NCCARF Synthesis and Integrative Research Program

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Climate Change Adaptation
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Case studies of extreme events

Resilience and water security in two outback cities

Image: Amanda Slater

Glenn Albrecht, Helen Allison, Neville Ellis and Megan Jaceglav

Historical Case Studies of Extreme Events

Resilience and water security in two outback cities

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

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Preface

The National Climate Change Research Facility (NCCARF) is undertaking a program of Synthesis and Integrative Research to synthesise existing and emerging national and international research on climate change impacts and adaptation. The purpose of this program is to provide decision-makers with information they need to manage the risks of climate change.

This report on Drought and water security: Kalgoorlie and Broken Hill forms part of a series of studies/reports commissioned by NCCARF that look at historical extreme weather events, their impacts and subsequent adaptations. These studies examine particular events – primarily extremes – and seek to explore prior vulnerabilities and resilience, the character and management of the event, subsequent adaptation, and the effects on present-day vulnerability. The reports should inform thinking about adapting to climate change, i.e. capacity to adapt, barriers to adaptation, and translating capacity into action. While it is recognised that the comparison is not and never can be exact, the overarching goal is to better understand the requirements of successful adaptation to future climate change.

This report compares water security issues in two Australian mining communities. Kalgoorlie in Western Australia and Broken Hill in New South Wales are towns with populations of around 30,000 and 20,000 respectively in semi-arid environments with limited local water supplies. Each has a rich history based on mineral resources and, more recently, a developing tourism industry. The catalyst for development has been the exploitation of mineral resources (silver, zinc and lead in Broken Hill and gold in Kalgoorlie); this development has been constrained and tested by water limitations. Throughout the history of each town, the reaction to extreme dry periods and economic booms has been to develop new infrastructure and strategies to deliver more water and increase efficiencies. The challenges of balancing water supply and growth are ongoing and likely to become more severe with climate change.

Other reports in the series are:

- Cyclone Tracy
- East Coast Lows and the Newcastle-Central Coast Pasha Bulker storm
- The 2008 Floods in Queensland: Charleville and Mackay
- Storm tides along east-coast Australia
- Heatwaves: The southern Australian experience of 2009
- Drought and the Future of Rural Communities: Drought impacts and adaptation in regional Victoria, Australia

To highlight common learnings from all the case studies, a Synthesis Report has been produced which is a summary of responses and lessons learned.

All reports are available from the website at www.nccarf.edu.au.

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Acknowledgements

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Executive Summary

In order to assess the past, current and future resilience of the water security of two of Australia's largest inland cities, the Murdoch University research team, within a very tight timeframe, undertook a series of rapid interrelated studies to determine the adaptive capacity of water managers and citizens in Broken Hill and Kalgoorlie with respect to scientifically based projections of a warming and drying climate. A Resilient Regions Assessment Process (RRAP) was used, for the two cities, to generate water resilience histories, qualitative data in the form of key informant interviews and additional data derived from community participation in future scenario assessments at professionally organised and run water expos.

The water resilience histories revealed that, while both Broken Hill and Kalgoorlie share a common context of being mining cities within arid environments, their 'solutions' to the problem of water provision in a highly variable climate have been quite different. Broken Hill has had to endure repeated failure of the water supply system under the impact of episodic drought. Kalgoorlie had the same problems in its early history, but the provision of the Golden Pipeline from Perth in the early twentieth century delivered long-term water security.

Community responses to the four futures scenarios created by the team for each city revealed that the people of Broken Hill, with their history and recent lived experience of severe drought, water shortages and water quality issues, have a far more pessimistic outlook about what the future holds with respect to climate change than the people in Kalgoorlie. The people of Kalgoorlie, with the safety net of a secure water pipeline from the Perth catchment, have much greater confidence that the future will remain reliable and secure through water technology and government support.

The key informant interviews revealed that global warming as a change agent has already delivered system-wide stressors to the local and regional contexts of the two cities. The Perth water catchment and hydrology are well understood by climate and water science, however, during a period of rapid drying, demand for potable water is outpacing supply. The building of resilience by planning and constructing diversity of supply options into the system is a classic adaptive response to the threat posed by declining natural rainfall. However, energy intensive water provision using technologies such as desalination and groundwater pumping has major implications for the cost of potable water, particularly for the remote community of Kalgoorlie. Similar considerations apply to Broken Hill, as it is dependent on the health of the Darling River for its water security once local storage is exhausted, and, as has been graphically shown with the recent (August 2010) release of the Guide to the Murray-Darling Basin Plan, the politics of water can readily trump the science of water.

The Murdoch research team has suggested that understanding the water 'panarchy' (Gunderson and Holling 2002) for both cities entails a system-wide understanding of the multiple interacting components of the social-ecological system in the context of a relatively new and powerful factor influencing every aspect of the evolution of the total system: climate change.

We argue that at present in both Broken Hill and Kalgoorlie, water professionals and some citizens have an emergent understanding of the complexity of the social-ecological system and produce

adaptive responses such as diversification of water supply and storage options, increased storage capacity and better water management (on both the demand and supply sides). All these adaptive responses increase water resilience; however, as climate change has the potential to push systems into unstable states with limited predictive capacity, further adaptation to such situations becomes difficult.

The water managers and citizens of Broken Hill will be capable of responding to water insecurity with adaptive change more readily than those of Kalgoorlie. This is because they have historical experience and a collective memory of water supply crisis and occasional failure. The citizens and water managers of Perth and, in particular, those in Kalgoorlie, will find the surprise events of a drying climate more difficult to anticipate and respond to as, for the last one hundred years, they have never had to contemplate the reality of looking at the bottom of the glass.

1. Background to the study

This project explores the adaptive capacity of two relatively large inland regional cities facing different challenges relating to climate change and water supply on two sides of the continent. Kalgoorlie in WA and Broken Hill in NSW are towns with populations of around 30,000 and 20,000 respectively in semi-arid environments with limited local potable water supplies. Each has a rich history based on mineral resources and a developing tourism industry. However, they face different resilience problems in the face of climate change and variable water supply.

Kalgoorlie is reliant on transported surface water and some groundwater from the Gnangara aquifer pumped through the Golden Pipeline from Mundaring Dam about 560 km away in the Darling Range catchment near Perth. Kalgoorlie has no alternative water source other than a possible desalination plant and another pipeline from coastal Esperance over 350 km south. Kalgoorlie will experience little direct climate change impact but a strong climate change impact on the source of its water supply. The natural water sources supplying the Perth catchment are under intense pressure with desalination already supplementing declining rainfall. Despite the likelihood of increasing costs for potable water, Kalgoorlie has a strong economic resource and population base that will continue to be supported by Government.

On the other hand, Broken Hill has a much diminished mining industry but strong social base and an emergent economy as an 'outback' tourist destination. With substantial industrial and domestic requirements for water, Broken Hill remains totally reliant on limited local groundwater catchment and irregular inflows to Menindee from the Murray-Darling Basin. The Australian Government is currently supporting further investigation into regional groundwater resources and the potential for managed aquifer recharge. There has also been speculation about the possibility of a connection to a proposed BHP coastal desalination plant 350 km away at the head of Spencers Gulf in SA.

Without a full understanding of the likely impacts of climate change, extreme variability and the increased technical difficulties and economic costs of providing potable water in remote communities, the future resilience of Kalgoorlie and Broken Hill is not secure. This project assessed stakeholders' current understanding and appreciation of climate variability and extremes. In the light of that understanding, Murdoch University then assessed community views on water security in the form of responses to futures scenarios at two water expos. The water expos provided information on the implications of community demand for water and water resource availability in the context of a hotter and dryer climate.

2. Project Objectives

1. To outline the challenge of water security and sustainability for the inland cities of Kalgoorlie and Broken Hill;
2. To identify the historical and current processes which interact to create this challenge, and which also provide the basis for a systematic understanding of water resource use;
3. To provide a range of water security future scenarios that will assist in planning for and adapting to climate change and other pressures; and,
4. To consider the infrastructure, cultural and organisational change needed to meet the water security and sustainability challenges for each city.

3. Outcomes

The research team:

- Produced research data on past and contemporary water issues for each city/region;
- Identified current stakeholder understanding of the complex issue of water security;
- Evaluated institutional and organisational capacity to manage change;
- Evaluated community willingness to live with the change; and,
- Trialled a research method that can be used and replicated in other contexts in Australia.

4. Methods

A Resilient Regions Assessment Process (RRAP) has been developed to enable delivery of project objectives. It has been developed by the research team to produce a transdisciplinary framework to evaluate water issues in the two cities. It consists of:

1. Literature Reviews;
2. Water Resilience Histories;
3. Key Informant Interviews; and,
4. Community Water Expos - Understanding the issues and incorporating resilience futures, which included different futures scenarios based on differing degrees of water scarcity, as defined within climate science, technological options and water price scenarios.

The combination of environmental history, qualitative research methods, resilience and complexity thinking and futures scenarios as a rapid assessment methodological approach to the issue of climate change and water security is, we believe, relatively novel.

4.1 Literature review

The literature review briefly reviewed the principal methodological literature underpinning the project in order to establish authenticity and assembled the relevant technical and cultural data on the two cities and their immediate regions in the context of domestic, commercial, agricultural and industrial demands for water. The material assembled enabled an overview of the key domains relevant to a transdisciplinary (Albrecht *et al.* 1998) view of water in the contexts of Broken Hill and Kalgoorlie. In order to develop and refine the key informant questions and the elements of the futures scenarios used in the water expos, a wide range of literature was consulted and incorporated into the new common transdisciplinary conceptual framework of the RRAP.

In the context of Australia, environmental histories allow us to examine the biophysical, Indigenous and colonial context of water (Dovers 2000). Social water histories (Cathcart 2009) are relatively new contributions to environmental history and are much needed in the consideration of general water resilience thinking. Water resilience histories have been documented for each city in order to describe the biophysical foundations for water security and to account for the ways the challenges of water needs have been met in the past. The engineering and technological responses to water needs have been documented as have the relevant cultural and political responses.

The use of complexity theory and resilience thinking in the research proposal was compelling, since the key issue of climate influenced water security in inland cities is one that fits the key elements of a 'panarchy' (Gunderson and Holling 2002) or an issue that must be understood within nested systems and sub-systems that evolve (change) over time. Complexity thinking opens up the idea of non-linear development in the face of disturbance or perturbation and some of the general characteristics of complex adaptive systems (CASs) apply to the issue of water resilience or the lack of it. The aspects of CASs that apply to this research project include:

- Local interaction can produce global order and global order can affect local behaviour;
- The role of disturbance can be both creative and destructive;
- Small changes to initial conditions can generate large changes to system behaviour; and,
- The dynamic interaction of local and global levels of complex systems determines their properties (Albrecht and Higginbotham 2001).

In a case study of the Goulburn-Broken Catchment, Walker and Salt (2006) apply resilience thinking to the issue of local land and water management in historical context. While instructive at the local level, this pioneering resilience case study does not engage with climate change as a major additional factor driving system resilience and evolution. This study of Broken Hill and Kalgoorlie is centrally engaged with externally imposed climate change as a global factor driving local and regional system evolution and since this factor is powerful enough to drive regime shifts in the total system, it is a major threat to resilience and, hence, to sustainability.

Walker and Salt (2006) also use future scenario building to illustrate key aspects of complexity, systems and resilience thinking. They argue:

> *Scenarios help organise information, and they are easy to understand ... Scenarios allow us to consider several possible futures instead of trying to predict a single one. These possible scenarios are not likely to come true exactly as described in the scenarios, but they let us think in broader terms about the impacts of the plans and choices we make, and how to make the kinds of system regimes we might like more resilient (Walker and Salt 2006).*

In this research, we have used contrasting futures scenarios to stimulate citizens' thoughts about possible futures and help them make connections between the diverse elements of what is a complex issue without the use of overwhelming amounts of technical information (World Business Council for Sustainable Development 2006, Wilkinson and Eidinow 2008, Gallopin 2002, Van der Heijden 1996). The relationships between temperature, runoff, rainfall, evaporation, economic and demographic variables are extremely complex and the scenarios allow the complex relationships between multiple variables to be easily seen from a non-expert perspective. Each scenario is internally consistent and plausible given certain assumptions about how the future will unfold.

4.2 The Futures Scenarios

The scenarios were created in the context of different climate change outcomes, a range of water technologies, economic conditions, mining activity and cost factors for the delivery of potable water. The scenario images were created from photographs of the town centre of each city and then digitally changed to create a picture for each scenario of the city in 2070. They were printed at AO size, large enough for the viewer to feel immersed in the scene. We were seeking a considered response from both the poster images and the support information/data. The support information was provided on A4 sheets with the scenario image on the reverse side (see Appendix 1 and 2). The scenarios were presented as poster displays in the community water expos with the opportunity for citizens to provide immediate responses to the research team by placing a vote in the form of a coloured sticker on a matrix of possibilities for the future vision they saw as most realistic and likely. The AO size matrix poster on which they placed their vote was constructed so as to provide the opportunity for discrimination based on a continuum from strongly held view to those that were weakly held.

The following summary provides an overview of what each scenario was attempting to convey about climate change and the future:

Scenario 1: She'll be right mate!

This scenario represents a secure and prosperous future for both inland cities. It depicts a future with no significant change to the climate of the region or the water catchment region. Water is still in plentiful supply. Projections of future mining activity are positive with new mineral discoveries. Life will go on much as it has in the past without major changes to the availability or price of water. Hence there is no pressing need for major adaptive responses. While the research team was aware that this scenario is impossible on current projections for the changing climate, nevertheless it was included to cover the possibility of mitigation negating the threats of a warming world. In addition, in the light of common knowledge about strongly held views about climate change in both communities, there was a need to acknowledge that some in the respective communities might respond to a scenario that allowed them to give expression to a degree of scepticism or even denial about the impact of climate change on the future.

Scenario 2: Chill out man! It’s all sorted!

This scenario represents changes to the climate under a model of low emissions. It depicts a future with increased temperature, reduced rainfall and increased evaporation. The adaptive response is increased investment in technology on a large scale with much greater cost to consumers. There is a diversified economy with new employment opportunities.

Scenario 3: Mmmmmm………it’s not looking good.

This scenario represents change in climate under a model of high emissions. The sky portrays storm activity representing an increase in extreme weather events. The decline in mining of the present day continues and mining is no longer part of the economy. Government provides less support to the provision of infrastructure. The key adaptive response is self-reliance with water and power mainly supplied by small scale systems. There is a much reduced and ageing population.

Scenario 4: Up shit creek (Kalgoorlie) “We’ll all be rooned” said Hanrahan (Broken Hill)

This scenario represents the cities with a change in climate at the extreme end of high emissions models. Mining is exhausted and there has been no diversification in the economy to support a population. One hotel remains open to provide for a small tourism industry with off-road vehicles the only passing traffic.

4.3 Community Engagement and the Water Expos

Key informant interviews and two community water expos (one in each city) were used as two-way conduits for information gathering and sharing. The community water expos facilitated both stakeholder and community involvement. Stakeholders were invited to attend the water expos as exhibitors and, in addition, were able to see how their own communities responded to the futures scenarios over the course of the expo event.

The two community water expos were professionally organised and managed events where ‘water’ stakeholders were invited to display their policies and practices and where community members could gain information. As two-way conduits, they were the prime mechanism for the researchers to characterise community understanding of water supply issues past, present and future.

The water expos were conducted in Kalgoorlie and Broken Hill on 16 and 24 June 2010 respectively and the research team presented four possible futures for each city. In both cities, prior to the expos, large colour advertisements were taken out in the local papers and a press release sent to all relevant media outlets. Citizens were invited to attend the expos in order to get information from Government and NGO exhibitors and to participate in the research question “What is the future of water?” in each city. Participants in the two expos were those citizens who responded to the advertisements and /or the publicity associated with the Murdoch University initiated expos.

5. Regional Resilience Histories and Water

5.1 Broken Hill

5.1.1 Summary

With the major remaining large-scale Broken Hill mine set to close in ten years, the future economic security of Broken Hill is not secure. The mines still heavily subsidise water prices in Broken Hill and remain the main users of water. However, when they close, the costs of upkeep of old, and provision of new, infrastructure will have to be fully met by consumers and the taxpayers of NSW. In a more severe climate regime where the whole of the Murray- Darling Basin is under intense pressure, Broken Hill might not have a strong case to defend its continued 'subsidised' existence in the face of a continent-wide retreat to the coast to be close to secure supplies of potable water.

The people of Broken Hill, historically, have shown great resilience in the face of a highly variable climate. The past engineering strategies used to build such resilience into the natural variability have been impressive and the professionals who have run this system have themselves shown great creativity and resilience in the face of multiple water security crises. It can be reasonably concluded that the people of Broken Hill, above all others in Australia, are capable of higher degrees of resilience in the reality of even greater variability and extremes under climate change and global warming. However, while the water engineers might be able to continue to guarantee water security with large corporate and government subsidies, they might not be able to do so in a harsh cost-recovery economic climate. If the mining corporations go, and a hotter climate enters, Broken Hill might not have a secure future.

The increasing cost of building greater resilience into the water catchment and supply system has already generated public concern in the city of Broken Hill. In 2009, a well attended community forum on water pricing expressed heated opposition to current prices and projected cost increases of 10% per annum over the next three years. Water is a "hot topic" in Broken Hill as a major crisis in water availability and quality was recently averted only by drought-breaking rains in the regional catchment followed by a 1 in 100 year flood event in the Murray-Darling Basin. A ten year period of extreme dryness in both the region and the wider catchment was relieved by natural rain events at a critical moment. In 2002-3 the city of Broken Hill almost ran out of water and the resumption of bulk water imports by train was seriously considered. Again, chance rainfall alleviated a crisis situation.

The need for water security for the city of Broken Hill has seen the two major agencies, Country Water and State Water, invest in new plant and infrastructure to maintain a reliable water delivery system. There is much discussion within these agencies and by community leaders about the various options for Broken Hill to maintain a reliable and resilient water supply. However, all options entail major engineering considerations and significantly increased costs. Moreover, a lack of serious consideration of the possible failure of both regional and catchment-wide water supply options suggests that more future planning is necessary.

A hotter and dryer climate and the implications of this for water storage and retention will likely generate new system-wide considerations of water security and resilience. The water supply issues in Broken Hill provide an illustration of the benefits of a ‘systems perspective’ on water. The case study of Broken Hill displays classic complex systems’ characteristics where the biophysical component covers a large geographical extent, the climate is naturally highly variable, major human activities in the catchment such as irrigated crops and mining are water intensive, the climate system itself is changing and technological innovation is providing new opportunities for adaptive management. As such it is possible to see the totality as a social-ecological complex adaptive system with water resilience a possible, but never guaranteed, emergent property (see Walker and Salt 2006).

5.1.2 Climate Change, Water and Indigenous History

Climate change is not a new phenomenon to those Aboriginal people living in central and inland New South Wales who possess traditional knowledge. The Aboriginal history in this region has been shaped by powerful climatic changes which have seen the landscape transform over tens of thousands of years from fertile wetlands, to barren saline wastelands, to the conditions we see today (White 1994).

Evidence of Aboriginal occupation in this region dates back 45,000 years with the discovery of Aboriginal archaeological remains at Lake Mungo. During that period the lakes of the Murray basin and Willandra Lake region were extensive when full. Lake Mungo would have been some 20 kilometres long, 10 kilometres wide and 15m deep (Flood 1983). On its shores lies evidence of the biological productivity within the lake, with masses of shellfish remains or middens piled next to ancient fireplaces, a scene replicated at the Menindee Lakes. Here also lie the remains of ancient stone tools, hearths, ochre and evidence of ritual cremation, the oldest in the world (Flood 1983). Evidently these communities were dependent upon the fresh water of the lakes.

About 21,000 years ago the lakes began to dry, coinciding with the peak of the Glacial Maximum (ice age). As the temperature dropped the land became hyper-arid and saline (Mulvaney and Kamminga 1999). Eventually the Willandra and Menindee lakes dried altogether, and the Murray basin became a “saline wasteland” (White 1994). In meeting the demands of the changing climate the Aboriginal people migrated away from the drying lake regions for the more secure waters of the Darling and Murray rivers. In addition, local economies were transformed with the development of grinding tools and mortars from freshwater to grass seed based economies. As the Glacial Maximum receded, temperature and rainfall began a steady change to modern day levels. The Willandra lakes were left permanently dry apart from the occasional flood run-off, however, the Menindee lakes still held water and its shores became more heavily populated than ever before with the development of more permanent base-camps (Mulvaney and Kamminga 1999).

It is evident that climate change and the resultant changes in natural water systems dramatically affected Aboriginal history in inland New South Wales. The Aboriginal peoples responded to the changing climate by altering their settlement patterns, local economies and by developing new technologies (Flood 1983). However, local Aboriginal populations did not just respond to crisis, they also planned ahead and provide evidence of adaptive management in the face of major change.

5.1.3 Aboriginal Water Management

Across Australia Aboriginal peoples engaged in water management activities for either the storage of water itself or for the production of food (Laudine 2009). According to Langton (2006) Aboriginal societies construed water sources beyond their physical domain to inform cultural and spiritual histories, social obligations and personal identities. Thus Aboriginal water management practices resulted from Aboriginal worldviews which entwined physical water systems with spiritual and cultural significance. This made Aboriginal societies sensitive to the fluctuations in Australia's water systems and allowed for the creation of water engineering that took into account seasonal variations. For instance, in several sites in the Western District of Victoria, an area characterised by drought and flood, fish weirs were constructed to store water in the summer and regulate the system during times of flood. Some of these structures were immense; a weir constructed at the foot of Mt William covered at least 15 acres. These systems were built to optimize water and food supplies during seasonal variations.

Equally impressive structures were found along the Darling at Brewarrina in western New South Wales. Here, the Ngemba people built the largest series of fish traps in Australia, extending some five hundred metres down the river. This system was called Ngunnhu and was used to capture fish as they migrated up stream (Cathcart 2009). It was believed that the ancient dreamtime ancestor Baiame spoke of Ngunnhu and taught the Ngemba people how to use it. The fish were chased into smaller and smaller ponds and either immediately speared or kept live in storage. The great abundance afforded by the Ngunnhu allowed for great gatherings on its shore. These were times for feasting, religious ceremony, games and tests of ability (Dargin 1976). Other fish traps have been reported 40 kilometres north of Brewarrina near Collewarry, on the present site of the Bogan River weir, and along the upper Lachlan and Murrumbidgee rivers (Laudine 2009).

The intersection of Aboriginal cosmology and water management allowed Aboriginal peoples to exist in one of the driest places on Earth for thousands of generations. Sensitive to the fluctuations of the seasons, Aboriginal peoples engineered resilience into local water systems which allowed the development of sustainable cultures with relatively simple technologies. These were people finely attuned to the characteristics of the Australian climate, able to adapt themselves and the environment to the demands of a highly variable climate.

The adaptations made by Indigenous people in the Murray-Darling basin in general, and in specific locations such as the Broken Hill region in particular, provide strong evidence that humans are capable of extensive adaptive responses to changing climates/environments. It remains to be seen if contemporary humans operating within a very different economy and lifestyle have similar adaptive capacity in the face of an even hotter and dryer climate than that experienced long-term by Indigenous people.

5.1.4 Colonial Settlement and its Relationship to Water.

Broken Hill incurred massive social and ecological change from its meteoric rise as a mining town in the 1880s to the development of the Menindee Lakes pipeline in the 1950s. In the space of a few decades Broken Hill rose out of a semi-arid landscape to become a world-significant mining community of 30,000 citizens. The influence of mining in Broken Hill reached beyond its locality, spurring industrial growth along Australia's eastern and southern seaboards and beyond to the industrial complexes of Europe. The rise of multinational mining companies such as the Broken Hill Proprietary Ltd owe their beginnings to the rich boomerang shaped lode of silver, zinc and lead which, as it was mined and processed, saw billions of pounds/dollars flow through the financial centres of Australia and its stock exchanges, buffering the Australian economy against several worldwide economic downturns. Yet, despite its influence, Broken Hill was a town often defined by deplorable social conditions resultant from the impacts of mining (eg lead dust), disease and the lack of water. This analysis further examines two key drivers, climate variability and mining, in relation to their impact on the social-ecological context of Broken Hill's water supply from its beginnings to the development of the Menindee Lakes pipeline.

5.1.5 Natural Climate Variability: Drought and Flood

The reoccurring cycles of drought and flood have significantly impacted upon the development of Broken Hill and its water supply. The aridity of the Barrier Range, upon which Broken Hill is situated, was noted by the first explorers to pass through the region. On an expedition to Lake Torrens, Surveyor-General of South Australia Captain Frome noted "*a succession of apparently barren ranges running north and south*" but he made no attempt to investigate the ranges (Hardy 1968). It was not until late 1844, after a year of pushing inland, that Charles Sturt and his team first penetrated the ranges. By this stage in their expedition Sturt and his men had already endured severe hardships, "tortured" by the unforgiving "molten desert" and the "ravages of thirst". Sturt camped on what was to become the shores of the Stephens Creek reservoir before pushing further onward, ultimately into the heart of the Simpson Desert (Hardy 1968).

The aridity of the region meant that the settlement of the Barrier Range region was not forthcoming. By 1866 a few sheep stations occupied the plains around Broken Hill and the Mount Gipps station was only nine miles from Broken Hill. A few soaks and wells were noted at this time, however, the lack of water meant small scale agriculture was not viable, giving rise to massive sheep stations. As Blainey (1968) put it, this was a land in which "acres were measured to the sheep, rather than sheep to the acre".

Silver was discovered on the Broken Hill site by Charles Rasp in September 1883. By mid 1885 Rasp had floated his company, the aptly named Broken Hill Proprietary (BHP), and mining began in earnest. The township swelled from 30 tents, 23 houses, 15 huts, 3 hotels, 2 blacksmith shops, 1 general store and a few sheds and humpies in 1885, to a population of 17,000 in 1888 and onto 31,000 by 1907 (Hardy 1968). Mineral exports grew at a staggering rate, from 600,000 tons in 1887 to 3.5 million tons in the year ending 1891 (Hardy 1968). All the while local water resources dwindled with each new resident and mining development. Heroic efforts to secure water supply included camel trains from river ports to Broken Hill and Wilcannia.

5.1.6 Water Security

It has been estimated that, over the long term, the Broken Hill region has received an average rainfall of 9.75 inches per year (Evans 2001, p. 176). However, averages can be deceiving as they do not depict seasonal and yearly variation. For instance, during the boom of 1888, Broken Hill received just 3.5 inches for the year, 2.0 inches of which fell in early February leaving 1.5 inches for the remainder of the year (Hardy 1968). From 1888 to 1952 Broken Hill experienced no less than five drought events, spanning two to five years each. Even this statistic can be misleading as such analysis does not take into account slow moving climate variations across decades or centuries (see Davis 2007).

During each drought event, engineering schemes were promoted to deliver Broken Hill from its water shortage. For instance, the combined drought and boom conditions of 1888 produced the Stephens Creek Reservoir. As demand out-stripped supply during the 1902-1903 drought, railways were completed so that water could be delivered via rail-cart from neighbouring Silverton and across the border from South Australia (Hardy 1968). The use of rail-carts to supply the dwindling water supply of Broken Hill was utilized in each subsequent drought (1925-26, 1941-46, 1948-51) up to and even during the building of the pipeline. Drought conditions also spurred the construction of the Government-built Umberumberka dam in 1914 and ultimately the Menindee pipeline itself.

In each instance the belief that the newly constructed engineering feat would save Broken Hill from episodic water shortages was confirmed with good rains and contradicted with each subsequent severe drought.

5.1.7 The Socio-Political Context of Change 1888-1940

Climate conditions coupled with mining developments, shifts in government policy, civic attitudes and world economic conditions interacted to produce shifting socio-political contexts under which each water engineering feat was developed and implemented. In 1888, with a mass of people arriving at the newly established mining fields, the residents of Broken Hill pleaded with the NSW government for the provision of a water supply. Locals had begun to dig their own small storages to collect the meagre rainwater. Although well intentioned, when the rain finally came, the drinking water often overflowed and mixed with households' cesspits, bringing devastating typhoid epidemics. These epidemics persisted well into the 1920s. In addition, blast furnaces, used for the extraction of silver, were inundating the town with lead dust. Lead poisoning was cited as one of the main sources of illness in Broken Hill. The problem was so bad that residents complained that they could not rear stock or domestic animals. The lack of water meant the cost of running a bath was beyond what an average resident could afford. Miners, filthy from an underground shift, were constantly covered in the toxic dust and were accumulating heavy metals in their bodies. So too were the children of the town with cumulative effects of lead poisoning readily apparent in unfortunate cases.

The Barrier country was geographically and economically isolated from the distant "Sydney Government" and, furthermore, much of the wealth produced from the mines was directed into the Melbourne and Adelaide stock exchanges. In addition, prior to Broken Hill, Sydney-based government had already invested in costly water projects in a few ephemeral mining towns near the Barrier, only to see the capital expenditure end in nothing but dust during the droughts. Indifference towards the plight of Broken Hill on behalf of the distant Sydney Government in conjunction with the severe drought conditions gave rise to competition among several newly established local water companies, resulting in the birth of the privately owned Broken Hill Water Supply Company and its reservoir at Stephens Creek. However, fearful of a private monopoly, the NSW Government ensured that the Water Supply Company could not control the price it would charge for its water to both domestic customers and the mines. In addition, Government proclaimed the company was to hand over all operations to the Government without compensation in 28 years (Hardy 1968).

Ironically the clauses in the Broken Hill Water Supply Contract that were meant to safeguard the government from costly capital expenditure on Broken Hill's water supply led to greater Governmental involvement. In the drought of 1902-1903, resenting its limited tenure and lack of control over water charges, the Water Supply Company was reluctant to expend capital. At the time, the future of the mines was uncertain and mine owners were also reluctant to help. With the Government footing the cost, the Broken Hill municipal council organized water rail lifts from South Australia to supply domestic and industrial water needs. Also, in desperation, construction of the Umberumberka reservoir began without Parliamentary authorization. As the drought progressed the mines slowed operations, the two breweries closed and unemployment soared. Relief rains came in late August 1903. For the first time since its construction in 1892 the Stephens Creek Reservoir filled to the brim and overflowed. Works at Umberumberka were discontinued by the NSW Parliament in favour of a scheme at Yancowinna Glen. The Water Supply Company did not share the Government's vision and renounced involvement in the project. The cycle of worry and apathy had begun.

As mines began to develop floatation processes for the extraction of silver, lead and zinc, they required additional amounts of industrial water. It quickly became evident that, if the mines were to continue to reap the revenue of the Broken Hill lode, much more water would be required. With the costs of the water rail lifts still escalating, the NSW Government passed the Broken Hill and Umberumberka Water Supply Act in December 1906 for the provision of a Water Trust. The Trust consisted of representatives from the government, the Broken Hill Council and each of the major mining companies. The mining companies were to lend 200,000 pounds to the construction of the Umberumberka reservoir. This was the first real coming together of the mines and government. Despite good intentions, by May 1908 the mining companies had only raised 100,000 pounds.

With growing community pressure and the rise of the Labor party's influence in NSW, the Government took control of the Trust's operations by the end of 1908. The Broken Hill water supply had finally been accepted into the fold of the Sydney Government (Hardy 1968). By 1915 works at Umberumberka were nearing an end and the town was transformed. Seventy seven miles of reticulation pipes had been laid down in Broken Hill town along with another six miles supplying the mines. Over two thousand homes were now connected to a water supply at a cost of 425,000 pounds. The mines accepted a higher charge for water so that the scheme could be paid off as soon as possible. By 1916 the Stephens Creek reservoir came under control of the Government. Fifty thousand pounds were spent removing silt and making additions to the ageing reservoir. It appeared at this time that Broken Hill's water problems had been resolved.

Conditions in Broken Hill remained relatively stable for the next three years. The new-found water security allowed some civic greenery to appear and gardens to grow. Although water use was still restricted compared to other towns, there was finally enough to go round. However, by January 1925, Stephens Creek was once again practically dry and Umberumberka was struggling to meet the peak summer demand. According to Hardy (1968), “a supply which had seemed a permanent solution to the water problem in 1915 was no longer satisfactory”. Typhoid once again ravaged the townspeople and living conditions became intolerable.

According to Blainey (1968) rail lifts were once again sought from South Australia. However, the neighbouring state was also suffering a severe drought. The nearest viable water source available was Adelaide, a haulage of over 300 miles with a change of gauge midway. These difficulties made the cost of water transport prohibitive. To make matters worse Broken Hill was connected by rail to Menindee but the connecting link with the rest of the NSW system from Condobolin had not been completed. Blainey (1968) observed that:

> *... a rail lift of water could not be organized without the necessary standard gauge rolling stock, and there was no way of sending this direct. The Public Works Department enlisted the aid of the railway Commissioners and the incredibly cumbersome business began of dispatching the necessary locomotives and tank wagons by sea from Sydney to Port Pirie. Here, each item had to be dismantled for haulage to Broken Hill by the narrow gauge South Australian and Silverton Tramway systems. In the event, only one of the four trains sent from Sydney was ever commissioned.*

The drought broke on 17th March 1926 after only one train had commenced running from the Darling to Broken Hill. Had the drought continued it had been planned to rail four million gallons per week to enable the mines to work part-time and to ensure some sort of domestic supply (Hardy 1968). Throughout the entire crisis the mines were forced to reduce their operations by half for a fortnight, and altogether for only a week. Complete economic and social disaster had been narrowly averted.

Reeling from the costly intervention in 1926, the NSW Government was more willing to listen to other proposals for a permanent solution to Broken Hill’s water supply problems. The Parliamentary Standing Committee on Public Works was commissioned to investigate the feasibility of schemes at Yancowinna Glen and of tapping the Darling River. The committee found that any augmentation would add to the cost of water, a cost not willingly accepted by townspeople or the mining companies. As chief engineer for the Water Supply Company put it, from the point of view of the mines, the issue was a matter of “what is the amount of security you are prepared to buy?”(Hardy 1968). Departmental policy over the next decade was one of gradual improvement of the existing systems but again apathy set in.

Throughout the 1930s, Broken Hill enjoyed a decade of stability and increased wealth. The “silver city” had become one of the largest producers of lead and zinc in the world. This up-turn assured the longevity of Broken Hill’s mining industry. This new conception of the city saw new standards of civic pride emerge. Further parks and sporting fields were constructed; its streets were lined with trees and its barren southern and western sides were subjected to a native plant regeneration effort within designated regeneration areas. By 1938 a confident NSW Government approved plans at Yancowinna Glen and the construction of a sewerage system. By the end of the 1930s Broken Hill and the NSW Government had been lulled into a false sense of security. Increasing demands for water from the mining industry coupled with the more liberal attitude to water from local residents placed greater pressure on existing water supplies. The lessons from the last decade had been forgotten.

5.1.8 Crisis and the Pipeline

By the end of 1941 Broken Hill was dry yet again. Stephens Creek had run out and the Umberumberka dam could not meet peak summer demand. Coupled with drought, fuel shortages and an increased price of coal, the cost of water rose. By 1944 the water situation was dire; Stephens Creek had been dry for the fourth year in succession (Hardy 1968). By August rail lifts had commenced again from the Darling River, with two trains a day delivering water to the drying town. By November that year the deliveries had increased to eight per day.

In the same year the mining companies jointly hired J. R. Dridan, an expert water supply engineer from South Australia, to report on augmentation of Broken Hill's water supply. Dridan reported that the capacity of both Stephens Creek and Umberumberka had been severely reduced due to siltation, a condition that would ultimately render Umberumberka useless within thirty years. In addition to dismissing the augmentation of local supplies, Dridan also reported that the Yancowinna scheme would not be able to meet Broken Hill's increasing water demands. After consideration of several proposals to draw supplies from different locations along the Darling and Murray Rivers, Dridan concluded that the original plan to tap the Darling at Menindee was to be preferred. Dridan argued that the Menindee-Broken Hill pipeline would provide the most cost effective solution to Broken Hill's water needs, that augmentation of the Menindee Lakes would not impinge upon riparian rights downstream, that it would provide storage of water for 16 months even when the Darling was not flowing, and that the unit price of water would be between 36-43d per 1,000 gallons depending upon its use as a primary or supplementary water supply. Spurred by the increasing costs of railing water, the Broken Hill Water Board adopted the Darling River Proposal.

The drought broke in mid 1946. The price of water now stood at 45.42d per 1,000 gallons. Between August 1944 and January 1946 water trains had operated continuously. A total of 172,433,000 gallons of water was transported via rail from the Darling River at Menindee to Broken Hill. One hundred and thirty six million gallons were consumed by the mines, 36 million by the town. In total the water trains travelled just over 280,460 miles. Despite the prolonged drought Hardy (1968) suggests improved rail and road communications plus the addition of air services made the drought more tolerable for Broken Hill residents.

By January 1947 the Water Board had to rethink its Darling pipeline. Broken Hill was enjoying a post-war boom; zinc and lead prices had sky-rocketed and mining had accelerated. Again there was another influx of people looking to earn quick money in the booming resource sector. Within the next decade the Zinc Corporation sponsored the construction of 1,200 new homes, particularly in Broken Hill South. At the same time the old frugality in the use of water was abandoned as residents demanded an improved standard of living to complement their new found prosperity. The Water Board increased the pipe size from 20 to 24 inches with a capacity to deliver an additional 0.5 to 1 million gallons per day.

By the end of 1950 only 10 miles of the required 62 miles of the Menindee pipeline had been built. Hardy (1968) suggests this was due to labour shortages attributable to the mining boom. However, Broken Hill was soon in drought again. By November 1951 rail lifts had commenced, continuing into February 1952. During this time construction along the pipeline was intensified. On June 11th 1952 the pipeline was finally completed. The pipeline, which was first dreamt of by Harry Stockdale in 1888, was now a reality, at a cost of over 2 million pounds. The final piece of the works was finished in 1958 with the completion of Weir 32, a 15.5 foot high weir that was built to ensure water security at the Darling River as part of the Lakes Storage Project. The feeling of the time is captured by Hardy's summation of the finishing of the pipe line and Weir 32:

> *Because of the Lakes Storage and the pipeline life on the arid Barrier has been transformed. Although as the demand for water in Broken Hill continues to rise….the Board's worries with regard to adequate storage are virtually at an end, and the city should never again know the anxieties of water famine. (1968).*

5.1.9 The Current Situation

Needless to say, the water crises of the 1940s and 1950s were not the last. In 2002-2003 the situation again reached a critical point, so much so that a contingency plan to transport water by train was put back on the agenda despite the potential multi-million dollar cost and a portable desalination plant was installed (but not used) in 2004 for emergency water production. In addition, because the water residue in the Menindee Lakes was so high in organic matter and salt, water quality suffered, so much so that many citizens still, in 2010, will not drink the scheme water, despite the recent commissioning of a new water treatment plant. In addition to the public health risks, the highly saline water extensively damaged hot water systems and other water-based technologies such as evaporative air conditioners.

The water crisis of this period also prompted a voluntary water conservation strategy for the city which has been successful; however, there have been unforeseen consequences as a result of its success. One is that the sewage system requires constant flushing to remain viable and too much water conservation in the home leads to system failure. A second is that the mining legacy of Broken Hill includes lead dust, and water is needed to minimise dust levels in gardens and public places. In the face of concern about blood lead levels in children, Broken Hill had previously embarked on a 'greening' strategy that countered dust with lawns, gardens and well vegetated public places and parks. However, under water conservation pressures this was reversed from 2004 onwards and the public health consequences of minimisation of greenery in the city, particularly lead exposure in children, have yet to be fully quantified. A third consequence is that, with an elderly population, dependence on high water use evaporative air conditioning systems for household cooling, water restrictions and increasing costs will see a rise in heat related health impacts. Hence, although water conservation is necessary, in a hot climate mining city such as Broken Hill, the consequences of conserving and reducing water use have yet to be fully considered.

With an official drought declared from 2005 onwards, the breaking of the regional drought in March of 2010 has seen the city once again narrowly avoid a major water crisis. While the Murdoch research team was present in May 2010 to conduct key informant interviews, the Menindee lakes were filling from the record Queensland floods and, with Umberumberka and Stephens Creek at capacity, it was estimated that Broken Hill had at least two years of water left in the pipeline.

5.1.10 Key Informant Interviews

The key informant interviews undertaken in May of 2010 by Murdoch University revealed that, while individuals were highly aware of their own role and responsibilities with respect to the provision of water, there was little evidence of awareness of system-wide issues. There is, however, an emerging awareness that change in one part of the complex system that is Broken Hill's water supply generates change in other parts of the social-ecological system. Water conservation leads to sewer flushing problems, greater toxic dust issues and potentially, greater heat stress in an elderly and vulnerable population. In a toxic landscape and a hot, dry climate, water conservation has its limitations.

A more serious systemic problem emerged as the interviews revealed that civic leaders, water management officials and community representatives all had differing views as to what might finally secure a reliable water supply for Broken Hill.

The following options to deliver more water to Broken Hill have been compiled from notes taken from the key informant interviews:

- Lachlan River pipeline;
- Diverting the Clarence River (Coastal NSW) into the M-D Basin;
- Lake Argyle (WA) Pipeline;
- Managed Aquifer Recharge (MAR) at Menindee;
- Bore fields at Menindee;
- Pipeline from the Murray (Mildura);
- Pipeline from Great Artesian Basin (GAB) bore field and pipeline;
- Rail lifts in emergency;
- Portable Reverse Osmosis plant to put on-line when needed; and,
- Tighter control of irrigation in the Murray-Darling system.

It was clear that no future scenario being contemplated for Broken Hill by key informants included consideration that the Murray-Darling Basin might itself be a victim of a drying and hotter climate. The Darling River was seen by community group interviewees to be under intense pressure upstream from irrigators but not from climate change. Moreover, options to tap the Lachlan and the Murray did not consider that these catchments may also be in water crisis at the same time as the city of Broken Hill and its local catchment. Finally, different officials differed significantly on the technical feasibility and cost of other options such as MAR and bore fields at Menindee and the GAB. Even though the research team mentioned the Spencers Gulf desalination scheme to the key informants in the Broken Hill region, nobody thought it was a viable option for the future of the city.

Beyond the engineering issues, adequate environmental flows through the system remain a hotly contested issue. The rain in both Broken Hill and the Murray-Darling Basin in early 2010 seemed yet again to provide a timely 'solution' to the perennial problem of water security. However, as one senior water official suggested, there just might be a degree of "complacency" even in the minds of people who manage the water system because of the fortuitous rainfall of 2010 and 'lucky' rain in the past.

The Broken Hill water situation can best be understood within the language of complexity theory. There is a basin of attraction with many ‘attractors’ or factors present that drive system evolution (Walker and Salt 2006, Higginbotham *et al.* 2001). Historically, the basin of attraction and the attractors have been unable to deliver long-term water security for Broken Hill because of the failure of all players and stakeholders to have system-wide knowledge. It could be argued that although there is a complex horizontal network of components within the catchment, the weak connectivity between the key players means that there is incomplete knowledge of the system as a whole.

5.1.11 The Future: A Hotter and Dryer Climate

By 2030 CSIRO (2009), based on international climate change models as summarised by the IPCC 4th Assessment Report (IPCC 2007), has predicted a likely 11-15% reduction in surface water flows across the entire Murray-Darling Basin. Winter rainfall is likely to be reduced and evaporation rates are likely to increase significantly with rising temperatures. Since the publication of the IPCC 4th Assessment Report it seems more likely that the high end predictions for temperature are the most likely to occur.

Now that the water system has a new and potentially powerful ‘vertical’ attractor, global warming, one that exists outside the natural variability of the basin of attraction, it is even less likely than ever for there to be full knowledge of total system dynamics and its emergent properties. The system now acts as a ‘panarchy’ (Gunderson and Holling 2002) where interactions occur at different levels and scales in the complex adaptive system. Without knowledge of panarchical system dynamics, it is unlikely that key stakeholders will have sufficient knowledge to plan for resilience in a future that will amplify the natural climatic variability into domains that will present formidable barriers for effective adaptive strategies.

5.1.12 Broken Hill: The Futures Scenarios

In response to publicity for the water expo in the form of advertisements in the local newspaper and a number of local radio interviews with the Chief Investigator, over fifty people voluntarily attended the Broken Hill water expo. As was the case in Kalgoorlie, the 47 people who actually participated in the exercise took seriously their choice of a future for their city and engaged in deep and prolonged conversation with Murdoch researchers during the event. There was a clear trend towards Scenario 3 with approximately 50% of participants opting for mild or strong locations on the matrix. There was another clear cluster (13 choices) of weakly held choices for Scenario 2. Two out the 47 opted for Scenario 4 while 7 voted for visions of Scenario 1. The significant differences between the results of the two water expos will be discussed below.

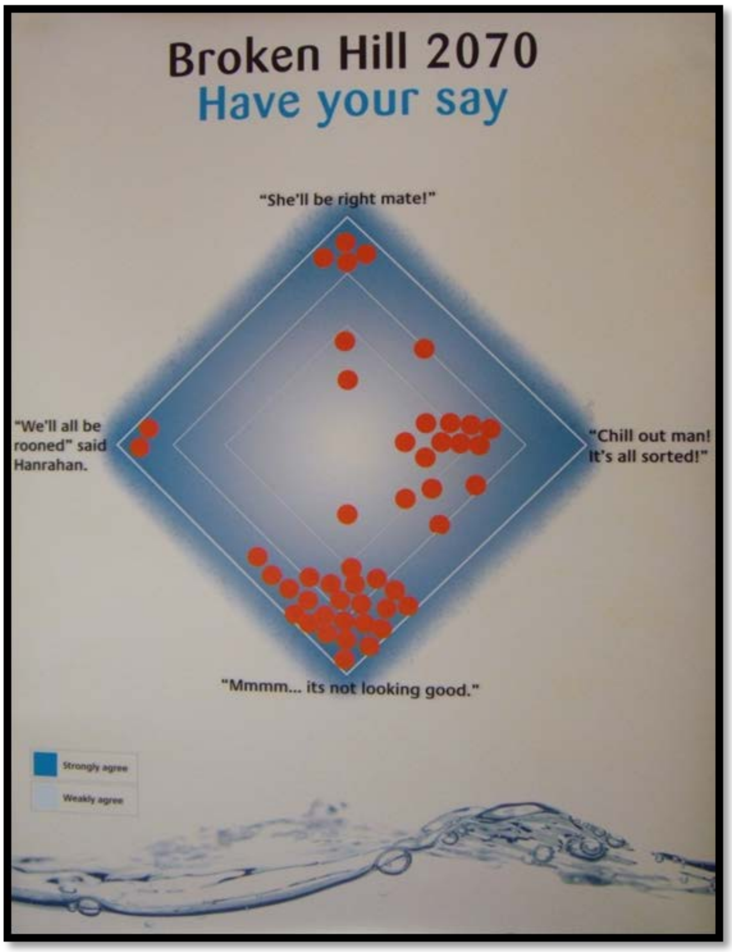

Figure 1. Results from the Broken Hill Water Expo

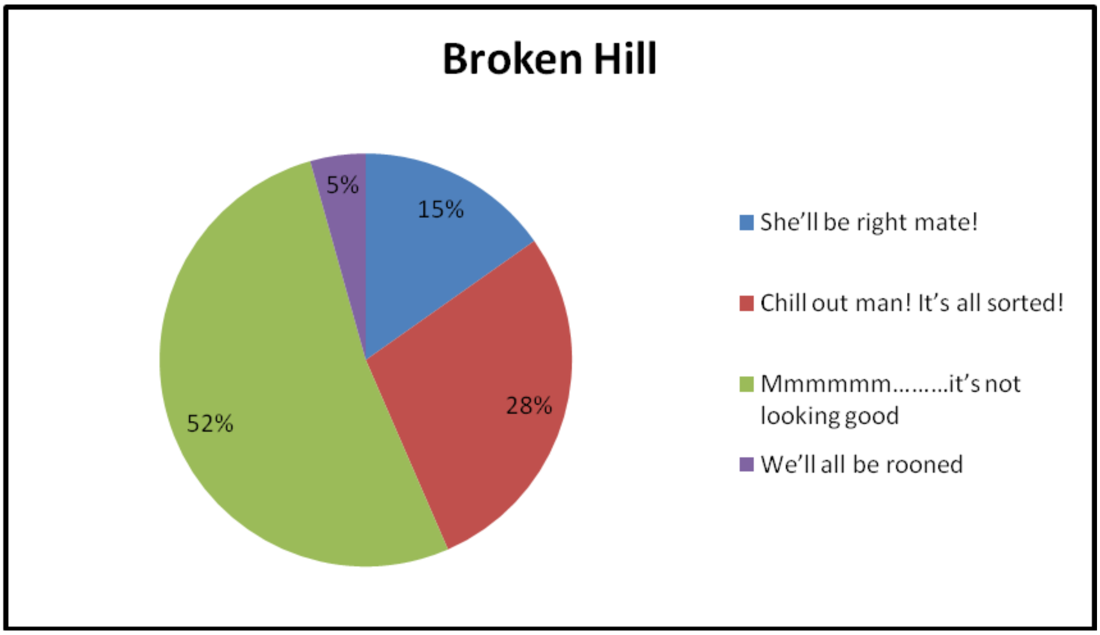

Figure 2. Broken Hill Percentage Response

5.2 Kalgoorlie

5.2.1 Summary

It has often been stated that, in Western Australia, water is the state's most valuable resource. This statement is as true today as it was when the State Government of just over 100 years ago launched the Goldfields Pipeline, an engineering undertaking which was the single most important contributing factor to the explosive development of the Western Australian mining sector in that period leading to the First World War (Jones 1996).

The city of Kalgoorlie-Boulder, with a population of around 30,000, has the largest population of any regional city in Western Australia and is also the largest city in the Australian outback. Kalgoorlie is a city of 6761 homes. In 2008 the median house price in Kalgoorlie was $350,000 and the median weekly family income is in excess of $1700. Kalgoorlie is Australia's 'gold capital'. Annual regional gold production is valued at more than $2.7 billion. Nickel is also an extensive and prosperous mining operation in the region. Approximately 5,800 people are employed in the Goldfields mining industry.

The South West of Western Australia (SW WA) has already experienced long-term decline in rainfall and the catchments and dams that supply water to Perth and the Goldfields are now rarely above 50% of capacity. Climate change models suggest that, for SW WA, the situation is likely to get much worse than the 15-20% reduction in rainfall that has already occurred over the last 30 years. In addition to reduced rainfall, reduced runoff by a factor of up to 66% into the dams that supply Perth and, hence, the Integrated Water Supply Scheme that supplies the Kalgoorlie-Boulder area, will decrease the reliability of supply and/or increase the overall cost of water.

With increased temperatures, declining rainfall and run-off and increasing evaporation, the water catchments of the Perth region are predicted to come under further extreme stress. Based on CSIRO and BOM research on the drying southwest climate, the Water Corporation has estimated that, by 2060, an additional 365 gigalitres of water will be needed to supply Perth and places such as Kalgoorlie that are connected to the reticulated water supply system. The users of water in the greater Perth and Goldfields regions will ultimately have to pay much more than they do at present for such 'expensive' water. Kalgoorlie water delivery cost increases fivefold as it moves from the catchment in Mundaring to a tap in a private house in the Goldfields and this gap is subsidised by the State Government.

In order to bridge the gap between supply and current and projected demand, natural, relatively low cost surface water produced by rainfall has had to be augmented with supplies extracted from coastal aquifers and now, desalination plants. However, building resilience into the water supply system with energy intensive technologies such as desalination plants comes at a cost.

Despite the likelihood of increasing costs for potable water, Kalgoorlie currently has a strong economic resource and population base that will continue to be supported and subsidised by the government and taxpayers of Western Australia. In return for being an income generating powerhouse, the people and community leaders in Kalgoorlie and the region have an expectation of a guarantee of water security. However, such support may not be guaranteed in the longer term as mining wealth and employment decline over time, and the price of supplying water continues to rise. Such a scenario is distinctly possible given that the working life of the gold super-pit is considered to be approximately 10 years from now (2020). When increased climate pressure on the Perth catchment is factored into the equation, the outlook for Kalgoorlie becomes more uncertain and future planning will have to take into account the possibility of regime shifts in the rainfall and hence water supply systems. Long-term planning, rather than the four year political cycle planning, will be needed to confront this increasingly uncertain future.

5.2.2 Climate Change, Water and Indigenous history

The name 'Kalgoorlie' is derived from the local Indigenous word *Karlkurla*, meaning "place of the silky pears". The Karlkurla vine or Native silky pear *(Marsdenia australis*) produced fruit and was also known as the bush banana and was a valuable regional food source. The Maduwonnga or Wongi people were the original inhabitants of the Kalgoorlie region, however, they were quickly displaced by the in-migration of both the colonial gold rush population and the arrival of different Indigenous tribes and clans from other parts of remote Western Australia as missions and other services were built in Kalgoorlie.

Humans were able to live in the arid environment largely because of the existence of waterholes in granite formations known by the Indigenous people as gnammas (Bindon 1997). The Indigenous people exercised stewardship over these water supply sites and maintained their purity with active management such as ensuring that animals could escape the depression via carefully placed sticks in the water reservoir. Such stewardship was vital not only for water purity, but also to maintain these sites as places where hunting could take place as animals came to the water to drink.

5.2.3 Early Colonial History

The Kalgoorlie-Boulder area was first explored in 1863 by H. M. Lefroy. He was followed by C. C. Hunt in 1864-1868. Neither party was looking for gold but rather for pastoral areas, and therefore missed the geological clues. In 1887 gold was discovered at Southern Cross, then in 1892 at Coolgardie, 38 kilometres west of Kalgoorlie-Boulder. Patrick (Paddy) Hannan first discovered gold east of Kalgoorlie on June 15th 1893 (Webb and Webb 1993).

As indicated above, the location of water holes was the key determinant of exploration and subsequent gold prospecting. It was the Aboriginal people who showed the Europeans how to find the water connected to gnammas and, because of the aridity of the region and the very real prospect of dying of thirst, prospectors were often told to look for granite before they looked for gold. Despite these warnings many prospectors did die either of thirst or of diseases such as typhoid, as water holes became poisoned through lack of sanitation and maintenance.

5.2.4 Early Colonial Water Resilience History

The landscape of the Kalgoorlie region was unable to provide adequate food or water for the increasing number of people who came seeking gold. All food had to be imported from Perth, some 300 miles away on the coast, although many miners eked out a living eating rabbits. In the summer months in particular, there was little or no potable surface water available in the Goldfields. With the need to use water to find and expose gold and the demand from people, the need for more water became an overriding concern. Blainey (1993) wrote of it that during the first summer of settlement:

> *Water to quench the thirst – it was warm and brown – was absurdly expensive. In drought a gold miner needed perhaps a quarter ounce of gold just to pay for the week's drinking water. A few miles away from Hannan's Find was a lake of salt water, and on the shores a few primitive condensing machines used wood stoves to boil the water and remove most of the salt, making the brackish water more fit for human consumption. As Kalgoorlie's first summer set in, water became scarce and dearer. The surface gold was also becoming scarce. Many prospectors decided to go to the coast. Even riding a horse in Coolgardie, merely the first stage of the journey could be risky; and on the long stretches of parched track towards Southern Cross long queues of horse teams stood at the few waterholes.*

With seasonal summer drought the norm and longer periods of low rainfall, Kalgoorlie identified its first colonially declared drought in 1894 and the township was officially declared a crisis area. The serving warden in charge of the Eastern Goldfields, John Finnerty, sent an urgent telegram from Southern Cross to Perth that read, "The scarcity of water is becoming alarming" (Blainey 1993).

A supply of water close to Kalgoorlie was a salt lake, known as Hannan's Lake. It was about seven and a half miles from Kalgoorlie, where salt water by the aid of steam condensers was converted into potable water. This was perhaps one of Australia's first desalination plants and the distilled water was carried by camel trains to Kalgoorlie. Brackish groundwater was found as mineshafts reached new depths and the condensing method was used to purify this source of water (Blainey 1993). In some circumstances, useful sources of potable water were found underground. Blainey notes:

> *On most mines the men received not only a daily wage but a daily allowance of water. Two gallons was the ration at the start of the shift and two gallons to take home at the end of the shift. The water was usually condensed from salt water at high cost, the salt water coming from lakes nearby or from shafts sunk on the mining lease in order to tap the water found in some abundance at a depth of about 200 feet. Many of the mines sank a special shaft solely to reach this rainwater which had been percolating down from the surface in past centuries. Many companies owned shafts in which the water was 20 to 25 feet deep. The shaft in Hannan's Golden Pebbles found no gold but something equally as valuable: 25 000 gallons of water were sold each day. (Blainey 1993)*

In addition to the drought, the early miners cut down trees for condenser firewood, pit props and housing. Prior to the Goldfields Pipeline, the town of Coolgardie about 30 kilometres from Kalgoorlie was said to have the largest condenser in the world. Run by the Government it had 30 wood-fired boilers flanked on either side by banks of condensers. The water was used to supply the locomotive boilers. Condensed water was about the only reliable source of high quality water for drinking and for boilers at the time (Webb and Webb 1993).

The lack of trees exacerbated the heat and many could not stay in the Goldfields during the height of the summer drought. Those who did stay had to pay huge prices for drinking water but so prohibitively expensive was water that washing clothes and other non-essential uses for water were rare. It was reported at the time that “successful prospectors would sometimes shout their friends a bath rather than a beer”.

Due to local concerns about the drought and lack of water, the then premier of WA, John Forrest, visited the region in 1895 and considered the plight of a great wealth-producing region for the state of WA that had no water security. By 1897 Kalgoorlie had a private water factory that delivered water to an exclusive list of private clients in a limited number of streets. Water recycling was the norm for all who had access to it and no water was wasted. By 1899 the town’s population reached 25000 and the need for a systematic approach to the supply of water had become overwhelming.

5.2.5 Engineering Water Resilience: The Golden Pipeline

The early pioneers of the Goldfields had shown a high degree of resilience in the face of their adopted hostile climate. Despite the technical difficulties and expense, small water supply companies existed, people were able to install iron tanks to roof capture and store their own water and the camel trains continued to deliver water from sources distant from the major towns of Kalgoorlie, Boulder and Coolgardie. However, there were huge health burdens placed on the residents of goldfields towns as a result of unhygienic water provision. Scurvy, typhoid and dysentery all caused major morbidity and mortality with, for example, a typhoid epidemic that killed hundreds of people in Coolgardie caused by diggers drinking from the stagnant Coolgardie Gorge during a drought.

As a result of his direct experience in Kalgoorlie Sir John Forrest asked the Director of Public Works to produce a practical plan for pumping water to the Goldfields. In 1896 the state parliament gave approval to raise $5 million to finance the scheme, with a high degree of confidence in the future of Kalgoorlie-Boulder and the surrounding Goldfields being able to repay the State for its investment with further economic growth and revenue.

5.2.6 C.Y. O’Connor

The engineer chosen to lead the construction of the Goldfields water supply scheme was Charles Yelverton O’Connor. O’Connor was born on 11 January 1843 in County Meath, Ireland. He migrated to New Zealand in 1865 and married Susan Laetitia Ness in 1874. They had seven children. In April 1891 O’Connor moved to Western Australia as Engineer-in-Chief of Public Works and Manager of Railways for Western Australia.

The new water supply scheme consisted of the building of a reservoir at Mundaring in the Perth Hills and the construction of what at the time was the world's longest pipeline to pump uphill (over 800 metres) five million gallons of water daily, through 330 miles of cast iron pipes to a reservoir to be constructed at Mt Burgess near Coolgardie. The scheme was later extended to Kalgoorlie with gravity feed to Coolgardie from the Mt Charlotte Reservoir.

In 1900 O'Connor authorised the start of the concrete pour for the dam wall. By early 1902 work on the weir was nearing completion. On opening the pipeline on 24 January 1903, Sir John Forrest announced that:

> *Future generations, I am quite certain, will think of us and bless us for our far –seeing patriotism, and it will be said of us as Isaiah said of old, 'They made a way in the wilderness and rivers in the desert'(Casey and Mayman 1964).*

Pumping began from Mundaring Weir in 1902; however, O'Connor was not to see the results of his plan as he took his own life at a Fremantle beach three weeks before the pumping all the way to Coolgardie began. The water reached Southern Cross on October 30, 1902, Coolgardie on December 22, 1902, and finally Kalgoorlie on January 16, 1903.

5.2.7 The Current Situation

Although Mundaring Weir was built in 1903 to supply water to the Goldfields, in 1951 its height was increased so that it could also serve the water needs of the agricultural areas of the Wheatbelt and changed its name to the Goldfields and Agricultural Water Supply Scheme (G&AWS). The Mundaring Weir also supplies water to some residents in the Perth Hills area and contributes to the Integrated Water Supply System (IWSS).

In its current configuration, the IWSS delivers water to 1.6 million people across Perth, the South West, Kalgoorlie-Boulder and the Wheatbelt, Goldfields and Agricultural regions.

According to Water Corporation key informants and publically available documents, the water for the IWSS comes from three sources:

1. Surface water is obtained from dams (storage reservoirs) in the Darling Range. Surface water sources supply approximately 25-45% of the water. The dams supplying water are Canning, Serpentine, Serpentine Pipehead, Conjurunup Pipehead, Victoria, Mundaring Weir, South Dandalup, North Dandalup, Wungong, Stirling and Churchman's Brook. Note that Mundaring Weir normally only supplies water to the Perth Hills, Goldfields and Agricultural Region.
2. Groundwater, supplying 35-50% through the integrated system, is obtained from huge aquifers in the deep sands of the coastal plain. It is treated at groundwater treatment plants at Jandakot, Mirrabooka, Wanneroo, Neerabup, Lexia and Gwelup before being added to the distribution system.
3. The Perth Seawater Desalination Plant supplies 15-20% of water needs. The largest desalination plant in the southern and eastern hemispheres, it produces on average 130 million litres of water a day.

5.2.8 Key Informant Interviews

The research team completed key informant interviews of people in both the Perth and Kalgoorlie contexts and their views on the future of water supply and security in the face of a changing climate are discussed below. In all, 48 interviews were conducted, 15 in Perth and 23 in Kalgoorlie.

From the interview material it became clear that interviewees in Kalgoorlie had confidence in an ongoing resilient water supply for their city. One reason given to justify why the city deserved such a reliable water supply was the revenue it raises for the State in the form of royalties and taxation.

In addition, it was evident in casual conversation with citizens of Kalgoorlie that, for many people, the geographical disconnect between the local reticulated supply and the source of potable water meant that they had very little awareness of water supply and security issues in the Perth catchment. However, when a recent fire along the pipeline cut the water supply from Perth, many people became aware that there was only three days' supply of water stored in the system. A number of interviewees commented on the lack of community understanding of climate change issues and put the view that a lot of people "simply don't believe in climate change". The prevailing attitudes of skepticism and denial in a town with "lots of geologists" were also reflected in anti-climate change letters and feature articles in the local papers.

However, the Perth-based water engineers and policy makers expressed much greater concern about the future of water security for the whole of the integrated water supply system, as they had much greater knowledge of demand pressures, a drying climate and metropolitan environmental impacts associated with aquifer extraction and desalination.

From information provided by the key informants in Kalgoorlie it was clear that there is an emergent awareness of the limits to gross water availability in the Goldfields. Information was provided that since 1980, expansion in gold mining activity has exceeded the capacity available from the G&AWS scheme and increased reliance on local saline groundwater resources to meet mining process water requirements. The saline groundwater is drawn almost entirely from aquifers within infilled paleodrainage channels (paleochannels) which have extremely low rates of recharge relative to abstraction rates. High rates of water abstraction are mining the aquifers, and the potential exists for depletion of the groundwater resource (Turner *et al.* 1996).

Two additional sources for Kalgoorlie's water supply have been seriously considered. One is groundwater sources via bores in the Officer and Eucla Basins while the other is piped water from a desalination plant at Esperance. According to information provided in the interviews, both options have so far been rejected on economic grounds with the costs of transporting water long distances the major factor in the analysis.

The water provided to the goldfields is subsidised by the state government as the community service obligation and results in Kalgoorlie's customers paying less than the cost-reflective price of supplying water. This cost is rising as the life cycle costs of desalination are added to the bottom line and new infrastructure to improve water security is completed. In addition, the replacement of ageing pipeline infrastructure will place even more pressure on cost recovery.

The Water Corporation (Water Corporation 2009) and Department of Water (Department of Water 2010), in their future planning scenarios for 2060, estimate that there will be a significant increase in demand for water due to population growth and a reduction in supply due to a warming and drying climate. In *Water Forever*, the Water Corporation has accepted the likelihood of a 20% decline in rainfall by 2030 and a 40% decline by 2060 (Water Corporation 2009). In addition to the need for potable water, there is also the need to expand the wastewater system to cope with the increased population.

The shortfall in water supply will possibly be met, according to Water Corporation and other key informants, by the provision of:

- Groundwater replenishment;
- Southern seawater desalination plant expansion;
- Wellington Dam desalination;
- Esperance-Kalgoorlie desalination;
- New desalination sites;
- NW metro coastal groundwater;
- Gingin-Jurien Bay groundwater;
- Jandakot groundwater expansion;
- Wellington dewatering;
- Catchment management;
- Gnangara water trading;
- Water efficiencies and recycling; and,
- Demand management.

However, groundwater extraction remains controversial as past use has been implicated as a contributing factor in the loss and degradation of coastal wetlands and lakes. The bulk of the water shortfall will most likely have to come from new desalination sites. While desalination is rainfall independent, it is not climate change immune as sea level rise combined with increased intensity of coastal storm surge may cause damage to plants and hence the security of the system. In the absence of other water options, such a future situation would put the security of the system at risk.

According to the key informants, the community, when looking at groundwater generally, sees it from two perspectives: firstly, as a resource that should be well managed and secondly, as a resource that has the potential to be polluted and spoiled. There is general community support for the idea that good aquifer management should only extract the through-flow of water. However, when there is the local groundwater situation facing many companies in the Goldfields there is little flow through, and therefore they are forced to mine groundwater as a non-renewable resource (Jones 1996). This creates a potential future problem in some localities as groundwater that has been extracted from many of the paleochannels cannot be replaced naturally at anything like the rate it is being extracted. Therefore, overuse this resource may limit further mining development or potential water extraction for desalination for potable purposes. It is important that the total water supply from local groundwater and sources supplying the Goldfields Pipeline be managed as an integrated system (Johnston *et al.* 1999).

The pollution of groundwater is also of concern, as any degradation of the resource diminishes potential for future use. Concern has been raised about the potential contamination as a result of seepage into groundwater systems from tailings disposal altering the pH, potentially mobilising many heavy metals. In addition, there is concern about contamination from mining treatment reagents including cyanide (Jones 1996).

5.2.9 The Future: A Hotter and Dryer Climate

As is the case for most of Australia, the climate projections for the Goldfields region suggest that it will become hotter and dryer with the likelihood of more extreme weather events. This, combined with similar projections for the Perth Region, suggest that there will be less naturally available potable water and increased costs in supplying water from managed aquifers and desalination plants.

5.2.10 Kalgoorlie: The Futures Scenarios

Based on the 30-70 year scientific projections for the climate of the Perth and Goldfields Regions, the research team constructed four scenarios for the future of Kalgoorlie. The scenarios, as was the case in Broken Hill, also contained assumptions about the state of the economy, population levels and the relative price of water.

The four scenarios were challenging and many people took considerable time examining the images and the interpretative material supplied for each scenario. The results of the choices made by participants at the Kalgoorlie water expo are given in Figures 3 and 4 (below). Their choices revealed that very few saw an apocalyptic future for Kalgoorlie. Most participants, about 40%, saw a future with problems solved by technology, but many saw a future with climate-induced difficulties that would entail major change. This finding suggests that there is a significant proportion of the people in Kalgoorlie for whom adaptation to changing circumstances will not be a major issue but that many are also fearful of a negative future unfolding.

Figure 3. Results from the Kalgoorlie Water Expo

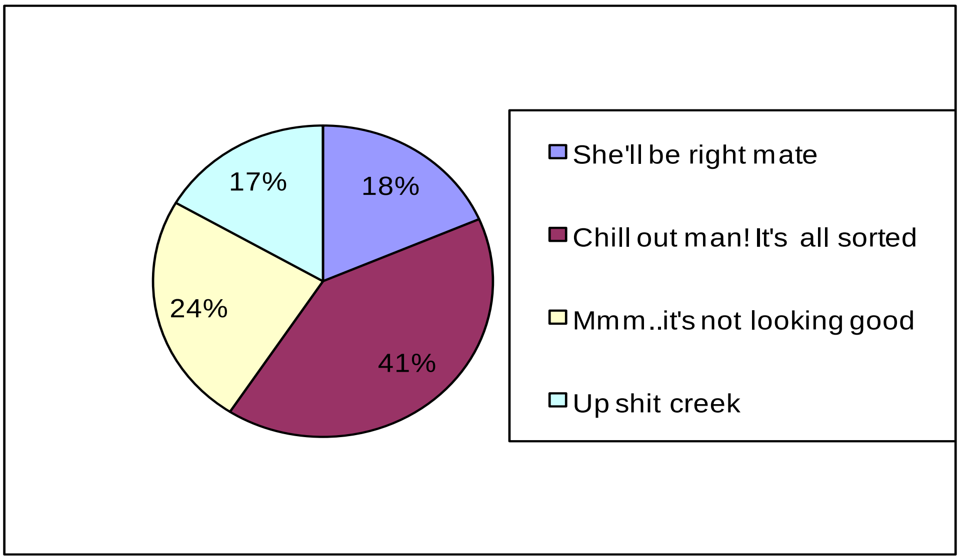

Figure 4. Kalgoorlie Percentage Response

6. Consideration of the infrastructure, cultural and organisational change needed to meet the water security and sustainability challenge for Broken Hill and Kalgoorlie

On the basis of information gleaned from the literature reviews and water histories, and generated by the key informant interviews and the water expos, a number of issues can be identified that will determine water security and sustainability in Kalgoorlie and Broken Hill.

6.1 Infrastructure Needs

A key finding is that, despite the similarities between the two cities, a vital difference is that for over 100 years Kalgoorlie has had reliable provision of potable water while Broken Hill has not. The Golden Pipeline infrastructure has produced a mentality of security about water quite independent of the reality of climate change in the SW of WA and the serious decline in rainfall that has emerged in recent decades. Broken Hill, on the other hand, has experienced water crises on a regular basis and has attempted, over time, via larger and increasingly sophisticated technologies, to gain water security. It is testimony to the challenge facing Broken Hill that, 120 years after its establishment, the Darling River Water Saving Project (DRWSP) 2009, an initiative of the State Government of NSW and the Commonwealth of Australia, still has, as one of its objectives, "to secure the water supply for Broken Hill". A budget of up to $400 million was committed to address problems such as evaporation and water storage in the Menindee Lakes to achieve that end (Sinclair Knight Merz 2010).

The different situation of the two cities is reflected in the community expo results with people in Broken Hill far less optimistic about their future than people in Kalgoorlie. Broken Hill people have a lived experience of water shortage during severe drought while the people of Kalgoorlie have been insulated from ecological and climate realities by the pipeline. Hence, Kalgoorlie remains optimistic that technology will continue to provide water security and a solid economic foundation, while the popular choice of Option Three by Broken Hill participants in the expo, one that reflects more self-reliance and a small role for government and 'big technology', suggests that people are sceptical or pessimistic about the ability of government and technology to ultimately solve the water security problem. Such a conclusion is also consistent with the history of Broken Hill, with an editorial comment in *The Conveyor* of June 1952 (The Conveyor 1952) where it is stated that, "[o]ld records reveal a sad state of apathy to the most vital necessity of the industry and community – an assured water supply."

The historically informed pessimism in Broken Hill even extended to discussion about the current DRWSP project, with community based key informants critical that in their opinion, for example, little money has been spent so far, that it has been wasted on consultants' reports, that the Menindee groundwater aquifer recharge option is hugely costly, untested and risky and that the issue of evaporation rates for water in Menindee Lakes has been overplayed. A number of interviewees even suggested that the money could have been better spent removing silt from the Menindee Lakes while they were empty over the last five years and that the real problems of upstream irrigation and excessive water extraction from the Darling River were not being addressed. Such conclusions prevailed despite the existence of the Commonwealth Government water entitlement buy-back scheme, 'Restoring the Balance in the Basin' Program. Community informants pointed out that evaporation cannot be a critical water security issue as the Menindee lakes have been often empty in the last decade and that evaporation rates are the same for all areas of exposed water, including large dams used for irrigation. Needless to say, there were a great many views aired on what should be done to fix Broken Hill's water supply. Furthermore, the current scheme on the table is not seen by many locals as any more likely to succeed than others in the past. The experience of putting out into the public domain the Guide to the Plan for the Murray-Darling Basin (Murray-Darling Basin Authority 2010) has seen a public outcry over proposed cuts to water allocations for irrigators across the Basin and outrage that social and economic factors have lower priority than environmental considerations with respect to water provision. Clearly, the 'no major change' future scenario resonated with many people in the Basin once the Guide was published and cuts were proposed.

The future water infrastructure needs of Kalgoorlie have been addressed as part of the State Government's attempt to respond to the well-documented decline in rainfall and associated hydrologic impacts on natural water sources supplying the IWSS (see the Department of Water: Gnangara Sustainability Strategy). The Water Corporation has a 'Water Forever' strategy and shows evidence of systematic water resilience planning in the context of increased population and declining water availability. Infrastructure investment into desalination plants has been a key strategy to respond to the decline in rainfall and runoff within a fifty year plan to meet water supply needs for the whole of the reticulation system. As indicated above, the Water Corporation has planned to build resilience into its water supply options by using a diversity of water demand management and supply options, including groundwater replenishment using recycled water.

With respect to Kalgoorlie, Water Corporation (2010) has committed to the Mundaring Weir Water Supply Improvement Project (2010-2014) which involves construction of a water treatment plant, a new pump station and pipelines and weir improvements. However, a substantial amount of water supplying Kalgoorlie is now sourced from the major coastal aquifers, and, with groundwater levels falling under a large percentage of Perth and visible signs of the drying-out of coastal lakes such as Lake Gnangara, the precautionary principle requires that a balance be reached between water extraction and infiltration. Currently, about 60% of Perth's drinking water supply is sourced from groundwater aquifers on the Swan Coastal Plain, and significant diminution of the aquifer source would be a major blow to the future resilience of both Perth's and Kalgoorlie's water supply. At the time of writing this report the Perth catchment had its second lowest June rainfall on record and June is usually the month of highest rainfall. Runoff into the dams is at historically record low levels and a water crisis is looming if the winter of 2011 is similar to the conditions present in 2010. With declining groundwater availability and a dryer climate, the water engineers are finding it increasingly hard to meaningfully deliver 'water forever' and resilience.

Without its first desalination plant, Perth's water security would already be in crisis. With a second desalination plant coming on-stream in late 2011, about 30% of SW WA's water will come from a climate independent source, the ocean. If groundwater supply is reduced because of over-extraction and/or environmental considerations, then more desalination plants will be required. The water agencies are currently assessing other coastal locations for additional desalination plants, although the State Government has already dismissed, on economic grounds, a possible private desalination plant at Esperance to service the needs of Kalgoorlie. Also, as indicated above, coastal locations have a measure of risk associated with them because of potential sea level rise and damage due to increased intensity and frequency of storms.

Finally, the high cost of technologically sophisticated and energy intensive 'solutions' to both Perth's and Kalgoorlie's drinking water security will inevitably mean an increased cost of water to consumers (both domestic and commercial). We have seen that if critical cost thresholds are passed in places like Broken Hill, the public backlash is something that the political and policy sectors will have to take into account. In this respect, Broken Hill provides a snapshot of the likely future of Kalgoorlie as it sees mining wind down and population decrease while at the same time experiencing ongoing, significant rises in the price of water. One interesting issue that will be factored into the future of both cities is that, as mining winds down, there is increased unused capacity in all utilities. The unused capacity can then be used as an attractor for new industries in the region.

6.2 Cultural Issues

The cultural issues relevant to both Broken Hill and Kalgoorlie are centered on the fact that both are mining towns in arid environments. In the case of mining, there is a culture of optimism that drives investment and ongoing extraction of mineral wealth. Even in Broken Hill, for some, there is a belief that the next big mineral discovery will see a resurgence of the city into something resembling its heyday. Similar considerations apply to Kalgoorlie in that, despite knowledge that the Big Pit will likely close in less than a decade, another huge load of gold ore is believed to be just waiting to be discovered.

The culture of optimism still prevails in Kalgoorlie and was expressed in the water expo findings, however, Broken Hill's optimism has been severely tested as more of the larger mines in the region close. Perelya, the largest remaining mine and the largest water user (which subsidises the water cost for the whole city) is set to close in 2020. The 'Big Pit', currently owned by KCMG is reputed to be closing down sometime between 2018 and 2020.

The optimism and the belief in the inevitability of 'progress' mean that there is a high likelihood of climate change skepticism and denial associated with mining communities. In Broken Hill this connection is reinforced by the fact that a noted climate sceptic, Professor Ian Plimer, has close professional and residential connections to the city and is also a non-executive Director of CBH Resources which owns one of the remaining underground mines in Broken Hill. As a geologist, Plimer has long reported on the potential of Broken Hill to deliver more mineral wealth into the future. Plimer's importance in Broken Hill was revealed in the key informant interviews, with both industry and community leaders confirming his influence on matters relating to climate change.

Climate change scepticism may also be an influence on water policy in both NSW and Western Australia. In both states, high profile politicians, some of whom are/have been ministers, are on the public record as being sceptical about the anthropogenic causes of a warming and changing climate.

With government locked into short term election cycles (3-4 years) and the problem of water security locked into the context of longer term anthropogenic climate change (decades and centuries), the role of political leadership in leading adaptation to change and anticipating future change becomes a critical issue. If political ideology is out of step with climate science and hydrologic evidence, then the future of issues such as water security for Broken Hill, Perth and Kalgoorlie may sit in the short-term with the political whim of individual ministers. Such an outcome is not likely to be conducive to sustainability and resilience of water supply for Broken Hill, Perth and Kalgoorlie. There is scope to further research the importance of political, institutional and community leadership in the water panarchies operating in Broken Hill and Kalgoorlie.

One element of the cultural history of both Broken Hill and Kalgoorlie is their long-term commitment to collective action on issues of mutual interest. The history of unionism in both towns might be a foundation for a collective adaptive response to climate and water challenges. However, there is also a history of libertarianism in both towns with people wanting to be self-reliant and not dependent on big government to organise their lives. Broken Hill, in particular, a city with an historically strong union presence, demonstrated that despite heavy dependence on both corporate and government investment and subsidy of water, they could see a future where they would have to be more self-reliant and supply their own water. Kalgoorlie, despite being a politically conservative federal seat with many prominent free market and ‘small’ government leaders, opted for continued investment by government and industry to deliver water security. Further research is needed to tease out these apparent contradictions and paradoxes in the local populations and in the views of the fly-in – fly-out work force of each city.

6.3 Organizational Change

The research undertaken for this project has revealed that, while civic leaders and water system individuals were highly aware of their own role and responsibilities with respect to the provision of water, there was little evidence of high level awareness of system-wide issues. In both contexts, the Murray-Darling Basin and Perth’s water catchments, there is an emerging awareness that change in one part of the complex system generates change in other parts of the social-ecological system. For example, in Broken Hill, water conservation leads to sewer flushing problems, greater toxic dust issues and potentially, greater heat stress in an elderly and vulnerable human population.

In the context of Kalgoorlie, Perth’s water supply catchments are under extreme pressure, with the connectivity between aquifer extraction, coastal ecosystem distress, land management, acid sulphate soil creation, South West river health all tied to population pressure, development pressures and dramatic evidence of a drying climate. (see; Department of Water, Gnangara Sustainability Strategy). The recent report, The Sustainable Cities Index (ACF 2010) judged Perth to be the least sustainable city in Australia and, in large part, this rating was achieved because of high water consumption and poor comparative performance on other environmental factors. Such a conclusion suggests that, despite the rhetoric of seeking to achieve a resilient and diverse water supply system for Perth and the pipeline, there is much more work to be done, particularly on the demand side of the water equation. In Kalgoorlie, the City is recycling the waste water and encouraging storm water storage in new residential developments. Both initiatives are reducing the demand for potable water by putting waste water into sporting fields and industrial needs. However, as was the case in Broken Hill, some water conservation measures such as water-wise gardens can have perverse outcomes. According to interview information, water use actually increased in Kalgoorlie as people took pride in their new ‘native’ gardens.

For each of the cities of Broken Hill and Kalgoorlie, as understood by complexity theory, there is a basin of attraction with many ‘attractors’ or factors present that drive system evolution. Historically, the basins of attraction (the Murray-Darling Basin and the Perth Region) and the local attractors (mines, domestic users, irrigators, pastoralists, the environment, government), have not been well understood by the key stakeholders in each region (Proctor *et al.* 2009, Wentworth Group of Concerned Scientists 2010).

While system-wide awareness is improving, the failure of players and stakeholders to have system-wide knowledge, including the cultural and political dimensions, has contributed to the inability to deliver long-term water security for Broken Hill. A similar situation is emerging for Kalgoorlie as the security delivered by the Golden Pipeline is undermined by excess demand in Perth, reduced rainfall in the Perth catchment and the growing cost of water supply.

It could be argued that, although there is a complex horizontal network of components/people within the catchment, the weak connectivity between the key players and their organisations means that there is incomplete knowledge of the system as a whole and a tendency toward silo mentalities and closed-system management. In both contexts, such a situation can be alleviated if water organisations commit to transdisciplinary and trans-specialist perspectives on water. The strengthening of the horizontal links in the complex adaptive system would see much greater communication and information sharing between social, ecological, geological and technological experts. In addition, political and policy leaders will need to receive such cross-system information in ways that enhance understanding of the connections between the social and biophysical elements of the complex adaptive system (Allison and Hobbs 2006).

In addition to the horizontal complexity, it was argued above that a new ‘vertical attractor’ was now an additional factor that organisations need to consider. Climate change and attendant global warming impact on <u>all</u> elements of the system and do so in ways that produce surprise and emergent properties. The climate change scenarios produced by CSIRO, BOM and the IPCC all point to a major challenge for the two inland cities studied in this research. Since the publication of the IPCC 4th Assessment Report the scientific consensus is that it is more likely that the high end predictions for temperature rise due to anthropogenic climate change will occur. Planning for such change will not be easy and the tendency to stay within known system parameters and avoid emerging uncertainties is not confined to the water policy professionals in either NSW or WA. Most of our institutions, including the institution of insurance, have relied on stable systems with pattern-generating data sets to make predictions and act prudently. As all social-ecological systems become more unstable under the global attractor of climate change, basing decisions on past experiences becomes increasingly risky.

Reduced rainfall, reduced run-off, increased evaporation and more severe flood and drought events all point to the need to understand system-wide properties at scales and within timeframes that exist outside the former comfort zone of regional and remote organisations and even their State and National counterparts. As argued in this report, the total system context within which we must consider Broken Hill and Kalgoorlie as inland cities is now global. As described above, the system now acts as a global 'panarchy' (Gunderson and Holling 2002) where interactions occur at different points in space and time in the complex adaptive system. Without knowledge of panarchical system dynamics, it is unlikely that key stakeholders and policy-makers will have sufficient knowledge to plan for or achieve resilience. Failure to understand the water panarchy in the Murray-Darling Basin and the Perth water sources will see major difficulties in 'selling' the idea of water reform and further, enabling the removal of barriers to enable citizens to see the urgent need for adaptive change in the face of now well-documented pressures (Matthews 2010).

7. Conclusion

The research conducted for this report has highlighted the issue that, despite very similar locations, histories and economies, the citizens of each city have discernibly different views about the future with respect to climate change and water availability. Ironically, Kalgoorlie, the city with the most reliable water supply system, is the one most likely to be unable to cope with major threats and change to its water supply. Kalgoorlie, because of subsidies and its great distance from the source of its water, has been largely insulated from the economic and biophysical realities of water provision, and its citizens will find price increases, interruption of supply and a hotter and dryer climate generating major shocks to their historical experience of stability.

Within the Goldfields region, it could be argued that there is a form of psychosocial resilience (Walker 2010) about water security which is formed out of long-term faith in engineered resilience (the pipeline) and organisational resilience (Water Corporation and the Department of Water) continuing to allow water flow on-demand from the tap into the glass. The lack of water scarcity makes citizens unprepared for system stress and, in particular, system failure. Such a conclusion is replicated in the international literature where, in the context of a comparative analysis of water rich and water poor regions in Iraq, Shahbazbegian and Bagheri (2010) researchers found that there is "a higher vulnerability to droughts in the water-rich region due to dependence on water abundance as opposed to the water-poor regions, which are well adapted to water scarcity conditions." By analogy, we can see the Kalgoorlie pipeline as the equivalent of a water-abundant environment, and the Broken Hill pipeline, on many occasions, as a water-scarce environment.

In the face of climate change, such psychological resilience could be seen as a 'closed system' of belief with little opportunity for creative change or response. In a system characterised by what is called 'perverse resilience' (Holling 2001, Raez-Luna 2008), the peculiarities of cultural and political attractors within the social domain ensure that undesirable features of a system prevail, despite the obvious need for change. In addition, a high level of ignorance about where Kalgoorlie's water comes from and the pressures on the Perth catchment and hydrology, generates complacency about water security.

By contrast, the citizens of Broken Hill have a lived experience of system failure and acute water shortages. In a significant majority, they revealed "It's not Looking Good" judgements about the future. The stakeholders in water provision have responded to these crisis events by delivering larger regional storage capacity, emergency desalination back-up and a pipeline from the Darling River at Menindee. However, community cynicism remains about the ability of policy-makers and engineers to deliver water security to Broken Hill. In addition, because of the enormous variability in the amount of water available in the storage system, periods of flood and huge water abundance delivered by nature have regularly ended severe drought and water shortages. Such 'luck' and the capacity of the current system to store two years' worth of water might also generate a degree of complacency in the minds of stakeholders and citizens.

For both cities, community education and information about their unique situations would be useful as perverse resilience and complacency both work against creative and adaptive responses to the pressure of climate change. In addition to work already undertaken by local and regional organisations to alert communities to the threat of climate change, it would be useful to extend the future scenario approach to a larger cross section of the community, and follow-up research on why people hold certain views. Education can then be targeted more precisely to those issues where resilience and vulnerability are most in need of attention.

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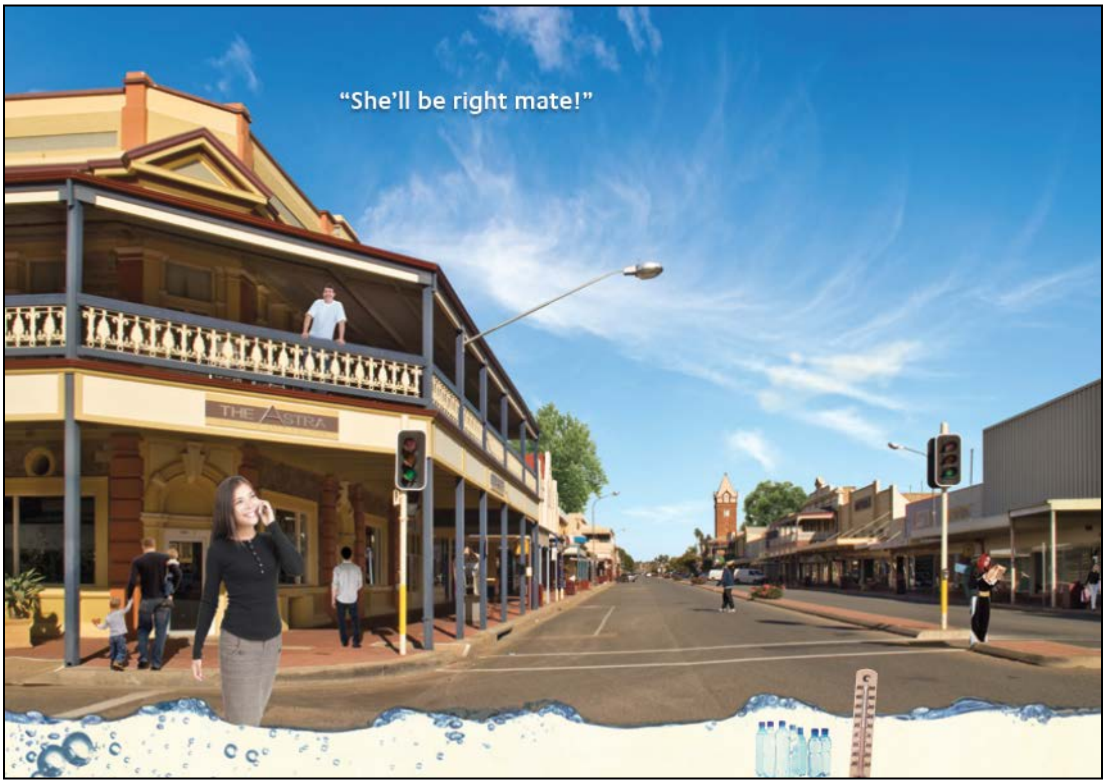
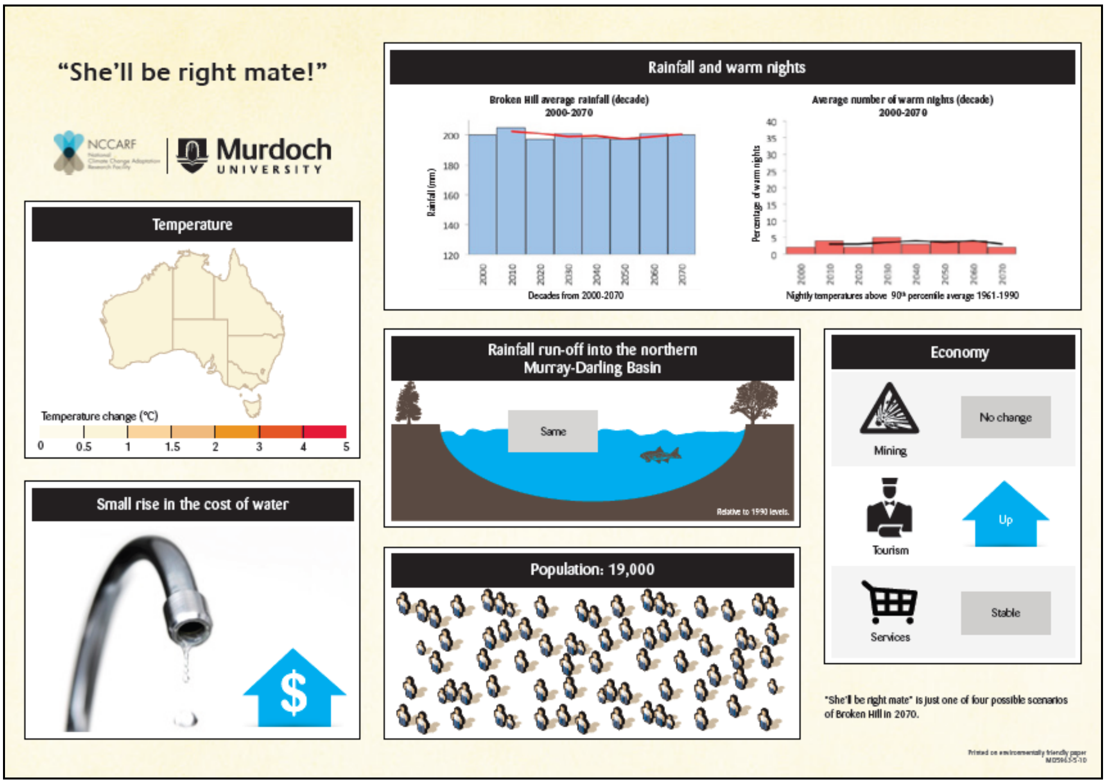
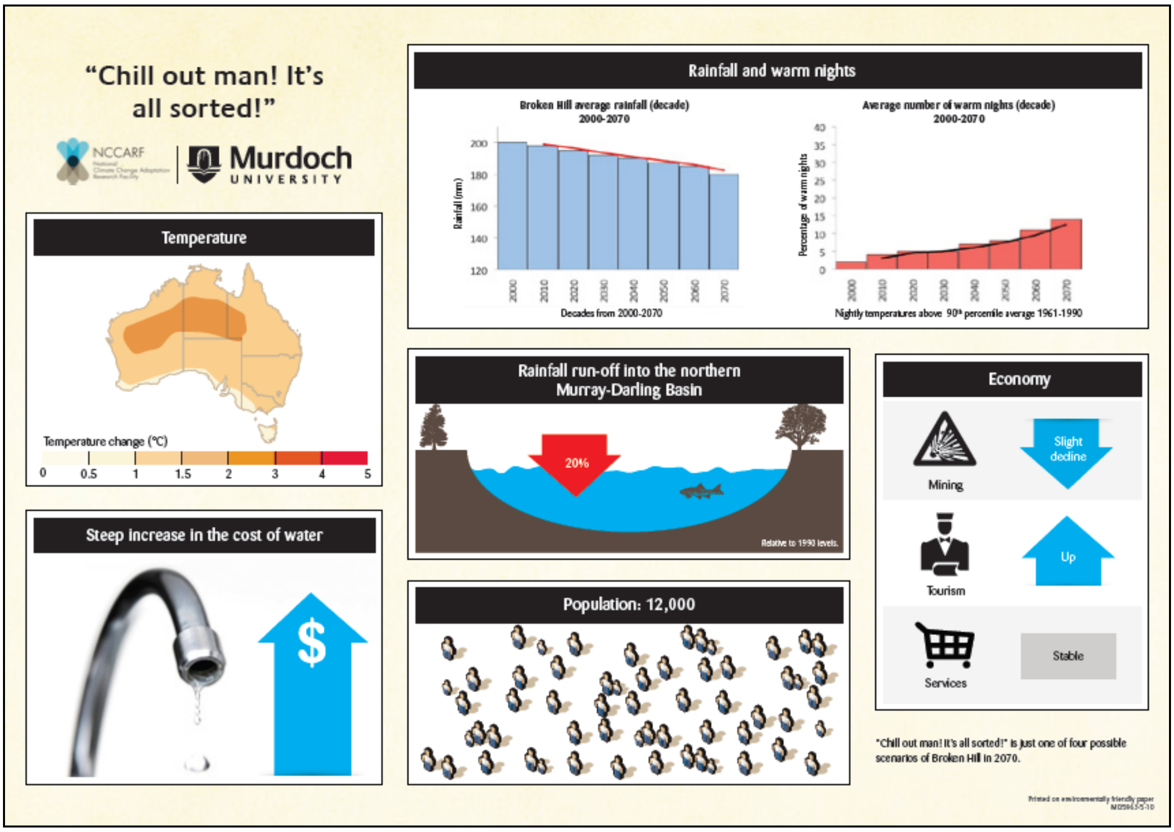
9. Appendix 1. Broken Hill Scenarios

Broken Hill Scenario 1

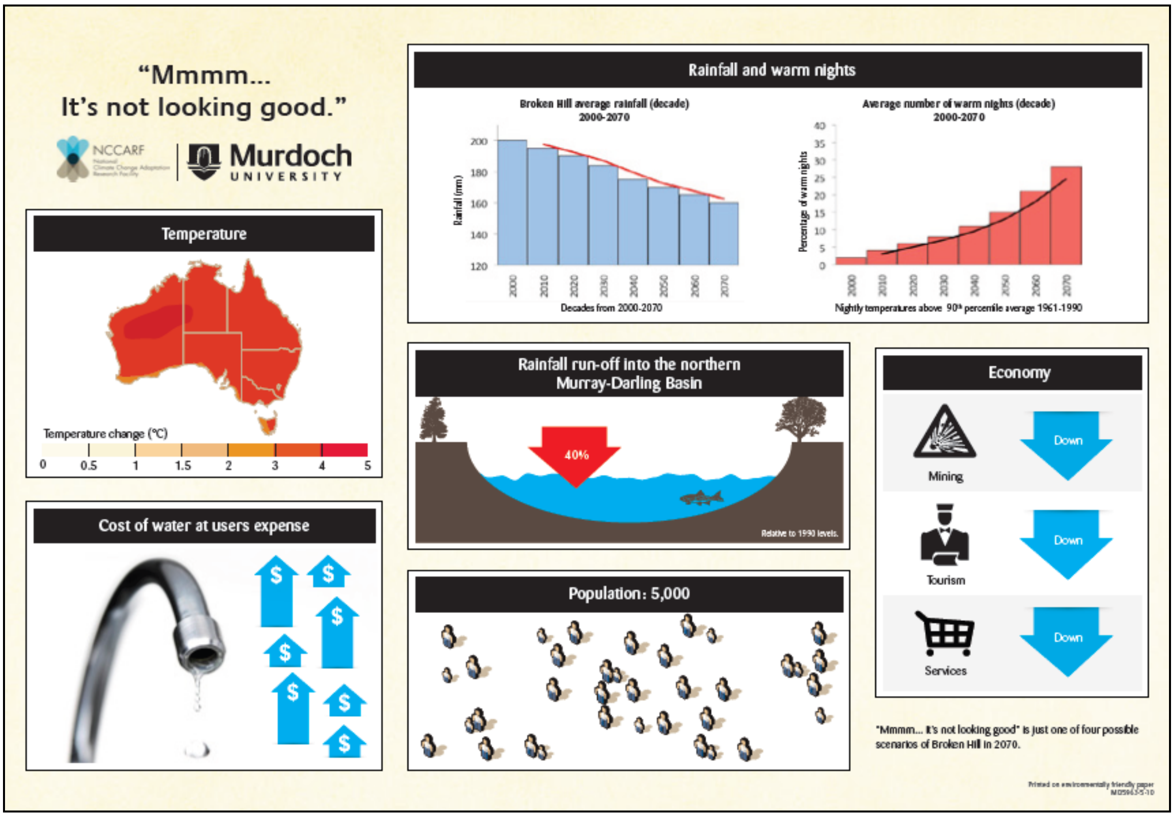




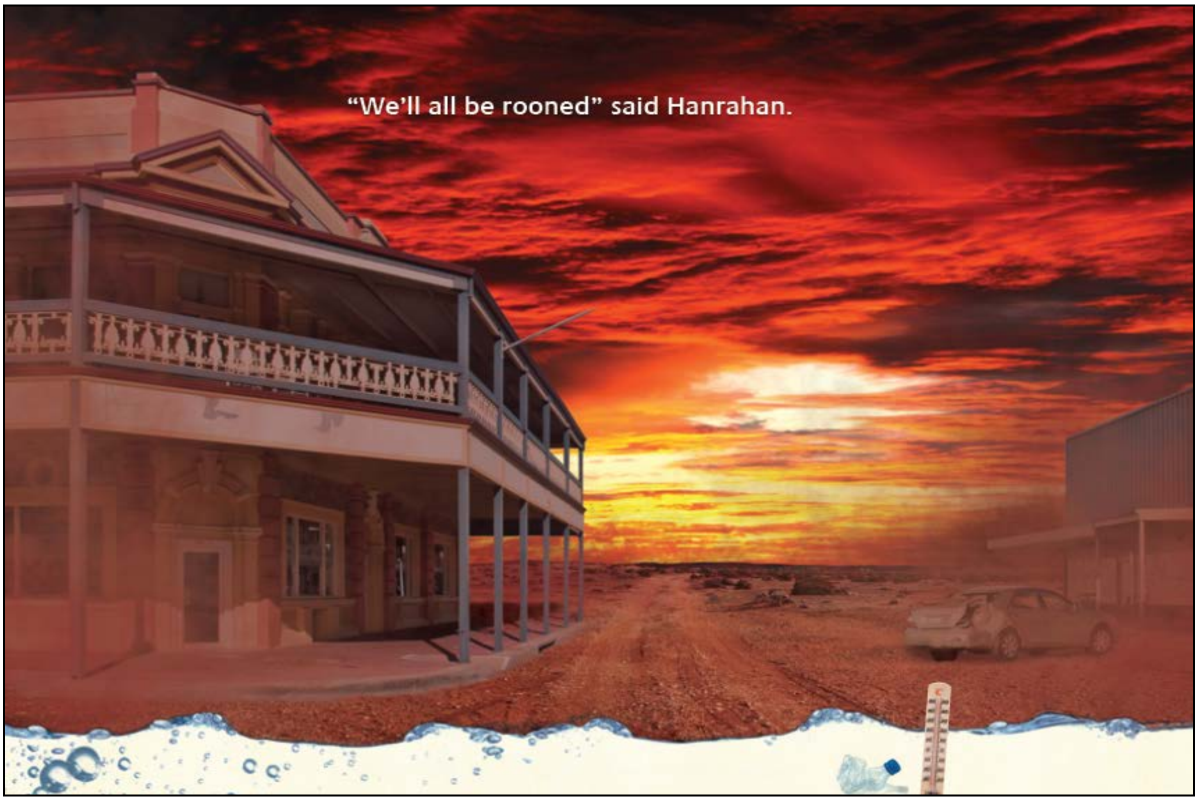
Broken Hill Scenario 2

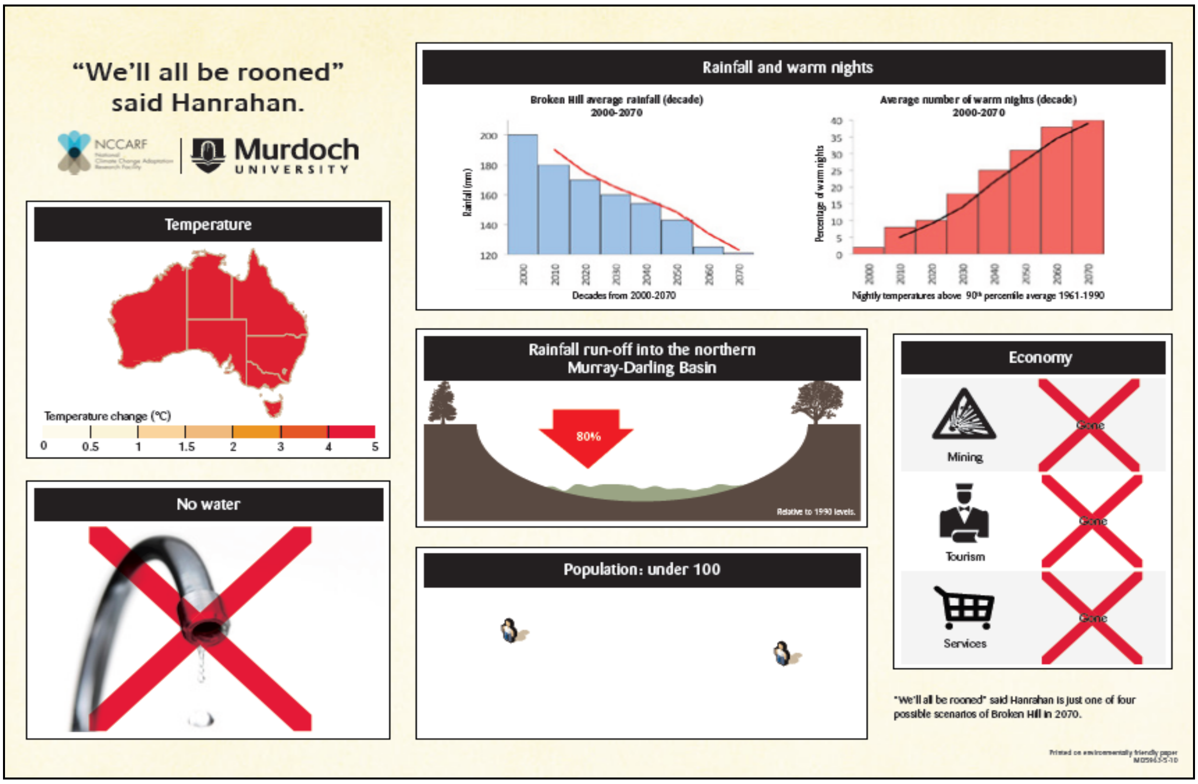


Broken Hill Scenario 3



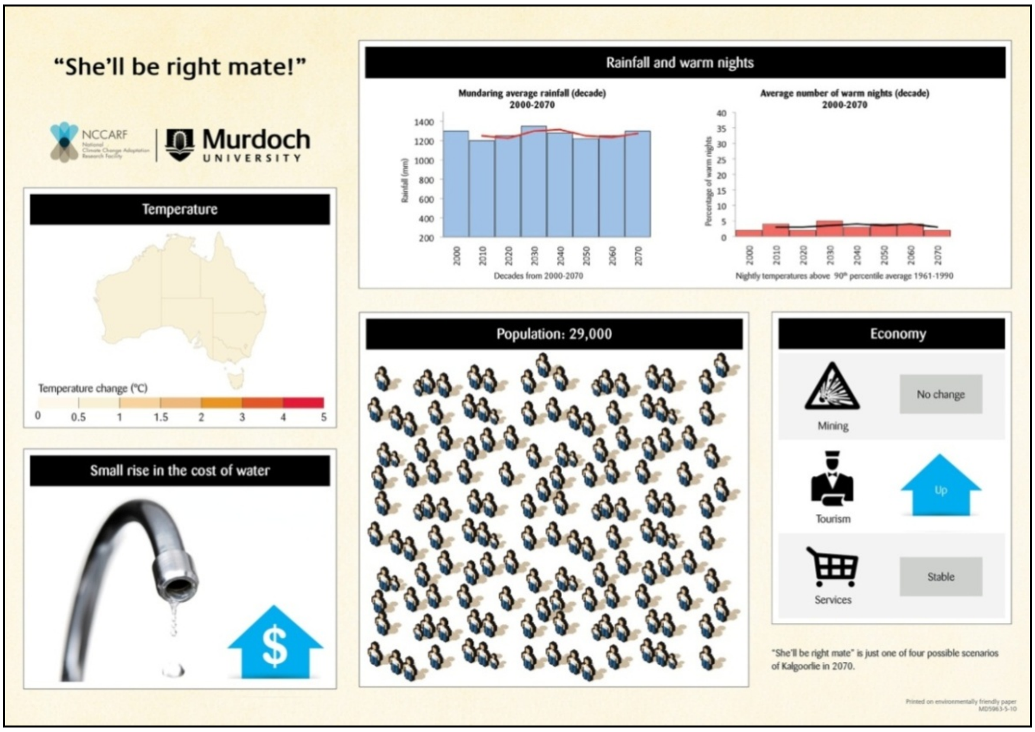
Broken Hill Scenario 4



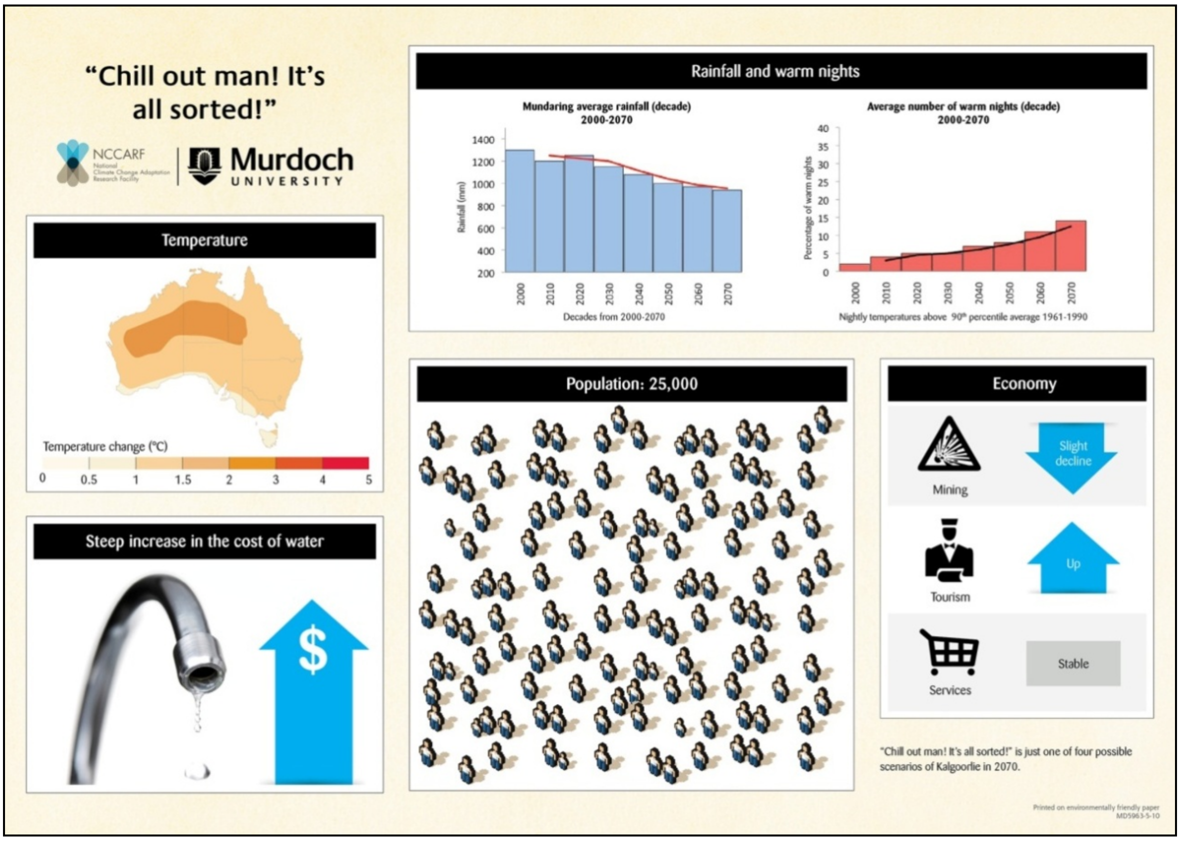


10. Appendix 2. Kalgoorlie Scenarios

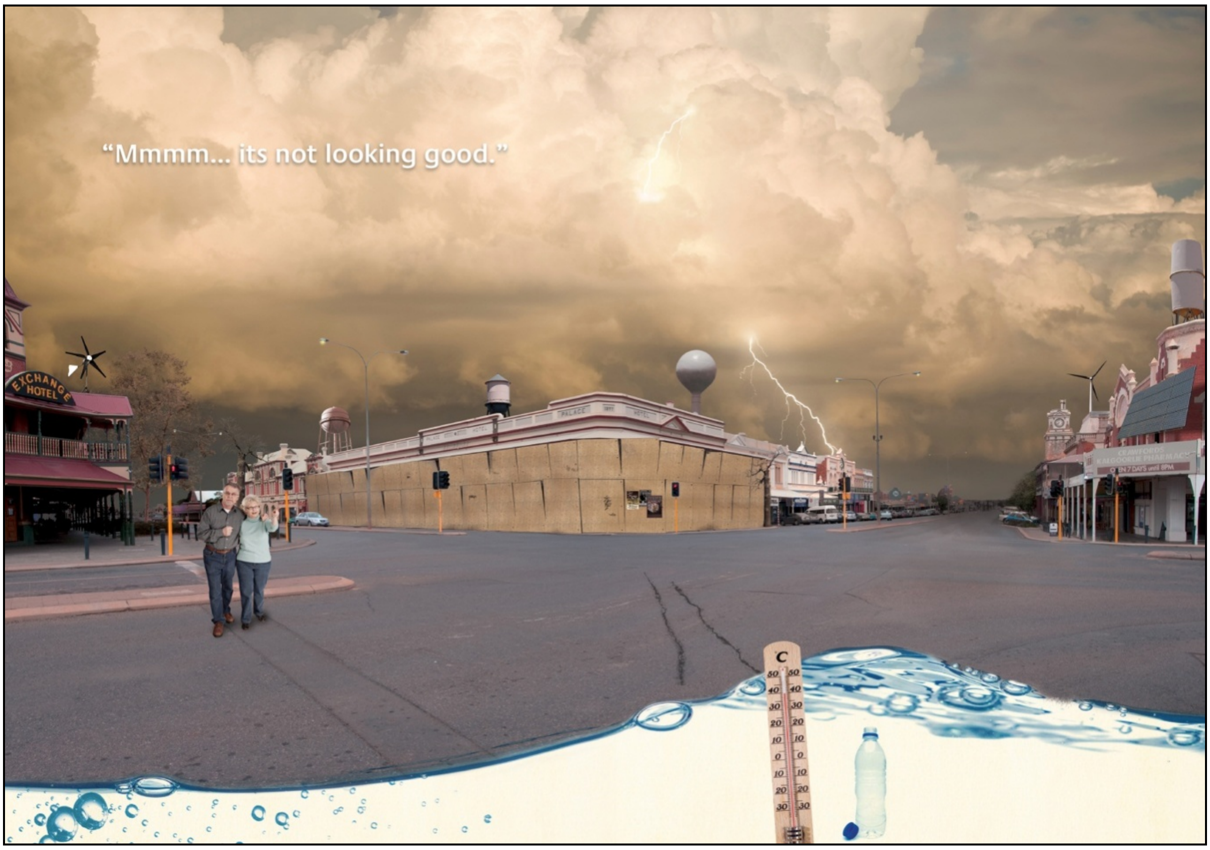
Kalgoorlie Scenario 1

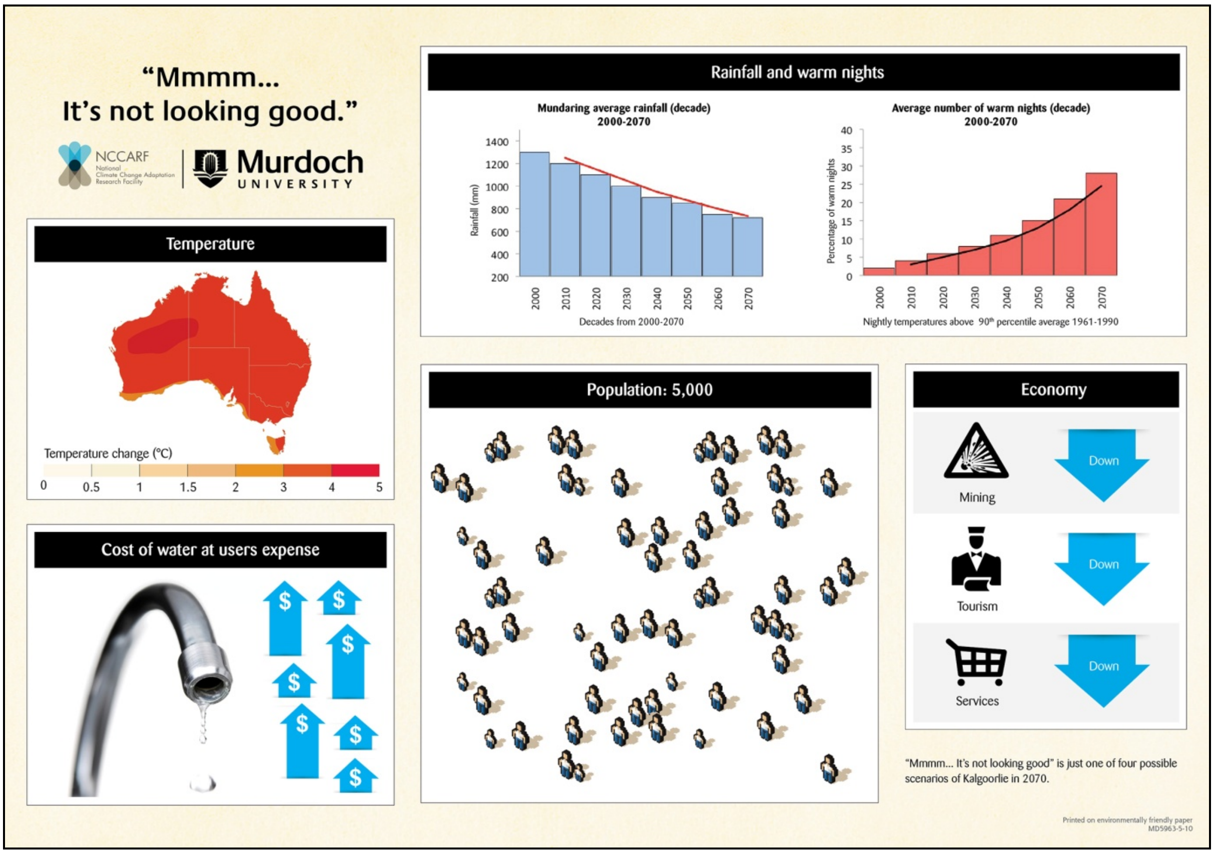


Kalgoorlie Scenario 2

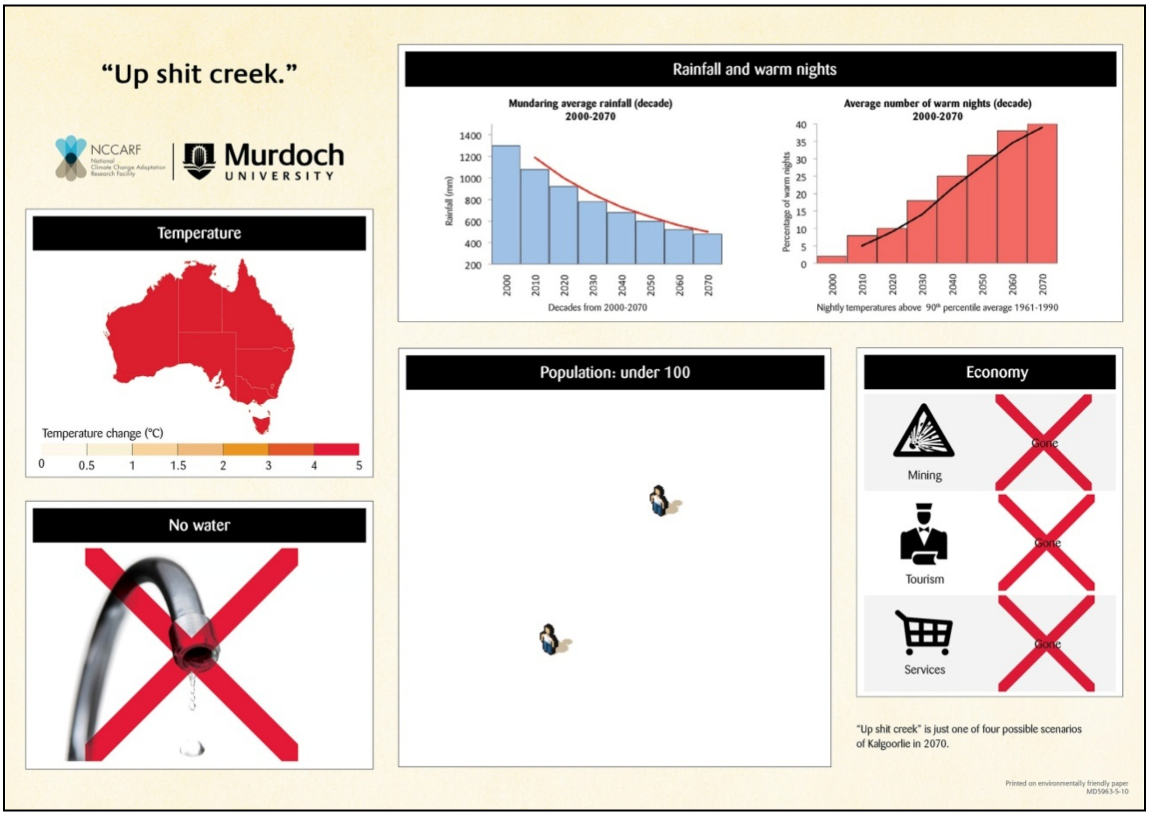


Kalgoorlie Scenario 3





Kalgoorlie Scenario 4



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