	-0.403	-0.248
% Single parent families		0.833	0.111	0.331
% Couple families		-0.818	-0.117	-0.369
% Single parent families with children under 15		0.816		0.283
Unemployment Rate (%)	-0.222	0.752	0.144	
% Aged 65 +	-0.175		0.902	
% Lone households 65+	-0.119	0.194	0.826	0.209
Average household size	0.116	-0.168	-0.739	-0.493
% Lone person households	-0.127	0.256	0.703	0.528
% Dwellings rented		0.387		0.777
% Living at a different address one year ago	0.237	0.287		0.716

Note: Cross-loadings between 0.1 and -0.1 are shown as a blank cell for the same reason.

Reduced set of indicators

The outcome from the PCA is a reduced set of indicators which provide a means of placing numerical estimates on the concepts shown in figure 2. The reduced set of indicators is summarised in table A1 and table A2 (appendix A).

Calculation of sub-indices and indices

The indices and sub-indices were calculated consistently with the relationships between the concepts and their application shown in figure 2. At the base of the hierarchy of calculations is the calculation of educational, socio-economic, age and mobility advantage from their constituent Census indicators as shown in table 6. This was done by the method of improper component scores, which involves multiplying the standardised values of each of the constituent Census indicators by the component score coefficients yielded by the PCA, and adding up the resulting products. For consistency with the capabilities of the MCAS-S

package, which is to be used to map the sub-indices and indices, values of Census indicators standardised to a range of zero to one were used instead of the usual z-scores. In a test of using both methods of standardisation of Census indicator values, it was found the resultant improper component scores for the two methods of standardisation were highly correlated. Improper component scores, which are based only on the Census indicators used in the interpretation of components, were used in preference to proper component scores which use all the Census indicators, so that the scores were a better measure of the concept represented by each component. For some components, it was necessary to take the negative value of the component score coefficients to ensure that the scores ran in the same direction as the concept they represented.

The method of improper component scores, described above, was used to calculate scores for each CCD for the educational advantage, socio-economic advantage, age advantage and mobility advantage sub-indices. These scores were then added unweighted to form the human capital sub-index.

- The social capital sub-index was calculated by adding the unweighted standardised scores for percentage of persons in voluntary work and percentage of female workforce in non-routine occupations.
- The Economic Diversity Index (EDI; or Hachmann Index) was calculated from ABS employment by industry sector data using the method described by Moore (2001).
- The adaptive capacity index was calculated as the unweighted sum of the standardised values of the human capital, social capital and economic diversity sub-indices.
- The agricultural dependence sub-index was calculated as the unweighted sum of the standardised values of the Census indicators listed in table A1.
- The SLA water dependence sub-index was calculated as the unweighted sum of the standardised values of SLA irrigation incidence and SLA irrigation intensity.
- The sensitivity sub-index was calculated as the unweighted sum of the agricultural dependence and the SLA water dependence.
- The potential impact sub-index is equivalent to the sensitivity sub-index, since no measures of exposure have been included in this project, for the reasons described in Section 2.
- The vulnerability index was calculated by subtracting the standardised value of the adaptive capacity sub-index from the standardised value of the potential impact sub-index.

This hierarchy of calculations reflects the relationships shown in figure 2.

Weightings

Weightings on indicators reflect assumptions about the relative importance of underlying factors that contribute to a community's vulnerability. Neutral weightings (that is of 1) were used in all of the community vulnerability indices and sub-indices in this project, except where the PCA solution specified the weightings for the adaptive capacity indicators.

6 Degree of influence of sub-indicators on the final community vulnerability index

10% increase from the mean in:	resultant change in vulnerability index (%)
SLA irrigation incidence	1.84
SLA irrigation intensity	0.37
Farm employment / agri-industry employment	0.26
Proportion of households with agriculture or agri-industry employment	0.44
Proportion of total employment in agriculture	0.60
Proportion of total employment in agriculture and agri-industry	0.71
Economic diversity index	-5.76
Socioeconomic advantage	-1.96
Age advantage	-1.70
Education advantage	-0.84
Mobility advantage	-0.51
Proportion of women in non-routine occupations	-1.87
Participation in voluntary groups	-1.58

Sensitivity analysis

A simple sensitivity analysis was undertaken to determine what indicators and sub-indicators have the most influence on the final community vulnerability index. The sensitivity analysis considered the effect on the community vulnerability index of a 10 per cent departure from the mean value of each constituent indicator (summarised in table 6).

The values are as expected from a consideration of the hierarchy of calculations described in the previous section. The economic diversity index has the most influence on the vulnerability index because it is a single sub-index that enters the calculation relatively high in the hierarchy. Hence its influence is diluted the least by the process of standardising and addition that occurs in the hierarchy of calculations.

4 Interpreting the index of community vulnerability

Indices mapped at a Basin scale

The following section provides analysis of the project outputs in three different ways. Firstly, a high level presentation of the indices of community vulnerability, sensitivity and adaptive capacity at the Basin scale. Secondly, an example of a regionally focused exploration of community vulnerability is presented. Thirdly, it discusses a 'two-way' analysis of adaptive capacity and sensitivity at the Basin scale.

Index of community vulnerability—Basin scale

A map of the final index of community vulnerability for the Murray–Darling Basin is shown in map 1, appendix B. A significant proportion of Basin communities exhibit only a low to moderate level of vulnerability. These communities in general have low levels of sensitivity and higher levels of adaptive capacity which lessen their vulnerability to changes in access to water for consumptive purposes.

However, there are a number of communities scattered across the Basin that exhibit a high to very high degree of vulnerability. It can be seen that there are several areas with relatively very high community vulnerability (in red), including in the Border Rivers, Gwydir, Namoi and Macquarie–Castlereagh Basin Plan Regions in the northeast of the Basin and in the Lachlan, Murrumbidgee and Murray Basin Plan Regions in the southern Basin. Communities in these areas have a combination of higher sensitivity to changes in water availability (that is very high dependence on water for agriculture and high agri-industry employment) and limited levels of adaptive capacity (that is low levels of human capital, social capital and economic diversity) in comparison to other areas in the Basin. This means that communities in these areas are more likely to be impacted by changes in water availability.

Sensitivity—Basin scale

The degree of dependence of communities on water for agriculture and on employment in downstream agricultural processing industries is represented in the map of sensitivity (map 2, appendix B), across the whole Murray–Darling Basin. A significant proportion of communities in the Basin exhibit low to very low sensitivity. The low level of sensitivity of these communities is due to the fact that they are outside of the major irrigation areas and/or have a low proportion of persons employed in agricultural related industries.

Sensitivity is highest for communities in the northeast of the Basin within the Basin Plan Regions of Condamine–Balonne, Moonie, Border Rivers, and Gwydir and in the southern Basin

communities within the Basin Plan regions of Lachlan, Murrumbidgee, Murray, Wimmera-Avoca and Loddon-Campaspe. This means that these areas have a combination of a higher dependence on water for agriculture at the farm level and a higher proportion of people in the community who are employed in agriculture and downstream agri-industries, such as food processing plants, abattoirs, canneries, etc compared with other areas. These areas have a very direct connection with irrigated agriculture.

Adaptive capacity—Basin scale

The degree of adaptive capacity — the resources and abilities that communities can draw upon — is represented in map 3, appendix B. Varying levels of community adaptive capacity are dispersed across the Basin and there does not appear to be a general pattern.

Adaptive capacity is lowest for communities in the northeast of the Basin within the Basin Plan regions of Border-Rivers and Condamine-Balonne, central west of the Basin within the Basin Plan regions of Barwon-Darling and the western and south western areas of the Basin within the Basin Plan regions of Paroo, Lower Darling, Murray and Eastern Mt Lofty Ranges.

These communities have lower adaptive capacity, meaning that they are likely to have fewer resources and a lower ability to respond to changes in their circumstances. On its own, adaptive capacity is not directly connected with a dependence on irrigation water or agriculture. Therefore, areas which come up with low adaptive capacity are those that show signs of general social and economic disadvantage.

While sensitivity is a measure of farm and agricultural dependence on water, the adaptive capacity measure is an indication of the wider community's general vulnerability to stressors, for example, climate change, changes in rainfall reliability, diversion limits or other socio-economic changes.

Regional example of community vulnerability—Coleambally and The Rock

The output maps can be viewed at a finer spatial scale to identify which communities within the Basin are more vulnerable, thus providing a gateway to further in-depth exploration of the factors contributing to vulnerability. Map 4 provides a spatial output of community vulnerability overlayed onto Google Earth adding finer spatial orientation. This regional example focuses on the Murrumbidgee Basin Plan Region encompassing a large section of the Riverina and part of the Murrumbidgee Irrigation Area (MIA).

Map 4 illustrates a contrast between the communities to the west that exhibit very high vulnerability (red) and the communities further east, which exhibit lower vulnerability (blue). The main differentiating variable between the eastern and western communities is their degree of sensitivity, and more specifically, their reliance on irrigated water for agriculture. The degree of adaptive capacity also has a significant influence.

The town of Coleambally (that is the CCD that comprises its Urban Centre/Locality (UC/L)) exhibits a high to very high degree of vulnerability. This is because of a combination of high to very high sensitivity and low adaptive capacity relative to other areas in the Basin. In contrast, the CCD that comprises the UC/L of The Rock to the southeast of Coleambally, exhibits only low vulnerability. This difference arises because The Rock exhibits a low to very low level of sensitivity and a high level of adaptive capacity relative to other areas in the Basin. At this spatial scale an in-depth analysis of the sub-indices of adaptive capacity and sensitivity can illustrate which communities are most vulnerable and why.

The differences can be illustrated in a comparison of the two towns of Coleambally and The Rock. The driving influences that determine their differing degrees of vulnerability are summarised in table 7. Coleambally's high degree of vulnerability is mostly due to its very high level of sensitivity driven by the high number of agricultural establishments that irrigate (85 per cent) and a moderate dependence on agriculture and downstream agri-industry employment. There are a number of social factors that contribute to Coleambally's low level of adaptive capacity and overall degree of vulnerability. Most notably, a high proportion of single parent households with children, a moderately high proportion of persons aged over 65, a high proportion of people renting and a lower degree of economic diversity. The Rock's low level of vulnerability (and sensitivity) is mostly due to its very low dependence on water for irrigation

7 Comparison of a high vulnerability and a low vulnerability area

urban centre/locality	vulnerability	sensitivity	adaptive capacity	comment on underlying indicators
Coleambally	High–very high	Very high	Low	High number of irrigating establishments High proportion of households with 1 person working in agriculture and downstream agri-industry High proportion of single parent households with children High proportion of people aged 65+ High proportion of dwellings rented Low economic diversity
The Rock (Lockhart)	Low	Low–very low	High	Very small number of irrigating establishments Low proportion of people working in agriculture Low proportion of single parent households with children Low proportion of dwellings rented High economic diversity

Note: Comments on underlying indicators are relative to other areas in the Basin.

and a very low proportion of persons employed in agriculture and processing industries. The Rock has a higher level of adaptive capacity, which in turn contributes to its lower level of vulnerability. Social factors contributing to adaptive capacity include; a higher proportion of persons employed in the public sector, a higher degree of economic diversity in the town, a lower proportion of persons in rented dwellings and lower proportion of people over the age of 65.

Population density coinciding with vulnerability

When displaying community vulnerability at the CCD level, the scale is very fine. This means that where there is a high population density, the CCD can cover a very small area, such as a few street blocks of houses in the suburbs of a country town. This is because CCDs by definition are spatial units that contain about 150 to 250 dwellings (that is the number of households for which one census collector can deliver and collect census information in a specified period of time).

It may be of interest to identify those regions which are highly vulnerable and have a larger number of people who would be affected by changes to the availability of water for agriculture. For the purposes of highlighting these areas spatially, we have generated maps in Multi-Criteria Analysis and Spatial Shell (MCAS-S), a spatial assessment tool developed by ABARE-BRS, which is designed to visually link and analyse mapped information. MCAS-S presents areas where higher population densities coincide with higher community vulnerability (map 5, appendix C). This was done by standardising the population density (persons/km²) for all CCDs in the MDB and creating a two-way map of this with vulnerability in MCAS-S. The CCDs with higher population densities and high vulnerability are clearly highlighted. This may be useful for guiding decisions regarding more highly populous communities that are likely to be vulnerable to changes in water availability and have fewer resources with which to cope. A more detailed version of this map overlaid by Google Earth is shown in map 6 (appendix C) for the Riverina/Murray region to provide an example of how this information could be used in consultation processes to depict socio-economic circumstances of communities.

Limitations

There are several limitations in using summary measures for community vulnerability. One of the key limitations is that community vulnerability is a complex concept and a single metric cannot capture the full experience of specific communities undergoing rapid change. Using Census data also reveals only part of the story. To overcome this limitation, it is important that further validation and scrutiny of the indicators is carried out to establish whether they represent people's experiences at a community level and to increase understanding of the community vulnerability index. Ways of overcoming this and other limitations are discussed further in Section 5—How can the indices and maps be used? and Section 6—Recommendations for further work on the index of community vulnerability.

5 How can the indices and maps be used?

The conceptual framework indices and maps can be used in several ways, which are introduced here and elaborated below:

- to better understand Basin communities' relative vulnerability to changes in water availability
- to communicate vulnerability to decision-makers in local communities to assist understanding of potential factors that contribute to vulnerability and incorporate local knowledge via interactive workshops
- to assist in prioritising potential policy interventions that may be required due to changes in access to water for irrigation
- to use as part of a long-term monitoring and evaluation strategy for tracking the socio-economic circumstances of Basin communities (for example, in the review of the Basin Plan every five years).

Understanding relative vulnerability across Basin communities

- Comparisons of community vulnerability sensitivity and adaptive capacity across the Basin
- Use to guide community and stakeholder understanding of socio-economic context

A single composite index was developed that summarises the complex socio-economic circumstances of diverse local communities across the MDB in the context of dependence on water for agriculture. This effectively provides a summary metric of the vulnerability of communities in a form that is easily digestible for decision-makers.

The output of this project provides measures of community vulnerability and adaptive capacity using consistent indicators across the Basin at a localised scale (CCDs). These measures enable an understanding of the likely differences in impacts and responses of communities and regions to any changes to water availability for agriculture at a very fine scale. It should be remembered that people move within many CCDs in a single day for work and spending purposes. Therefore, conditions in a CCD are not purely determined by conditions within its boundaries, but by socio-economic conditions in nearby regions. The maps and indices need to be interpreted with considerable local knowledge of factors that account for local conditions.

Communicating vulnerability to decision-makers in local communities (interactive workshops)

- Incorporating local community knowledge
- Assisting communication with local communities
- Use as a basis for adjustment discussions with communities.

A potential advantage of maps and indices at a very local scale is that communities can 'see themselves in the data'. The maps and indices can therefore play a role in communicating to assist local communities' understanding of the potential factors that contribute to their vulnerability.

A related use is to incorporate community knowledge about whether there are particular indicators that better represent their circumstances and if any other community knowledge or data can be brought into the analysis. The key question is: what do local communities think are the factors that contribute to their circumstances, compared with those generated in this project? The PCA could be re-visited for individual towns or regions as part of this interactive process to derive a unique set of independent indicators relevant to a specific community.

Verification of the maps and indices at the community level could stimulate discussion of responses to changes and incorporate community knowledge to strengthen the index of community vulnerability. Qualitative input and feedback from Basin communities on the factors that contribute to their vulnerability is important for increasing transparency and legitimacy of any decisions.

Prioritising potential policy interventions

There are two ways in which the information about vulnerability might be used in policy interventions in the Basin. In the first way, the information would not be used in the negotiations about SDLs. The SDLs would be set solely with regard to the needs of agreed environmental assets in the Basin. However, the vulnerability information could subsequently be used in the negotiation and design of support and adjustment programs to ameliorate the potential impacts.

The index of community vulnerability is useful for highlighting particular combinations such as high sensitivity and low adaptive capacity communities—or other combinations that may need more immediate policy attention.

The consideration of particular combinations could assist with discussions among inter-governmental stakeholders about what actions could be taken to reduce or ameliorate potential impacts, including policy interventions beyond those of the Authority. As required in the Water Act, such a process could assist with optimising and making the economic, social and environmental outcomes of decisions more transparent.

Potential interventions of this kind may include:

- Strategic partnerships or planning — between key agencies to align goals and strategies
- Coordination — alignment of priorities, investment and effort
- Promotion of innovation — research and development especially in cases of market failure
- Design and implementation of incentives — for example, regulation, cross compliance, payments based on farming practices, environmental taxes, tradable rights / permits, technical assistance, community based measures
- Communication — provide information, or technical assistance / extension.

The second way in which the vulnerability information might be used would be to bring it directly into the negotiations among Basin stakeholders on the SDLs themselves, either in matters of quantity, reliability or transition arrangements from present diversion levels. In this case, the needs of environmental assets would be considered simultaneously with the needs of irrigated agriculture. Naturally, this does not preclude the subsequent use of the vulnerability information in the negotiation of support and adjustment programs.

The two basic policy approaches described above might also be pursued simultaneously, but at different scales. For example, the first approach might be employed when considering the Basin as a whole, while the second approach might be used within a particular river valley or irrigation district as part of the development of water sharing plans to meet the SDL for that region.

Longitudinal monitoring

- Use as baseline information to measure future socio-economic changes
- Potential framework for measuring effects of the Basin Plan on communities

The community vulnerability assessment in this project represents a single point in time and is reliant on 2006 ABS Census data. This could however represent a baseline against which to measure future changes to socio-economic conditions following from SDL changes.

The indices and indicators could form the basis of a framework for understanding long term trends in community vulnerability and adaptive capacity. For example the measures could guide the social and economic monitoring and evaluation framework — using 2006 census data as the baseline followed up with 5 yearly reviews — to track the impact of the Basin Plan on the socio-economic circumstances of communities. This would require populating the community vulnerability index using Census data for future years as they are released (for example, 2011 with release in 2012).

The indicators could also be populated with data from previous Census years. This would be useful for determining how communities have responded to the significant changes to water availability that occurred already over the last decade. However, the problem arises that CCD boundaries are periodically altered by the ABS and this would affect the consistency of the analysis.

A great many changes occur in communities between Censuses. This raises a question of whether dedicated socio-economic data, specific to the MDBA, should be collected more frequently than ABS Censuses. There are opportunities to assess the utility of using alternative data sources that may have more frequent collection periods, for example, social and economic data collected by local government authorities, state governments and non-government organisations.

6 Recommendations for further work on the index of community vulnerability

The summary indices produced in this project provide some insight into real world concepts of community vulnerability, adaptive capacity and sensitivity to changes in water availability. Defining measures of community vulnerability, however, is necessarily a balance between describing and representing the concept adequately and finding consistent data sets to populate the measures. There are a multitude of other possible data items and sources that could be incorporated into the indices, including from qualitative and quantitative, primary and secondary data sources, to improve its robustness.

Stakeholder and community interactive workshops would generate useful feedback on the indicators and stimulate discussion of potential additional data items. This would assist with understanding socio-economic circumstances of specific communities and with incorporating community knowledge. The emphasis could be on drilling down to the local level and looking at the factors that are contributing to community vulnerability. Initially, expert input may be needed in such meetings to respond to questions about how the maps were built and to provide plausible explanations as to why the indices appear as they do and to guide the incorporation of local knowledge.

This section outlines some initial directions on potential indicators and data sources that could assist with refining the indices of community vulnerability, sensitivity and adaptive capacity.

Constructs and data items

Figure 2 (conceptual framework) illustrates the available indicators that were considered useful for measuring community vulnerability and adaptive capacity to changes in water for agriculture. The data items in grey were either not available or not used. However there are alternative data items and sources that could be incorporated into this analysis to more fully represent community vulnerability, and contribute to the following constructs, for example,;

- Sensitivity — farm financial status; gross value of agricultural production; water trading; economic linkages across regions
- Exposure — climate changes; declining diversions
- Adaptive capacity — water efficiency adaptive capacity; agronomic adaptive capacity; institutional adaptive capacity; community health and welfare; provision of services; social cohesion.

The main complexity is that not all of the alternative data sets are of a comparable time and spatial scale to ABS data. Thus there are likely to be a range of non-ABS data sets that could be incorporated to help measure these concepts, but their utility is limited because of the quality, scale or patchiness of the data. Some potential measures and data sources are elaborated below.

Sensitivity

Several items have been suggested for better representing the level of dependence on water. Some of these pertain to farm production and financial values. Potential additional measures include: the value of agricultural production and a measure of farm financial status.

Value of agricultural production could be taken from ABS Water Account (cat. no. 4610.0), such as the estimates of Gross Value of Agricultural Production (GVAP) or Gross Value of Irrigated Agricultural Production (GVIAP). GVIAP is produced every four years, available for some irrigation regions. GVIAP per megalitre of water applied is also estimated by ABS. However, the volume of water applied data is not consistently collected and appears to be available for 2002–03 and 2006–07 only.

Farm financial status could be represented by applying a measure of farm equity (that is the net value of farm assets with no debt against them). A debt to asset ratio is a measure of the farm sector's financial condition, particularly as a measure of the degree of reduction to water access that the farm sector can absorb or as a measure of potential investment capacity (for example, for gaining on-farm water efficiencies). Farm financial data for various agricultural industries, such as the meat and livestock, dairy and broadacre industries, are collected by ABARE-BRS in their regular farm surveys. Intermittent data is collected on the financial performance of irrigated farms by ABARE-BRS.

Exposure

- Exposure (to the stressor or change) – measures representing the change in water availability or climate change outcomes

Water availability may change as a result of climate change and/or changes to sustainable diversion limits. Given that SDLs have yet to be decided, we did not populate the 'declining diversions' exposure index. We have assumed a baseline situation where changes in water availability and climate changes occurred equally across the whole Basin. However, it is worth considering potential indicators of changes to water availability (that is rainfall and irrigation water) to see what influence this has on the community vulnerability index. As a way of putting potential reductions in SDLs into perspective, one approach could be to calculate reductions in water use over the period 1996–2006 and compare this with projected SDLs.

Adaptive capacity

- Water efficiency adaptive capacity

There is scope for considering a measure of the potential for irrigated farm businesses to use technologies aimed at increasing the efficiency of water use to better cope with climate change and changes to water availability in the measure of adaptive capacity. This could take the form of production value of the commodity per megalitre of water applied, or the level of investment in water use efficiency infrastructure on the farm. Similarly, a regional measure of efficiency could also be incorporated to represent regional level irrigation infrastructure

efficiency, such as the water delivered to all ‘farm gates’ in an irrigation district as a proportion of the total water (including conveyance water) allocated to the district. This would give an indication of the losses and evaporation in the system.

- Agronomic adaptive capacity

There is considerable scope for the incorporation of agronomic adaptive capacity in the calculation of overall adaptive capacity. Agronomic adaptive capacity is conceptualised as the climatic, natural resource and market characteristics that determine the feasibility or otherwise of substituting dryland agriculture or extensive grazing for irrigated agriculture.

Climatic characteristics would include such measures as length of growing season and the seasonal distribution of rainfall and soil moisture deficits. Natural resource characteristics would include soil types, soil salinity and other constraints on crop growth, as well as rangeland vegetation types. Market characteristics would include the input costs, transport costs and commodity prices for the particular alternative to irrigated agriculture.

A possible indicator that could simplify the calculation of agronomic adaptive capacity could be the ratio of the gross margin (the profit at full equity, which takes the profit minus any variable and fixed costs of production, could be an alternative to using the gross margin. Profit at full equity has been estimated by the Australian Government in the Australian Natural Resources Atlas nationally for 1996/97, refer to <http://www.anra.gov.au/topics/economics/costs-returns/index.html> for the method and mapped results) for the most profitable form of irrigated production to the gross margin for the most profitable alternative. The greater the value of the indicator in excess of one, the lower the incentive to adapt by switching to dryland agriculture and the greater the financial loss (vulnerability) from such a switch.

- Institutional adaptive capacity — water trading

The trade of irrigation water permanently or temporarily could be another useful measure of how well irrigated farm businesses have adapted, or could adapt in future. Water trading has the potential to facilitate redistributions of the social and economic impacts of changes to water availability. Water use changes as a result of water trading may be a measure of the changes in farm reliance on irrigated water over the long term.

Water trading data was not readily available for this project. However, it would be useful to consider incorporating an indicator of water trading in the community vulnerability index. Water trading data would need to be consistent across the whole Basin and cover a comparable time period as data sets used to populate the index of community vulnerability.

Interrogation and interpretation

Weightings

Weightings could be further explored and validated using two approaches.

The first would involve the specification of an outcome measure such as population change, or change in household income or change in employment. The choice of outcome measure could itself be subject to community consultation as to what measures are regarded as an acceptable indicator of community socio-economic wellbeing. This would be followed by regression analysis using time series data as has been done by Alasia (2008). The various indicators used in calculating the vulnerability index would be used as independent variables, and the chosen outcome measure as the dependent variable. The regression analysis would yield a set of weights that could be used in the place of the neutral weightings described above.

A second approach would be to use a modified Delphi process to obtain the views of a range of stakeholders, including local community representatives, industry stakeholders, policy specialists and scientists as to what values the weights should take. The aim of using a Delphi approach is to gather the opinions of a range of experts to produce the best estimate in the light of current knowledge. 'Experts' in this context would ideally be people who have knowledge of community processes, policy relevant knowledge, technical and/or scientific knowledge.

The process could be applied at different levels. Firstly, at a Basin or regional scale. Secondly, at the local community level to engage local community 'experts' in understanding the vulnerability of a particular locality. This approach could add legitimacy and transparency in the allocation of weightings to different factors that contribute to community vulnerability and could be combined with efforts to gather locally relevant information. The weights obtained in regression analysis with past data could be used to inform the Delphi process and bring historical validation to the process.

Class intervals

In the presentation of maps in this report, a limit of five class intervals were used in all maps (that is defining classes of 'very high', 'high', 'moderate', 'low' and 'very low'). However, these classes could be revisited in order to focus on particular issues of significant policy interest, such as those Basin communities that have a high vulnerability made up of a combination of high sensitivity to changes in water for agriculture and low adaptive capacity or limited resources to respond.

appendix **A** Indicator specifications

A1 Index of sensitivity at a Basin scale - indicator definitions

index	indicator name	indicator definition	scale	source
SLA Water dependence	SLA irrigation intensity	Megalitres of water applied divided by number of irrigated farm establishments	SLA	2006 Agricultural Census, ABS
	SLA irrigation incidence	% of agricultural businesses irrigating	SLA	2006 Agricultural Census, ABS
Local economy agricultural dependence	% work in agriculture	Ratio of total working in agriculture/ mining/forestry sector to total employed persons 15+	CCD	2006 Census of Population and Housing
	Ratio of agriculture and agri-industry employment to total employment	Ratio of persons employed in ANZSIC Division A Subgroup 01 (Agriculture) and Subgroup 02 Minor subgroup 05 to total employment	CCD	2006 Census of Population and Housing
	Proportion of households with agricultural and/or agri-industry employment	Households with at least one member employed in ANZSIC Division A Subgroup 01 (Agriculture) and Division C Subdivision 21 (Food Beverage and Tobacco) as % of all households	CCD	2006 Census of Population and Housing
	Ratio of employment in agriculture to downstream agri- industries employment	Ratio of persons employed in ANZSIC Division A Subgroup 01 (Agriculture) to persons employed in Division C Subdivision 21 (Food Beverage and Tobacco)	CCD	2006 Census of Population and Housing

A2 Index of adaptive capacity at a Basin scale - indicator definitions

Description of reduced set of adaptive capacity indicators from the PCA and the data items used to calculate them.

index	sub-index	indicator	data items	scale	source
Adaptive capacity – human capital	Education advantage	% Graduates	Total bachelor degree + total graduate diploma/ certificate + total postgraduate degree / total persons 15+	CCD	2006 Census of Population and Housing
		% Employed in public sector	Total employed in public admin sector / total employed persons 15+	CCD	2006 Census of Population and Housing
		% Over 15 no qualifications	% Of persons 15+ with no qualifications: certificate, diploma, undergraduate degree, postgraduate degree	CCD	2006 Census of Population and Housing
		Median weekly rent as a fraction of the Australian median	Median weekly rent as proportion of the 2006 Australian median (\$190)	CCD	2006 Census of Population and Housing
		Median household income as fraction of Australian median	Median household income as proportion of the 2006 Australian median (\$1026.80)	CCD	2006 Census of Population and Housing
		Income/mortgage differential	(Median household weekly income * 52 / 12) – median monthly housing loan repayment	CCD	2006 Census of Population and Housing
Adaptive capacity – human capital	Socio-economic advantage	% One parent	Total single parent families/total families	CCD	2006 Census of Population and Housing
		% Couple families	Total couples without children + total couples with children / total families	CCD	2006 Census of Population and Housing
		% single parent with children <15 only	Total single parent families with children < 15 years old / total families	CCD	2006 Census of Population and Housing
		Total unemployment	Total unemployed / total labour force	CCD	2006 Census of Population and Housing
Adaptive capacity – human capital	Age advantage	% 65 over	Total persons aged 65 and over / total persons	CCD	2006 Census of Population and Housing

continued...

A2 Index of adaptive capacity at a Basin scale - indicator definitions continued

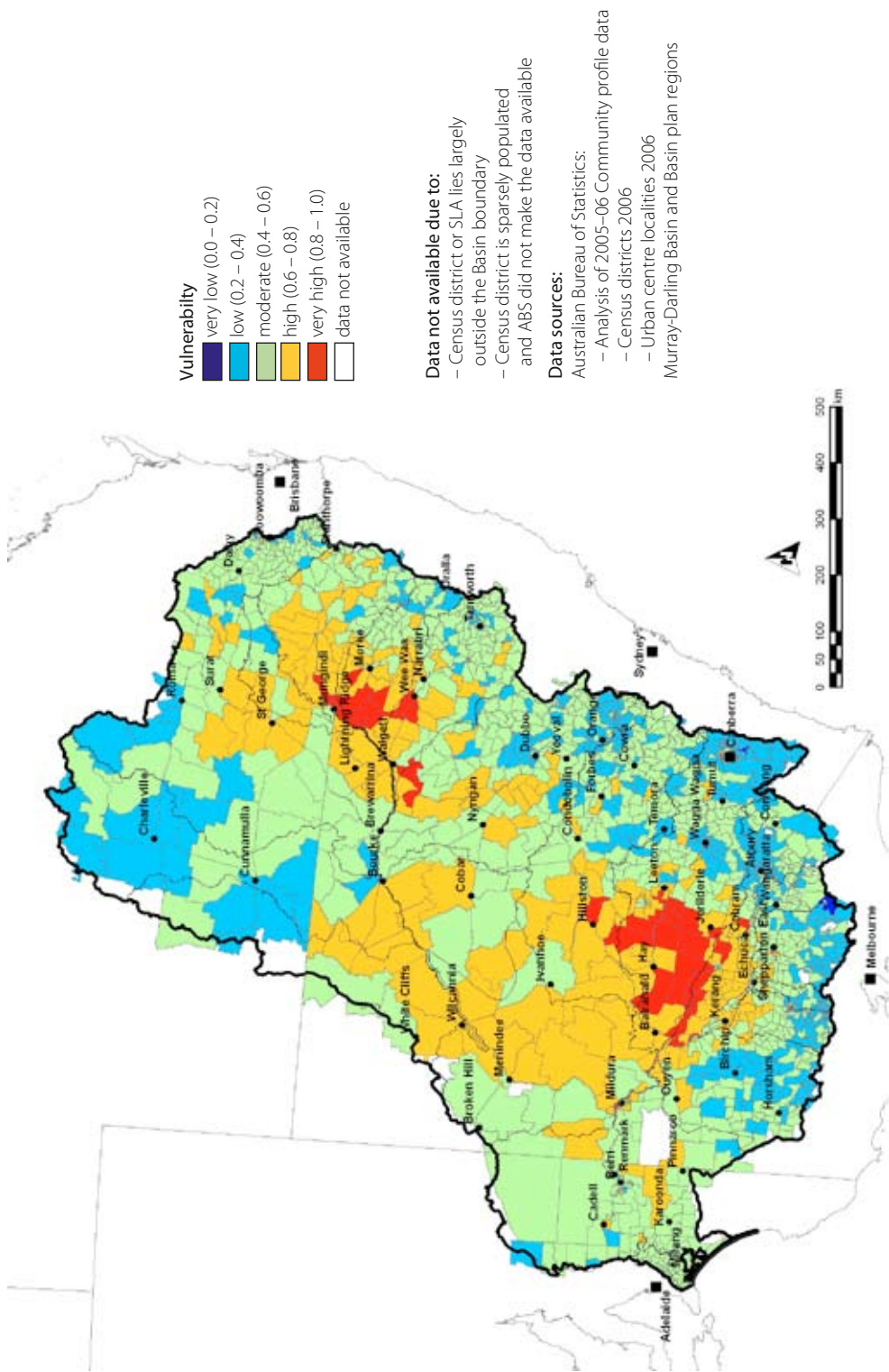
Description of reduced set of adaptive capacity indicators from the PCA and the data items used to calculate them.

index	sub-index	indicator	data items	scale	source
Adaptive capacity – human capital	Mobility advantage	Average no. Persons per household	Average household size	CCD	2006 Census of Population and Housing
		% Lone person households	Total one persons households / total occupied dwellings	CCD	2006 Census of Population and Housing
		% Dwellings rented	Rented properties / total dwelling structures	CCD	2006 Census of Population and Housing
		% Different address to 1 yr ago	Lived at different address 1 year ago / lived at different address 1 year ago + lived at same address 1 year ago	CCD	2006 Census of Population and Housing
Adaptive capacity – social capital	Proportion of females in non-	Women in non-routine occupations	Female managers + female professionals + female technicians + female community and personal / total female employed persons	CCD	2006 Census of Population and Housing
Adaptive capacity – social capital		% Voluntary work	Total volunteers / total persons 15+	CCD	2006 Census of Population and Housing
Adaptive capacity – local economic diversity	Economic diversity index	Economic diversity index	Diversity of local economy relative to Australian/MDB economy, calculated using employment by sector data	CCD	2006 Census of Population and Housing

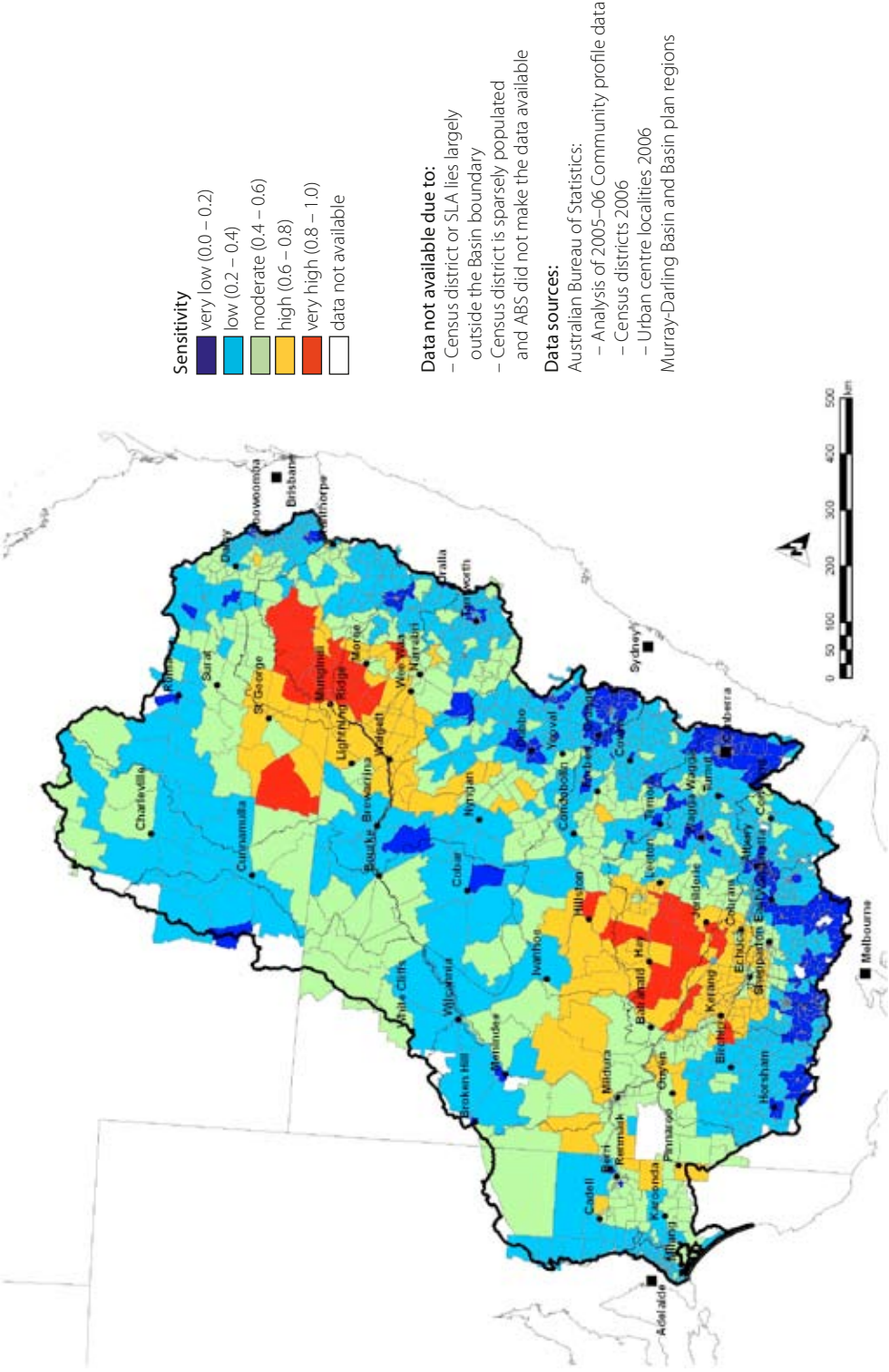
appendix **B** Indices maps at the Basin scale

- Map 1: Index of community vulnerability for the Murray-Darling Basin
- Map 2: Sub-index of sensitivity for the Murray-Darling Basin
- Map 3: Sub-index of adaptive capacity for the Murray-Darling Basin
- Map 4: Index of community vulnerability map overlaid with Google Earth focussing on regions with lower vulnerability (blue) in the east to areas with higher community vulnerability (red) in the west

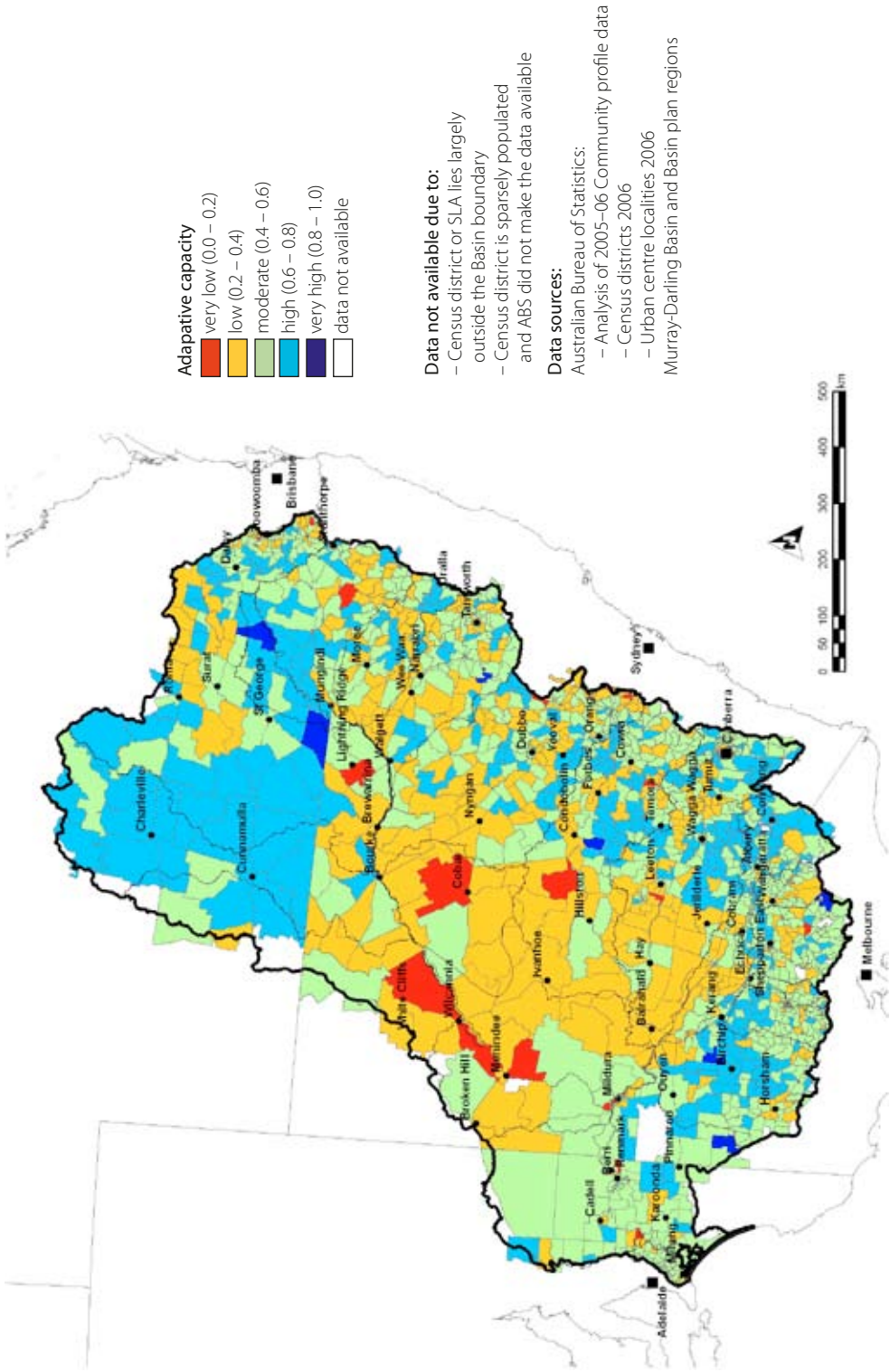
map 1 Index of community vulnerability for the Murray-Darling Basin



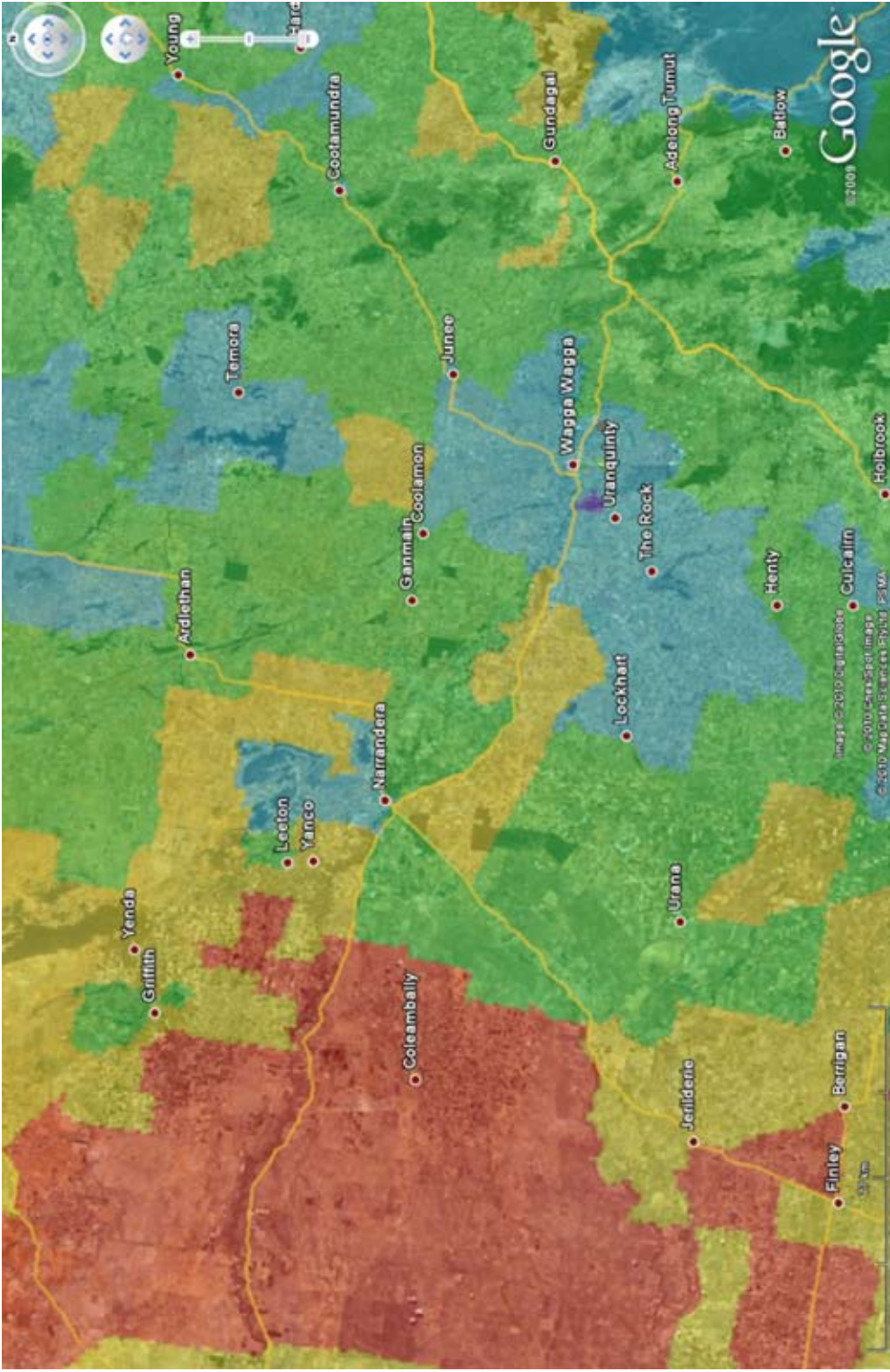
map 2 Sub-index of sensitivity for the Murray-Darling Basin



map 3 Sub-index of adaptive capacity for the Murray-Darling Basin



map 4 Index of community vulnerability map overlaid with Google Earth focussing on regions with lower vulnerability (blue) in the east to areas with higher community vulnerability (red) in the west

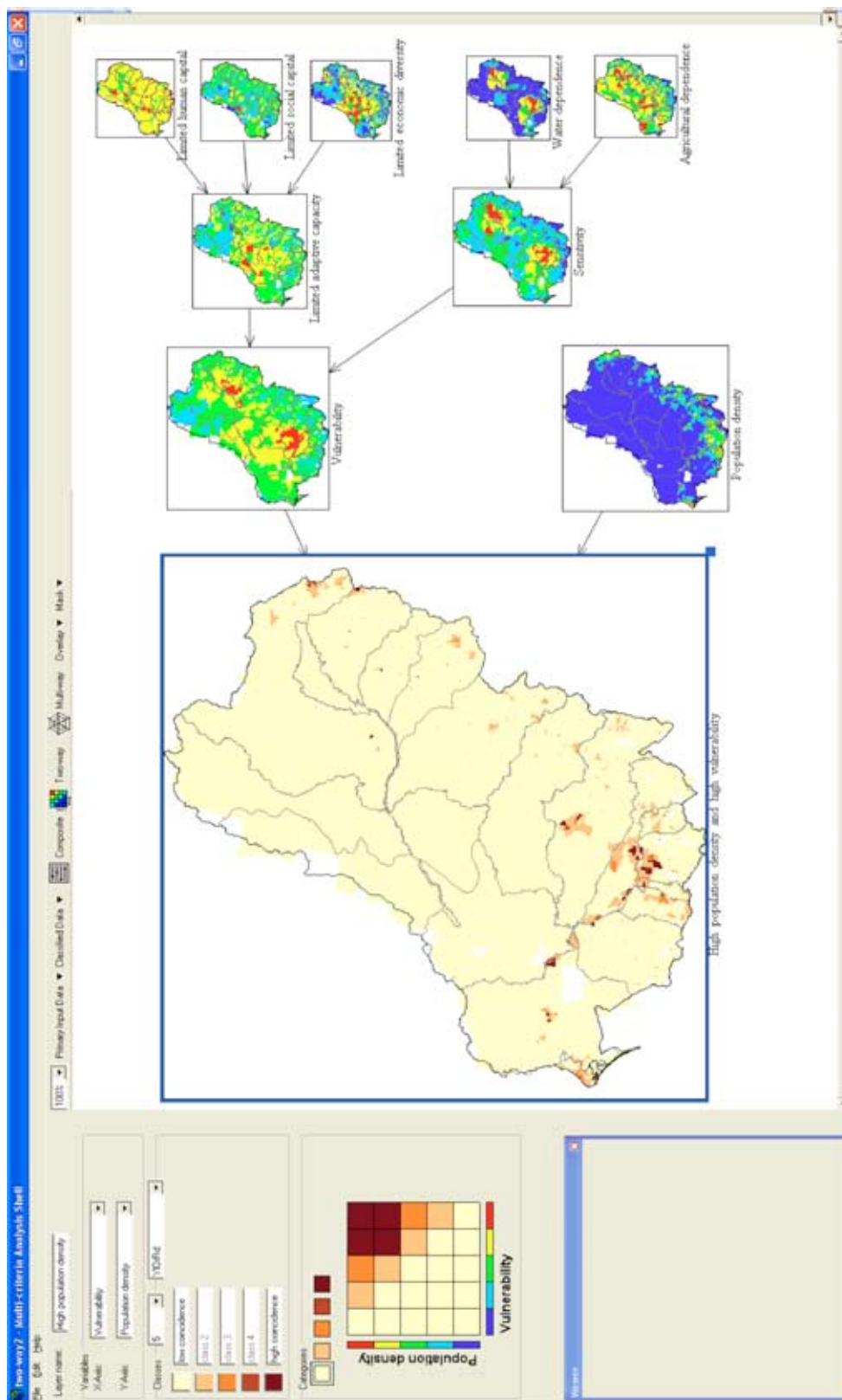


Note: this map should only be used for analysis at a broad scale

C Population density and community vulnerability at the Basin scale

- Map 5 High population density coinciding with high community vulnerability for the Murray-Darling Basin
- Map 6 High population density coinciding with high community vulnerability for the Riverina/Murray region displayed in Google Earth

map 5 High population density coinciding with high community vulnerability for the Murray-Darling Basin



Note: In the colour ramp classification on the X and Y axis of the co-incidence matrix, blue denotes low population density or vulnerability and red denotes high. Therefore, dark brown represents the co-incidence of high vulnerability and high population density.

appendix **D** Annotated review of key studies

Maguire, B and Cartwright, S 2008, Assessing a Community's Capacity to Manage Change: A Resilience Approach to Social Assessment, Bureau of Rural Sciences, Canberra.

The authors discuss the relationships between vulnerabilities, adaptive capacity and social resilience. The framework points to measures of resilience that identify the capacity of communities and industries to adapt to changes in the availability, access or allocation of water. These social and economic measures of resilience can be integrated with biophysical information to identify communities and industries that are less resilient to changes in water availability.

Definitions/interpretations of key terms used by the authors:

- *Vulnerabilities*: The components that may weaken a community's ability to respond adaptively to a change
- *Adaptive capacity*: The resources and ability of a community to cope with change
- *Social resilience*: The ability of a community to adaptively respond to change rather than simply returning to a pre-existing state.

Hence, with reference to the schematic adopted for this review (Allen Consulting Group 2005):

- 'Exposure' is referred to by Maguire and Cartwright (2008) as 'vulnerabilities'
- 'Sensitivity' is essentially 'resources' and 'adaptive capacity'
- 'Adaptive capacity' is a measure of 'social resilience'
- 'Vulnerability' is the equivalent of the final measurement of 'community resilience' as a result of social assessment.

Consequently, review of this document concentrates on aspects of social resilience that will henceforth be referred to as 'resilience [adaptive capacity]' to clarify interpretation. [The fact that the same terminology is used by different authors to mean different or even contradictory things is noted by Preston and Stafford Smith (2009), among others].

Perspectives on resilience [adaptive capacity] have been summarised by Maguire and Cartwright (2008) into three major views:

1. Resilience [adaptive capacity] as stability: buffer capacity
2. Resilience [adaptive capacity] as recovery: bouncing back
3. Resilience [adaptive capacity] as transformation: creativity

Although a common aspect in all perspectives is the ability to withstand and respond positively to stress or change, the approach that concerns the current study is the third: resilience [adaptive capacity] as transformation.

Resilience [adaptive capacity] as transformation

This view considers social resilience [adaptive capacity] to be the capacity of a community to respond to a change adaptively. Rather than simply returning to a pre-existing state, this can mean changing to a new state that is more sustainable in the current or changing environment. The authors use the example of an agriculturally-based rural community developing different economic activities (such as tourism) or innovative farming practices that better suit the current environment (in our case as the direct result of SDLs).

Maguire and Cartwright support Folke's (2006) contention that the transformation view of resilience [adaptive capacity] is concerned with concepts of renewal, regeneration and re-organisation. Folke (2006) argued that 'in a resilient social-ecological system, disturbance has the potential to create opportunity for doing new things, for innovation and for development'. Accordingly, Maguire and Cartwright describe a resilient community (one that has stores of adaptive capacity) as one that is able to:

... use the experience of change to continually develop and to reach a higher state of functioning. Rather than simply surviving the stressor or change, a resilient community may respond in creative ways that fundamentally transform the basis of the community. This perspective recognises that given the dynamic character of communities, they are unlikely to return to a pre-existing state, but will transform in an adaptive way to external change.

Because the transformation view accepts that change is inevitable rather than seeing change as a 'stressor' from which a community needs to recover to its original state, Maguire and Cartwright describe their view of transformation resilience [adaptive capacity] as one that:

- Embraces the dynamic character of communities and human-ecosystem interactions and sees multiple potential pathways within them
- Rejects the deterministic views of resilience which see resilience as a community simply returning to a pre-existing state are unable to incorporate this complexity
- Draws the focus to the adaptive capacities of a community — the characteristics which enable it to develop and innovate in response to a change — rather than its vulnerabilities
- Acknowledges that people themselves are able to shape the 'trajectory of change' (Herrera et al. 2006) and play a central role in the degree and type of impact caused by the change.

We note that these observations lead to specifying crucial roles for human and social capital in determining adaptive capacity and resilience.

Importantly, Maguire and Cartwright point out that it is here that the difference between social resilience [adaptive capacity] and ecological resilience becomes clear. Social resilience [adaptive capacity] recognises 'the powerful capacity of people to learn from their experiences and to consciously incorporate this learning into their interactions with the social and physical environment'.

Thus a community with resilience [adaptive capacity] builds upon the resources and flexibility already established within it rather than relying on external interventions. Crucial in the authors' view to assessing resilience [adaptive capacity] is an effective partnership between governments and communities. This approach would not only allow the capacity of the community to mobilise its resources for adaptation to be assessed but would also promote understanding, enhance skills and contribute to the transparency of decision-making.

Maguire and Cartwright identify the following elements or indicators for examination in terms of measuring adaptive capacity in a water-dependent community:

- Diversity of the local economy. If one (water-dependent) industry suffers decline due to changes in access to water resources, there might be other sectors within the community that will not be affected by reduced water access; alternatively, there might opportunities for new industries to be developed
- Ability for the community to effectively organise itself
- Presence of leaders (individuals or groups) in the community who can mobilise awareness and resources to manage the process
- Ability of the community learn from change
- Potential for the community to seek creative solutions to change
- Length of time for the community to respond to changes
- Strong communication channels in place within the community.

The selection of indicators and the type of data collected will depend on the constraints and opportunities surrounding the particular assessment. Many of these elements cannot be directly measured quantitatively, and require resource-consuming qualitative assessment. Thus there are some obvious constraints to effective measurement of resilience [adaptive capacity].

In summary, Maguire and Cartwright observe that a community which is able to employ its resources in a proactive and pre-emptive way is less vulnerable to exposures (such as SDLs) than one that may only be able to take action after the change has had an impact (or not at all). Furthermore, they identify the presence of redundancy in the system as a crucial component of the ability to adapt. The flexibility and creativity in communities with adaptive capacity permits them to develop and embrace new ways of doing things. It is through this flexibility and redundancy that a community can translate its resources and social resilience [adaptive capacity] into adaptation and thereby demonstrate aspects of resilience rather than vulnerability.

Maguire and Cartwright also describe a conceptual basis for a social assessment framework. The framework points to social and economic measures of resilience [adaptive capacity] specifically in the face of change in the availability, access or allocation of water. Such measures could, they suggest, be integrated with biophysical information to identify communities and industries that are vulnerable to changes in water availability. The authors proceed to scope key activities that the authors believe should be undertaken in applying their social assessment framework.

Brooks, N 2003, Vulnerability, Risk and Adaptation: A Conceptual Framework, Tyndall Centre Working Paper 38, Tyndall Centre for Climate Change Research and Centre for Social and Economic Research on the Global Environment, University of East Anglia, Norwich.

Brooks presented a tentative conceptual framework for studies of vulnerability and adaptation to climate variability and change which the author considers could be generally applicable to a wide range of contexts, systems and hazards. He recognised that the relationship between the *vulnerability* and *adaptive capacity* of a human system depends critically on the nature of the hazard faced. As well, adaptation by a system may be inhibited by processes originating outside the system and thus it is important that external obstacles to adaptation and links across scales are considered when assessing adaptive capacity.

Brooks discussed the terms used in the literature on adaptive capacity, resilience and vulnerability, and highlighted the fact that they often have different meanings when used in different contexts by different authors.

The terminology used by Brooks is used differently from those adopted in the current project. We attempt to tease out the meaning of the concepts explored by Brooks and the relationships between them and, in so doing, clarify his contribution to the discussion. Not all the terms used by Brooks are discussed here. Instead discussion concentrates on aspects of vulnerability and adaptive capacity.

Brooks observed that social scientists and climate scientists often mean different things when they use the term 'vulnerability' For example:

- *Vulnerability (climate scientists)*: the likelihood of occurrence and impacts of weather and climate related events (Nicholls et al., 1999). Brooks referred to this form of vulnerability, a combination of the functions of hazard, exposure and sensitivity, as 'biophysical vulnerability'.
- *Vulnerability (social scientists)*: the set of socio-economic factors that determine people's ability to cope with stress or change (Allen, 2003). Thus vulnerability is something that exists within systems independently of external physical hazards [exposures]. For many human systems, vulnerability viewed as an inherent property of a system arising from its internal characteristics. This is termed '*social vulnerability*' by Brooks among others.

Factors identified by Brooks (citing Blaikie et al. 1994; Adger and Kelly 1999; Cross 2001) as generic determinants of social vulnerability to a range of different specific exposures, including non-climate ones, include:

- poverty
- inequality
- health
- access to resources
- housing quality
- social status.

Thus it seems Brooks' use of the term 'social vulnerability' is equivalent to 'sensitivities' — those characteristics of a local system or structure that would increase or decrease the impacts of the effects of exposures — as understood in the current project.

Brooks viewed reductions in 'social vulnerability' [sensitivities with negative connotations] as arising from adjustments in a system's behaviour and characteristics that enhance its ability to cope with external stresses; he labels these (the realisation of adaptive capacity) as adaptation. He states that, given constant levels of hazard [exposure] over time, a system will reduce the 'risk' (that is, reduce its vulnerability) associated with these exposures by reducing its 'social vulnerability' [sensitivities with negative connotations].

In other words, the measurement of risk as defined by Brooks is the equivalent of the human system's vulnerability (or, inversely, resilience). The final outcome as a result of exposure to a hazard depends on the extent of that risk [vulnerability] and can be ameliorated by social vulnerability [sensitivities of the system].

Brooks viewed reductions in social vulnerability [reduced negative impact of sensitivities] as arising from the realisation of adaptive capacity in the form of adaptation. He used the term adaptation to mean 'adjustments in a system's behaviour and characteristics that enhance its ability to cope with external stresses'.

Brooks further elaborates (with our interpretations of the author's terminology inserted in square brackets):

'Given constant levels of hazard [exposure] over time, adaptation [adaptive capacity] will allow a system to reduce the risk [vulnerability] associated with these hazards [exposures] by reducing its social vulnerability [negative impact of sensitivities]. Faced with increased hazard [exposure], a system may maintain current levels of risk [vulnerability] through such adaptation [adaptive capacity]; reductions in risk [vulnerability] in the face of increased hazard [exposure] will require a greater adaptation effort [level of adaptive capacity]'.

The typology acknowledges that 'adaptive capacity will fluctuate over time as the environmental, political, social and economic factors that determine adaptive capacity change. Adaptive capacity may also be reduced by the impacts of the very hazards that a system must adapt to'.

According to Brooks, factors determining adaptation or realisation of adaptive capacity could include measurements of:

- health
- education
- access to information
- financial resources
- natural resources
- the existence of social networks and
- the presence or absence of conflict.

There are overlaps and similarities between Brooks' determinants of social vulnerability (sensitivity) in the face of change, and adaptive capacity. This is not surprising as both are functions of the socio-economic characteristics of communities.

Brooks notes that different systems would be characterised by different scales and would also interact with one other. Furthermore, the processes operating within one system may directly or indirectly affect another system. Cross-scale linkages, including links between the local and national scale could be expected. Moreover, Brooks noted that intervention at the national or international level affecting a commodity produced by a community could have dramatic consequences for the latter's economic status and resulting adaptive capacity. Thus, a region's adaptive capacity assessed prior to implementation of, for example, SDLs might be different to a post-SDL measurement. Accordingly, measurement of adaptive capacity needs to be ongoing during an adjustment period.

In other words, systems are not closed; nor can adaptive capacity for a local area be measured without due consideration to other processes or exposures operating outside that system. Brooks additionally suggests that determinants of adaptive capacity could be categorized as 'endogenous' or 'exogenous' although this may be difficult in practice.

The view of adaptive capacity as something 'inherent' in a system leads Brooks ponder if a system with high adaptive capacity will automatically adapt; in other words, 'is adaptive capacity self-realising'. Accordingly, he suggests the term 'adaptation likelihood' as more appropriate as it implies consideration of better encompasses determinants at different scales.

This review of Brooks' paper is concluded by quoting from his conclusion and is intended to clarify and validate our interpretation of his terminology:

'Within this framework, the risk posed to [vulnerability of] a human system by [to] a particular type of hazard [exposure] will be a function of the severity and probability of occurrence of the hazard [exposure] and the way in which its consequences are likely to be mediated by the social vulnerability [sensitivity] of the human system in question. Risk [vulnerability] may be quantified in terms of outcome, for example in terms human mortality and morbidity and/or economic losses... Social vulnerability [sensitivity]... is more likely to be measured in terms of predictive variables representing factors such as economic well being, health and education status, preparedness and coping ability with respect to particular hazards [exposures] and so on. The adaptive capacity of a human system represents the potential of the system to reduce its social vulnerability [negative impact of sensitivities] and thus to minimise the risk [vulnerability] associated with a given hazard.'

Vinson, T 2009, Social Inclusion — Markedly Socially Disadvantaged Localities in Australia: Their Nature and Possible Remediation, Department of Education, Employment and Workplace Relations, Canberra.

Vinson's (2009) report on social inclusion/exclusion draws on earlier research by Vinson and others which indicated that the high correlations between employment, education and social dysfunction were not solely the result of individual shortcomings such as lack of commitment

to improving their situation, weak motivation, unlawful conduct, and parents' inadequate attention to child-rearing. If unemployment and crime correlate with limited education and limited work skills, then preventive pathways need to take heed of other inter-connections which are discussed in this and earlier publication by this author.

Vinson's research over the past decade has been primarily concerned with aspects of inequality, social disadvantage and social exclusion in Australian communities. This has led to the identification and ranking of local areas in the nation's most populous states by postcode, in terms of their level of disadvantage. Thus he has generally been concerned with the 'downside' components of communities and high levels of disadvantage rather than considering the 'upside' or opportunities. The most recent report continues in a similar vein in that he concentrates disadvantage, although he also discusses the 'inherent social climate of disadvantage' and 'collective efficacy', concepts that can be compared with our interpretation of (lack of) adaptive capacity. Consequently, this review tends to concentrate on these and on identification of potential indicators of adaptive capacity.

Vinson cites research that has found that, in a limited number of localities, when social disadvantage becomes entrenched a disabling social climate can develop that is more than the sum of individual and household disadvantages. As a result, the prospect of disadvantage being passed from one generation to the next is increased. In such circumstances, an accumulation of problems can have serious and sustained impacts upon the wellbeing of residents. This 'disabling social climate' can be akin to a lack of, or negative, adaptive capacity over time in that it fosters increasing levels of disadvantage upon individuals.

Vinson describes people's entrapment within highly disadvantaged communities as their being within a 'web of disadvantage'. Within this, 'progress in overcoming one limitation, say, unemployment, can be inhibited by related factors like limited funds, poor health, inadequate training or having a criminal record. This web-like structure of disadvantage restricts attempts to break free of it.'

Vinson maintains that disadvantaged areas can be identified by selected indicators, but these are not identified in the report. He notes that if the indicators chosen to represent social disadvantage are different manifestations of the same underlying concept, they should be significantly correlated. Indeed, Vinson's previous research appears to bear this out.

Identification of the distinguishing features of the most disadvantaged localities was another way Vinson viewed the linkages between different strands of disadvantage. This was one of the aims of his 2007 national study (Dropping off the Edge) which pulled together information yielded by 25 indicators of the overall susceptibility to social disadvantage (a measure of vulnerability) of 2140 localities across Australia. Vinson explained:

The statistical procedure called upon to assist in this endeavour... enables the researcher to capture along a single dimension many aspects of disadvantage previously reflected in 25 separate indicator scores, while at the same time enabling us to see what features are most prominent in the make-up of the disadvantage factor. The Dropping off the Edge findings convey a picture of the especially damaging consequences of limited education, deficient

labour market credentials, indifferent health and disabilities, low individual and family income, and engagement in crime.

The elements identified by Vinson, such as limited education, could be measures of sensitivities or (lack of) resources within an area. Accordingly, these findings could be used to help to identify Australia's highly vulnerable localities. Further investigation of his approach might be warranted for the current project. He also asserts that stability of those differences observed over time reinforces the importance of the evidence of substantial differences between areas in their degree of cumulative disadvantage. This would plausibly be a measure of their potential vulnerability when exposed to change.

Vinson argued that deprived communities are often held back to an extent greater than can be explained by individual and household characteristics, because environmental and infrastructural factors can compound disadvantage. This is because the inherent social climate of disadvantaged places (akin to our interpretation of adaptive capacity) can mean that inputs targeted at either individuals or on improving the local environment or infrastructure can be absorbed and dissipated without lasting benefit.

Research by Vinson and others has shown an association between local area qualities and the containment of the ill-effects of financial and other deprivations. Vinson adopted the term 'collective efficacy' for this linkage of mutual trust and willingness to intervene for the common good. [This can be seen as one dimension of social capital]. Reduced levels of crime and better health have been associated with resulting social benefits for the local area. In fact, Vinson's earlier research into social cohesion (Dropping off the Edge) showed a consistent association between combined aspects of cohesion and the containment of the ill-effects of disadvantageous community conditions. The harmful consequences associated with limited education and unemployment are ameliorated in localities where residents belonged to local groups, attended local events, were involved in neighbourly exchanges and operated in an atmosphere of trust [that is, where strong social capital existed].

Thus it seems that collective efficacy corresponds with this project's understanding of adaptive capacity and can be assessed through indicators that measure cohesion including:

- local networking
- extent of community involvement
- extent of community interaction
- levels of trust.

Similarly, strengthening adaptive capacity in this context includes:

- developing connections and trust between people and between organisations
- developing the confidence and ability to identify ways of promoting the common good
- securing the resources, internal and external, needed to pursue them.

Vinson's work implies that other indicators of adaptive capacity might include:

- the rate of prison admissions
- levels of disability and sickness support
- non-completion of high school or other training
- evidence of child maltreatment
- long-term unemployment.

Vinson indicates that a range of necessary communal capacities (elements of adaptive capacity) can be further grown 'by sensitive attention to the sequencing and blending of interventions and by using the interventions to exercise the capacities that are needed to sustain community wellbeing'.

According to Vinson, key characteristics of successful interventions for strengthening adaptive capacity in disadvantaged communities involve:

- the maximum practicable engagement of community members in decisions of all kinds
- adequate time for the cultivation or nurturing of community capacity; problems that have often been decades in the making cannot be reversed in a few short years
- attention to characteristics that differentiate markedly disadvantaged areas from other areas
- attention to other specific needs of an area identified either by formal indicators or by residents
- identifying possible sources of community strengthening funding; although the strengthening of disadvantaged areas inevitably requires substantial government outlays.

Vinson also identified the priority components that intervention plan would need to consider.

Walcott, J and Wolfe, EC 2008, 'Estimating adaptive capacity in Australian farming environments', Global Issues Paddock Action, proceedings of the 14th Australian Agronomy Conference, September, Adelaide South Australia, accessed 19 January 2010 from: http://www.regional.org.au/au/asa/2008/concurrent/emerging-opportunities/5819_walcottjj.htm

This paper describes an exercise in mapping potential indicators of adaptive capacity of Australian farms, and discusses the deficiencies in this approach in relation to potential improvements. The authors conclude that 'both quantitative and qualitative tools are needed to assess the likely levels of adaptive capacity of agricultural activities, spatially and industrially'.

Definitions/interpretations of key terms used by the authors:

- Resilience: the maximum amount of disturbance that a system (biological, ecological or agricultural) can experience and still return to the same equilibrium.
- Adaptive capacity: a measure of ability—based on managers' capacity to learn and anticipate—to adjust to change, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences of change.

The authors recognised that adaptive capacity is difficult to measure in practice. This is in part because it is likely to have so many contributing factors as to be quantitatively unmanageable, particularly in deciding upon a weighting for each one and whether or not the factors interact. Some elements such as institutional well-being are essentially subjective. Despite these difficulties, Walcott and Wolfe believe that adaptive capacity has conceptual utility and can be handled qualitatively. They suggest this might be by way of a Conway (1985) analysis or a modification of this analysis. The particular value of the concept lies in grouping a range of factors (perhaps within the five capitals framework?) for higher level discussion and priority setting.

Specific concerns about measures of adaptive capacity as identified by Walcott and Wolfe include:

1. the underlying theory is not robust, with many indicators based on intuitive assumptions of the attributes underlying adaptive capacity
2. the accuracy with which any indicator measures the attribute
3. the strength of the relationship between indicator and attribute, that is does a change in the indicator relate to a similar change in the attribute
4. some indicators are best gained from local qualitative studies
5. matching the scale of adaptive capacity to that of the driver of change
6. there is danger in conveying more precision than is warranted.

The authors collated data collected by the ABS Agstat series and SEIFA which was available at the (2001) Statistical Division level. They did not appear to weight the components and thus did not present a composite result. Elements included which they suggested may correlated with or contribute to adaptive capacity (and thus be used as proxy variables) were:

1. Farmers who have changed management practices during the 5 years before 2002 (per cent);
2. Farmers who used computers or internet for business purposes during 2004-05 (per cent);
3. Farms that have a whole-farm plan at 2002 (per cent);
4. Farmers who participated in activities such as Landcare and Bushcare in 2001-02 (per cent);
5. Farmers who undertook courses or learning activities during 2001-02 (per cent); and
6. The advantage-disadvantage index for whole communities of ABS.

In their discussion and conclusion the authors made the key observation that there are components of adaptive capacity that require context-specific, location-specific analyses, actively involving the stakeholders and the decision-makers and that these analyses could require a diverse set of approaches.

Preston, BL, Smith, TF, Brooke, C, Gorddard, R, Measham, TG, Withycombe, G, Beveridge, B, Morrison, C, McInnes, K and Abbs, DC 2009, Climate Change Vulnerability Mapping as a Stakeholder Engagement Tool: Case Study from Sydney, Australia, Sydney Coastal Councils Group.

This document was reviewed because the climate change vulnerability maps prepared by the authors were assembled by separating vulnerability into the three constituent components of exposure, sensitivity and adaptive capacity (Allen Consulting Group 2005; Smit and Wandel 2006), the schematic adopted for the current project.

Definitions/interpretations of key terms used by the authors:

- Exposure and sensitivity: Dictate the 'gross vulnerability' of a system or process, and thereby provide an indication of potential 'susceptibility' to adverse impacts.
- Adaptive capacity: Reflects the ability of the system to manage, and thereby reduce, gross vulnerability. Adaptive capacity was broadly conceptualised with emphasis placed on the fact that 'successful adaptation is a function not only of capacity in the form of the availability of resources to address vulnerability, but also the institutional barriers or constraints on the application of that capacity' (Hulme et al. 2007).

The authors did not identify indicators used. Given the obviously different characteristics and contexts of the Sydney and Murray–Darling Basins, there may be limited commonality of relevant indicators. The article did discuss, however, the methodology and lessons learnt. These may be pertinent to this project:

The four stage methodology was outlined as follows:

1. A spatial vulnerability assessment was conducted to visualise the general pattern of regional vulnerability to different climate change impacts, identify 'hot spots', and explore a range of different components of vulnerability as well as specific indicators.
2. The vulnerability assessment was utilised as a gateway to engaging with stakeholders in a series of fifteen workshops (one with each Sydney Coastal Councils Group member council), where assessment results were used to elicit stakeholder discussion and feedback regarding vulnerability and adaptive capacity at the local scale.
3. These workshops led to a series of in-depth case studies where capacity issues common to the various councils were explored in more detail.
4. An ongoing process of project assessment and evaluation was conducted, with particular emphasis on the impact of the project with respect to stimulating adaptive responses in Sydney as well as the utility of the various methods and tools for use with other local government areas and municipalities in Australia. This paper focuses on the first two phases of the project and the lessons learned.

Clearly qualitative as well as quantitative analyses were preformed. The authors opined that, 'given the inherent complexities and uncertainties associated with complex environmental and social systems, direct quantitative modelling approaches are often inadequate for capturing the concept of vulnerability in a comprehensive manner'.

Individual indicators were given equal weight due to a lack of knowledge about their relative importance or the quantitative relationships among variables. Indicators for the adaptive capacity component of vulnerability were integrated with the other components (exposure and sensitivity) in such a way as to prevent any one component from biasing the results. This was achieved by calculating the sum of all indicators; sums were then rescored to a scale of one to nine based upon quintiles, with one representing high adaptive capacity (low exposure, low sensitivity) and nine representing low adaptive capacity (high exposure, high sensitivity). Integration of the three component layers was accomplished by summing the scores from adaptive capacity with the two other vulnerability layers, with the result again being rescored to a scale from one to nine. Different components were weighted in the calculation of vulnerability according to expert judgment regarding their relative importance. If possible, resulting vulnerability maps for the impact of SDL should be compared with independent data sources as a validation test.

Lessons learned from the Sydney case study regarding the strengths and challenges associated with vulnerability mapping as a stakeholder engagement tool might warrant consideration in subsequent consultation stages of the MDB Plan.

Herreria, E, Byron, I, Kancans, R and Stenekes, N 2008, Water 2010: Assessing Dependence on Water for Agriculture and Social Resilience, National Assessment of Community Dependence on Water and social Resilience, Bureau of Rural Sciences, Canberra.

The purpose of this report was 'to develop methodological tools for understanding and measuring:

- community dependence on water for agriculture
- social resilience to changes in water access at different spatial scales including national and regional levels.

By exploring measures of socio-economic dependence, resilience and capacity to manage change, an index of community susceptibility to changes in water use and access was derived. The authors' intended this to provide tools for identifying communities most likely to be impacted by changes to water access and use and those least able to adapt and manage change.

Measures of what the authors called 'community dependence on water for agriculture' should contribute to an understanding of the immediate and flow-on effects of reduction in water availability for irrigated agricultural production and, in the parlance of the schematic adopted for the current project, would to some extent resemble the component 'exposure'. Community dependence should also consider characteristics of local economic and social structure that would increase or decrease the impacts of the effects of reduction in water availability; in other words, the 'sensitivity' component of our schematic for a local system. Consequently it appears that community dependence represents the combined effects of 'exposure' and 'sensitivity'; that is, the 'potential impact' of reduction in water availability for agriculture.

Social resilience was assumed to enable resilient communities to sustain social vitality, lessen levels of social distress and enhance social participation. Thus a low level of resilience constrains collective action to manage change; a high degree of social resilience enables collective action to reshape the course of change. Accordingly social resilience as interpreted by Herreria et al. appears to closely resemble 'adaptive capacity' (after Schröter).

Indices that measured the identified aspects of community dependence and social resilience were overlaid to produce an overall index of 'community susceptibility'. The intent of the project was to contribute a better understanding of the complex processes that shape dependency on water resources for agriculture and the capacity to manage changes in agricultural communities.

In summary, terminology adopted by Herraria et al. can be interpreted according to the Allen Consulting Group schematic as:

- community dependence being a measures potential impact
- social resilience being akin to adaptive capacity
- community susceptibility can be likened to vulnerability.

Herreria et al. selected indicators, weighted them and then calculated indices for spatially qualitative assessments of community dependency on water for agriculture [potential impact], social resilience to change in water access [adaptive capacity], and susceptibility of agriculture communities to changes in water use and access at a regional and a national scale [vulnerability]. In their report, they present the results at the national level and at a local scale for one selected region (the Burnet Mary region in Queensland).

In other words, they measured and reported on indicators which they had selected to be representative of community dependence [potential impacts] and social resilience [adaptive capacity] and applied these in an Australian context. This is one of few reports reviewed that presented results which can be assessed to validate or, alternatively, question — and perhaps improve — the approach used.

Not only have results been reported but the authors also outlined the theoretical framework and the hypothesised models for community dependence [potential impact] and social resilience [adaptive capacity] which they have used to construct the methodology for calculating and mapping the indices. They also described their approach to creating the indicators, their dimensions, and indices. Furthermore, they have identified and used indicators that:

- gauge relative outputs
- can be easily understood by general audiences
- are available at a national and sub-national scale
- are readily available from quantitative secondary and reliable sources
- are most likely to be available so that the opportunity to measure changes and trends over time is relatively high
- cannot be highly correlated with any other within the particular dimension.

This report effectively demonstrated one social theory approach that can be used 'to help frame and guide the use of widely available national data sets to help unravel the complex

relationships between agricultural communities and the resources they depend on to maintain their livelihoods’.

The authors recognise that further work needs to be undertaken in regard to the measurement of adaptive capacity.

One apparent drawback with data sources used by Herreria et al. — and this would most likely apply to any contemporary methodology adopted for a project such as this — is the heavy dependency on ABS Census data. This means that changes and challenges faced by local areas during the five inter-censal years cannot be measured as an ongoing process but rather only at the end of that period. Additionally, understanding and measuring potential impact and adaptive capacity are complex matters that should be closely monitored during the development phases of methodological design. Perhaps some additional indices can be incorporated to better measure change as a process and more representatively quantify adaptive capacity. This component would also benefit from qualitative assessment, but that can, of course, be resource-consuming.

Yohe, G and Tol, S RJ 2002, ‘Indicators for social and economic coping capacity — moving toward a working definition of adaptive capacity’, in *Global Environmental Change*, vol. 12, pp. 25–40.

Yohe and Tol claim to offer a practically motivated method for evaluating systems’ abilities to handle external stress. The definition of vulnerability used parallels that of the schematic adopted for the current study; that is, ‘the vulnerability of any system to an external stress (or collection of stresses) is a function of exposure, sensitivity, and adaptive capacity’.

Yohe and Tol stress that adaptive capacity varies significantly from system to system, sector to sector and region to region. They cite the work of others to argue that assessing adaptive capacity depends critically upon (a) defining a coping range — a range of circumstances within which, by virtue of the underlying resilience of the system, significant consequences are not observed — and (b) understanding how the effectiveness of any coping strategy might be expanded by adopting new or modified adaptations.

Eight determinants of adaptive capacity which include a variety of system, sector, and location specific characteristics are identified:

1. the range of available technological options for adaptation
2. the availability of resources and their distribution across the population
3. the structure of critical institutions, the derivative allocation of decision-making authority, and the decision criteria that would be employed
4. the stock of human capital including education and personal security
5. the stock of social capital including the definition of property rights
6. the system’s access to risk spreading processes
7. the ability of decision-makers to manage information, the processes by which these decision-makers determine which information is credible, and the credibility of the decision-makers, themselves
8. the public’s perceived attribution of the source of stress and the significance of exposure to its local manifestations.

The article provides functional representations to add detail and context to their structure of vulnerability with the intent of illustrating that it is possible to build indicators directly from systematic evaluations of the feasibility of available adaptations, taken one at a time, and their relative worth in reducing either sensitivity or exposure.

The authors offer some empirical justification for the roles of selected factors in determining vulnerability. They also construct an indicator for coping capacity from the determinants of adaptive capacity. Furthermore, the article includes a hypothetical example of applying the 'eight determinants' indicator methodology listed above to a nominated river system and exploring how three different adaptation options might alter potential impacts of river flooding. The article reports on an extensive macro-scale assessment of adaptation; specifically, it characterises the adaptive capacity of Dutch society by working through the eight adaptive capacity determinants and quantifying the details of adaptation options against increased risk of flooding in the lower Rhine Delta.

The authors assert that their method when applied forces systematic thinking about adaptive capacity. Indeed, their eight determinants of adaptive capacity might present a useful albeit generalised checklist. However, most determinants have large macro components to them and Yohe and Tol acknowledge that the local manifestations of macro-scale determinants of adaptive capacity can be their most critical characteristics. Accordingly, their representations assume the adoption of remedies at the macro-scale.

Defining micro-scale adaptive capacity determinants that operate independently of macro-scale remedies — with a view to being able to influence adaptive capacity within selected local area systems without necessarily applying remedies at the national, state or MDB level — essentially appears to be the focus of this project even though strengthening such determinants by themselves may not sufficiently overcome potential impacts. Accordingly, this article has limited applicability to our project.

Smit, B and Wandel, J 2006, 'Adaptation, adaptive capacity and vulnerability', in *Global Environmental Change*, vol. 16, pp. 282–292.

Smit and Wandel recognise that adaptive capacity is similar or closely related to a host of other commonly used concepts such as adaptability, coping ability, management capacity, stability, robustness, flexibility, and resilience some of which have been previously referenced in this review. Their article and discussion, nevertheless, is based on the ACG schematic; that is, that adaptive capacity, together with exposure and sensitivity are the components of vulnerability.

The authors draw heavily upon and are to some extent supportive of the theoretical approach to adaptive capacity proposed by Yohe and Tol (2002), namely that this component varies from one community or region (local area) to another, over time, and in terms of its value and its nature. They also recognise that its scales are not independent or separate; that is, the adaptive capacity of a local area reflects the resources and processes of the region, state or nation. Furthermore, a system's adaptive capacity and coping range (one feature of capacity; after Yohe and Tol 2002) are not static. Thus coping ranges respond to changes in economic, social, political and institutional conditions over time and conditions which are within the coping range may introduce unforeseen side effects which will narrow that range.

While these are valid notions, they do not by themselves contribute concepts about or elements of adaptive capacity that have not previously been considered. Furthermore, although they observe that, beyond broadly accepted categories, there has been very little consensus (or documented support) for a robust, specific model of the elements and processes of not only adaptive capacity but also local exposure and sensitivity, they do not appear to remedy for this.

Indeed, the main focus of this article appears to support the active involvement of stakeholders in the local area being assessed so as to 'ensure legitimacy, information collection on relevant phenomena and processes, the integration of information from multiple sources, and the engagement of decision-makers'. With the knowledge and understanding of how the components of vulnerability – including adaptive capacity – interact, stakeholders of the local area could be expected to respond with adaptations that subsequently produce a future or different degree of adaptive capacity.

In the methodology proposed by Smit and Wandel, the goal is not to produce a score or rating of a local area's current or future vulnerability. Rather, the stated aim is 'to attain information on the nature of vulnerability and its components and determinants, in order to identify ways in which the adaptive capacity can be increased' and, accordingly, potential impacts decreased. This approach requires the involvement of stakeholders at the local level throughout this process of attainment to the extent that these members of the local areas themselves identify the component elements of adaptive capacity (also exposure and sensitivity). Thus the article has limited relevance to the methodological constraints which will be imposed on this aspect of the MDB.

Preston, BL and Stafford-Smith, M 2009, 'Framing vulnerability and adaptive capacity assessment: Discussion paper', CSIRO Climate Adaptation Flagship Working paper No. 2, available from: <http://www.csiro.au/org/ClimateAdaptationFlagship.html>

This paper briefly examines various perspectives regarding key concepts associated with climate change vulnerability and adaptation as well as, in general terms, some of the commonly used methodologies and frameworks for assessing vulnerability and its components, including adaptive capacity. As such, the paper could be a useful starting point for gaining a general appreciation of the status of some current beliefs and methods.

The paper acknowledges that there are significant disciplinary differences with respect to how vulnerability is defined and framed. They assert — it appears with considerable validity — that the topic is 'jargon-rich, multi-disciplinary research arena, often burdened, but also enriched, by debate and confusion over meaning'. In effect, it is a recap and update of Brooks (2003) discussion of terms used in the literature, albeit with some references to the Australian context. The authors argue for some consensus to be reached regarding which terms and definitions are most relevant for Australia.

Preston and Stafford-Smith point out that at present there is no framework or formal mechanism in place in Australia for monitoring and evaluating adaptation policies and measures. They assert that any such construction would need to give significant attention

to adaptive capacity as a core component of the vulnerability equation. One reason they promote for this viewpoint is an awareness that adaptive capacity is the component that is perhaps most amenable to management. Moreover, local areas which might be subjected to assessment for vulnerability are most likely generally sensitive to the importance of adaptation and capacity-building in achieving development goals. An understanding of the duality of adaptive capacity — on the one hand as a constraint to future adaptation policies and measures and on the other hand as an opportunity to develop adaptation measures specifically targeted at increasing adaptive capacity — further contributes to its currency. Despite these factors, the authors point out that:

‘... there have been few attempts to evaluate and assess adaptation policies and measures, in part due to the rather recent emergence and uptake of adaptation as a risk management strategy (at least in the context of future climate change) as well as the inherent difficulties of evaluating actions largely designed to address future vulnerabilities.’

The authors suggest that identification of assessment approaches to adaptive capacity that reflect its nested nature while avoiding ‘paralysis through complexity’ may require the development of a different framework and set of methods to those already proposed or simply the more thoughtful application of the existing toolkit.

The value of this paper to the current project is that it essentially confirms that we have not overlooked any key areas in the current thinking on components of vulnerability.

Nelson, R, Kokic, P, Elliston, L, King, J, 2005, ‘Structural adjustment: a vulnerability index for Australian broadacre agriculture’, in *Australian Commodities*, vol. 12, issue 1, pp. 171–179.

An indicator of the vulnerability of farm households to structural adjustment was constructed using ABARE-BRS (former ABARE) farm surveys data. Mapping the index identified regions of Australia where farm households are likely to be most vulnerable to external influences that may force structural adjustment. The method was based on the ‘rural livelihoods’ framework (Ellis 2000) which uses measures of the five forms of capital, as will the measure of adaptive capacity to be developed in the current study.

Alasia, A, Bollman, R, Parkins, J, Reimer, B 2008, *An Index of Community Vulnerability: Conceptual Framework and Application to Population and Employment Changes 1981 to 2001*, Statistics Canada, Agriculture and Rural Working Paper Series.

The following excerpt is taken from the executive summary:

The main goal of this research was to develop two indices of community vulnerability, one [vulnerability] to population decline and one to employment decline, and to investigate the factors associated with the vulnerability for these processes of change.

The concept of vulnerability has been used in recent policy analysis to describe a specific dimension of socio-economic disadvantage. Unlike the notions of economic deprivation, or poverty, which focus the attention on present conditions, vulnerability is a forward-looking concept. In its general meaning, the idea of vulnerability relates to the way in which events

impact on a certain system, and specifically on the likelihood of experiencing loss or negative outcomes in the future [emphasis added] because of particular events or actions.

Vulnerability was defined as the likelihood of a worsening of socio-economic conditions for the community. The conceptual framework for vulnerability analysis at the community level included three types of dimensions-indicators: stressors (for example, exposure to global competition), assets (for example, human capital), and outcomes (in this context, population decline).

Using the “stressor-asset-outcome” framework, a set of econometric models was estimated for the period 1981–2001. All the data used for the estimations were from the Census of Population 1981 and 2001, for 2382 communities. The econometric models estimate the probability of population and employment decline (1981–2001) as a function of stressor and asset indicators in 1981. A total of 29 community and regional indicators were used. The coefficients generated by the 1981–2001 estimations were then used to predict the long term probability of community decline based on the conditions of stressor and asset indicators observed in 2001. This probability represents the Index of Community Vulnerability (ICV), computed for population and employment decline.

The results show that exposure to global restructuring trends increases community vulnerability to population and employment decline. Similarly, other conditions of community distress, such as high unemployment rates and low participation rates, increase the *vulnerability to decline*. *Community assets, such as human capital, economic diversification, and proximity to agglomerations, reduce vulnerability to population and employment decline.*

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